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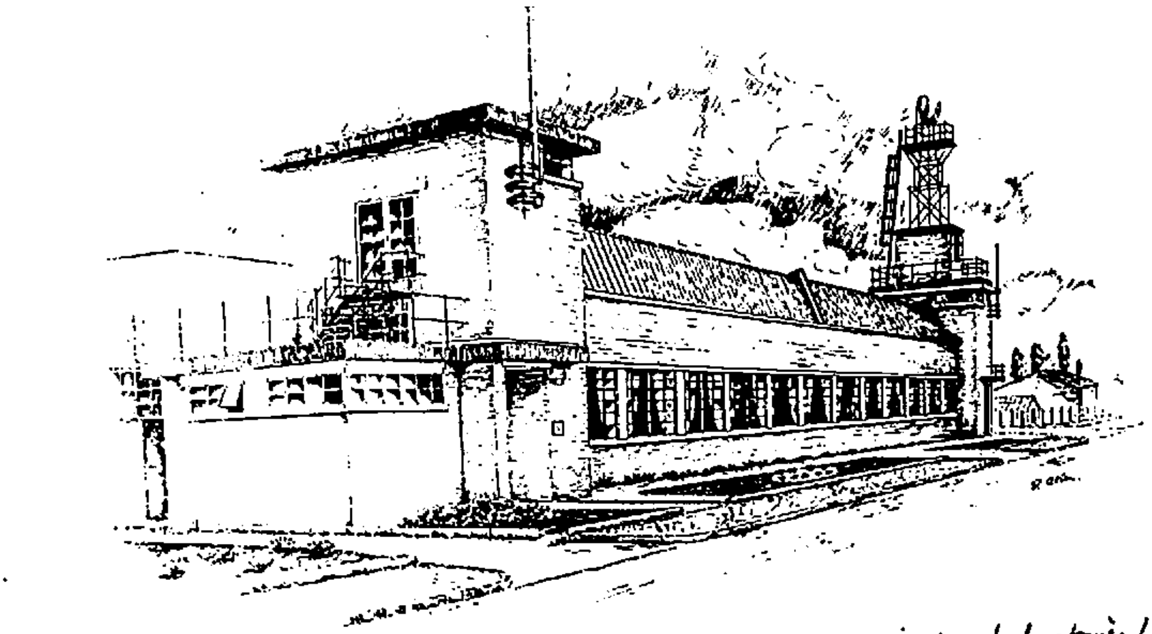
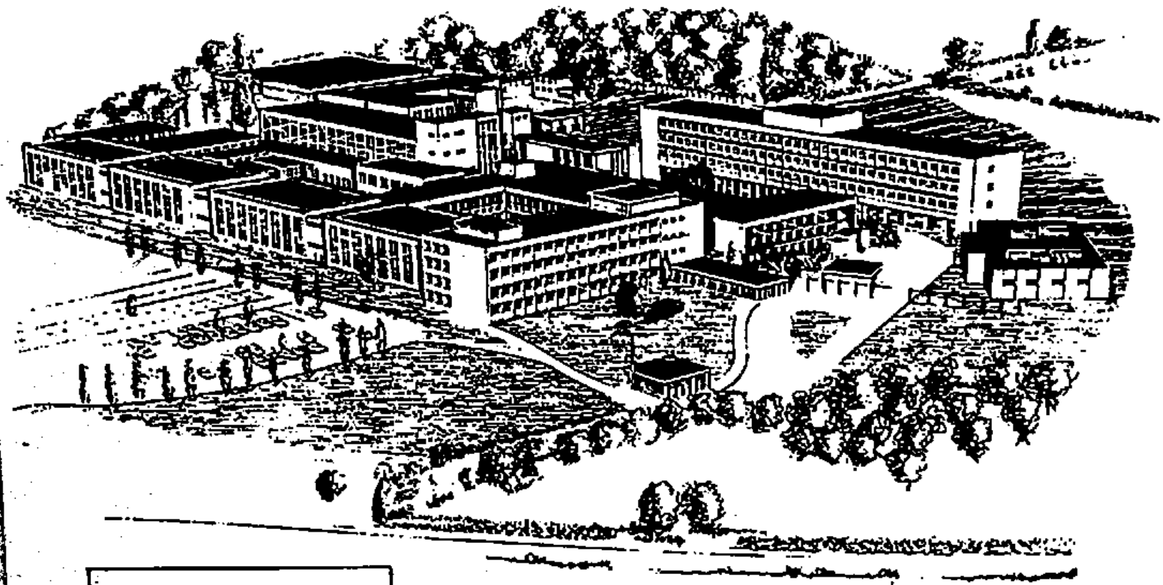
THE CHALLENGE OF THE SPECTRUM

A History of STL Since 1945

Of all the wondrous gifts that Nature has placed at Man's disposal, to challenge him and against which he may measure his progress, the electromagnetic spectrum must surely be pre-eminent. This brief history tells of STL's part in the utilisation of this gift, between the end of the Second World War and the 30th Anniversary of its move to Harlow.



Standard Telecommunication Laboratories Ltd
Progress Way, Enfield, Middx. c. 1950



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CONTENTS

PART I - EARLY POST-WAR PERIOD

Reserved and other occupations

1945 was the Year of Victory. After six years of unprecedented death and destruction the Second World War had at last come to an end. The country was now faced with an indefinite period of major reconstruction against a background of serious material shortages and economic imbalance. Telecommunications growth and refurbishment, not an obvious priority in a time of war, had been in a state of suspension for six years, so that the systems used in the war years could be described as state-of-the-art in 1939.

The STC people important to these pages had been 'doing their bit' in a number of different ways, each according to his skills and to the national interest. Some had joined Government research establishments for the duration; others had remained with STC on 'reserved occupations', while others had joined the armed services. Of those who joined the Government establishments or remained with STC, there was much to occupy them on providing the Services with new and improved accessories of war.

Notable was the support to the RAF in radio and navigation aids. Navigation errors, and accuracy in target identification and pinpointing, were major causes of wasted effort and lives, especially in the early days. Indeed, STC's contribution to the war effort had been profound, ranging from the provision of a national communications infrastructure to providing a bedside telephone for Prime Minister Mr Winston Churchill in his bunker below No. 10 Downing Street.

A name already important in the history of telecommunication was that of the late Alec Reeves (1902-1971), who back ln 1937 had invented pulse-code modulation (PCM), one of the cornerstone technologies of today, and who is credited with the invention of a navigation system Oboe, a blind marking and bomb release mechanism controlled from a home base. For this and other major contributions to the war effort Alec Reeves was awarded the CBE.

A person of comparable stature to Alec Reeves was Charles Earp, who made fundamental contributions to radio direction finding, both during the war and after. His name was to become synonymous with aircraft landing aids, in particular the Doppler system, to be mentioned again later. He received the OBE for his wartime activities and was in due course to receive many other awards for his services to civil aviation. But there are many of our ex-colleagues around today who made substantial contributions to 'the secret war' and who would have some interesting tales to tell of those days, given the chance!

A new laboratory for ITT ln the UK

At the end of the war we see them drifting back in twos and threes from the Services and research establishments, bringing with them unique and invaluable experiences and knowledge. A number of those of concern to this history will have returned to the radio division at New Southgate in north London, reuniting with old colleagues and sharing their anxiety as to what the future had to offer. They need not have worried. The military establishments were keen to continue the research of the war years; the civil aviation industry had to get going again, and the Post Office - STC's major customer for many years - had a major problem of repair and replacement, not to mention modernisation, on its hands. And there was of course this wonderful new service, television, the expansion of which had had to be shelved as 'non-essential' during the war years. There was plenty of scope for radio experts!

There was no separate STC research organisation as such in those days, R&D being conducted by individual divisions to satisfy their specific business needs. Mounting pressures, however, were creating such a need, and a new company, Standard Telecommunication Laboratories Limited, was formally set up by parent company ITT (International Telephones & Telegraphs Corporation) on the 1st December 1945 on the site of the STC cable factory ln Progress Way, Enfield.

At the time, ITT's research needs in Europe were being met by the French company LCT (Laboratoire Central des Telecommunications); but a second laboratory was deemed imperative, West Germany being a keen contender. However, with the support of ITT General Technical Director Dr LM. Deloraine, the balance was swayed in favour of the United Kingdom, and the necessary financial, administrative and material arrangements went ahead.

The first Managing Director was Mr. A.W. Montgomery, previously STC Technical Director and located at the STC Woolwich site, a function he continued to perform contiguous with that of Managing Director, while his deputy, Mr. T.R. Scott, saw to the day-to-day running of STL on-site, eventually taking over fully in 1956. The staff originally numbered about 90, but was to rise to more than 400 over the next five years.

The Progress Way site had been an STC factory for producing rubber and plastic cables; it was timely that STC Plastic Cable Division should take over a previous munitions factory in Newport, in east Wales, thus leaving a vacant site.

For the most part the new occupants came from Woolwich (materials and components specialists, particularly cables), and New Southgate (radio and telephone systems), and there was an important nucleus of skilled mechanics to set up the first model shop.

Staffing, both technical and non-technical, was a problem for the first personnel manager, Mr. P.J. Rogers, who, because of the primitive state of the organisation, had the additional task of bringing together all the paraphernalia of a back-up service usually taken for granted in an established business, down to tables and chairs. This was a particularly frustrating task considering the shortages of just about everything. One lasting service from those days was the first STL library established by 'PJ', which included technical books presented by senior members of the technical staff: an STL spirit was already much in evidence.

Technology miscellany at Enfield

In the materials laboratory, research was aimed at providing electrical components for STC and ITT exchange and telephone equipment, and for their off-the-shelf components businesses: ferrites for magnetic cores; the preparation of special alloys; etched rolls for electrolytic capacitors; selenium and titanium dioxide rectifiers.

A special section was set up in 1947 for the preparation of EDT (ethyl diamine tartrate), a substitute for quartz used in channel filters. Work on synthetic quartz had begun during the war at STC's Crystal Division when the supply of natural quartz (from Brazil) had ceased. Most of the equipment for EDT preparation was brought from Woolwich, where it had been held following the closure of a small ITT laboratory at Hendon in north-west London and the decision to concentrate R&D facilities at the ITT Paris laboratories.

The scope for materials research was further broadened when the nucleus of a materials evaluation centre was established by the installation of two x-ray diagnostic machines, of the building of an x-ray diffraction camera and the provision of facilities for chemical and radio-chemical analyses. Some early work was being done at this time on germanium, to identify impurities which were affecting charge carrier lifetime.

Elsewhere on the site, and in spite of the somewhat primitive conditions, the staff were engaged in an impressive range of specialist activities (bearing in mind also the limited instrumentation and other facilities of the day), which encompassed radio valve development, electrical measuring instrumentation, waveguide design (for next-generation radar equipment), telecommunication switching and signalling; and there was an acoustics laboratory for telephone testing and evaluation programmes.

Also, the great strides made ln microwave digital and pulse technology soon provided the impetus for setting up a team, under Dr A.T. Starr, to apply this technology to telecommunications.

Special mention should be made of the switching and signalling work done at this time for the new telecommunications networks, with which the name of E.P.G. Wright will ever be associated, especially his work on common channel signalling. Highly inventive, 'EPG' and his colleagues were also much occupied in next-generation electronic switching, effectively laying down firm foundations for STC’s later role in TXE3 and TXE4 telephone exchange and other developments, and, further into the future, System X. Strad, a store-and-forward message switching system, also owed much to this inventive group.

STC was already well established in microwave radio. Back ln March 1931, and in cooperation with ITT's laboratories at Hendon and Paris, STC had demonstrated the feasibility of 'micro-rays' for radio transmission by setting up a two-way ultra-short-wave (18 cm wavelength) link across the English Channel.

Early triumphs with television

Work of the 1950s was not only a continuation of post-war work in support of the Post Office's renewal programme, but now had the additional impetus of the new service, television.

Microwave links would be needed for the emerging television networks and a trial system was soon set up between North Woolwich and the Laindon Hills in Essex. A portable TV link was set up to broadcast the last leg of the 1950 Boat Race between the Queen's Head, Chiswick and the Riverside Exchange, Hammersmith.

The TV link equipment was later used by the BBC for the first live broadcast to the Continent. This was ln August 1950 and was set up to celebrate the 100th anniversary of the laying of the first cross-channel submarine cable ln 1850.

Using the results of work at STL, STC's Woolwich establishment designed, manufactured and installed for the Post Office a 4-GHz multi-hop TV link between Manchester and Kirk O'Shotts, near Edinburgh. It was used by the BBC to show Scottish viewers the funeral of H.M. King George VI on television in February 1952.

Another pioneering and historical broadcast was that of the Coronation of Queen Elizabeth II in 1953, to two-and-a-half million viewers in Europe, when STC supplied and manned portable links between London and Cassel. The network extended from Cassel into Belgium, The Netherlands and West Germany, providing the longest European TV link-up to date. The STL microwave survey team planned and checked the routes and sites for the whole operation.

Expansion and dispersion

The 1950s was a time of great expansion, and accommodation for the various groups soon became critical. To ease the situation it became the practice to hire outstations in the area to house particular groups - using premises for purposes which the original owners would never have imagined! Thus we were to have germanium and silicon metallurgical work carried out in an old bakery in Enfield town, while further afield at Watton-at-Stone in Hertfordshire, an old family residence, Frogmore Hall became the home of a radio survey section and the site of long-haul waveguide experiments and other work. A temporary measure at the time, STL's occupation of Frogmore Hall was to last 25 years.

Another group important to STL and to telecommunications was the Systems Planning team. Initially set up in the 1930s at STC's Greenwich site and moved to Enfield in 1946, it was now to occupy 'The Thrifts', another but less imposing country house near Ware, a few miles south of Frogmore Hall, to remain in peaceful isolation until moved to Harlow in 1963. Some important survey and installation work performed abroad was launched from 'The Thrifts'.

Enter the semiconductor

The 1950s saw research at the Enfield laboratories directed towards four principal areas: materials chemistry and physics, microwave circuit and system development, including long-haul waveguide, PCM transmission over junction cables, and switching and computer technologies. But changes were on the way, and they were being led by the chemists and solid-state physicists.

Since the early 1900s the thermionic valve had been a key electronic component, first as a signal detector (diode); later as a triode signal amplifier, then in combination with a switch. Its size and relative unreliability, however, despite decades of research and development, had given impetus to replace it with a product of semi-conductor research by the physicists and chemists: the semi-conductor diode and its derivatives. Great progress had been made. Electrons and 'holes', charge carriers, valence and conduction bands, p-n-p and n-p-n junctions, needed to be understood to explain the actions of the new components.

Its small size, intrinsic reliability and anticipated low cost in the great quantities in which it would be used, made the semi-conductor diode highly attractive to electronics designers and equipment manufacturers alike.

The invention of the germanium transistor by three Bell Laboratories scientists, John Bardeen, Walter Brattain and William Shockley in the late 1940s was to profoundly change the direction of basic materials research as the thermionic valve was rendered obsolescent. Wherever the valve was employed its place would be taken by the transistor, of millimetre dimensions but destined to shrink in size as the materials and techniques for its production were refined.

Germanium crystal growth facilities were established. The reduction of pure germanium from its ore, and slicing and polishing techniques, would provide the transistor-based technology for the component parts of a new generation of telephones and exchange equipment. The design of computers would be revolutionised; indeed, the miniaturised switch or 'gate' was just what was needed. The bipolar junction transistor, credited to William Shockley, soon followed, paralleling in miniature form the triode valve of the previous decade. Transistor radios were introduced in the middle 1950s. The light-emitting diode would follow shortly.

At Enfield, new ultra-clean laboratories were established and white cap and gown-clad figures were much in evidence in the new restricted areas. Material purity was of the essence: a one-part-per-million impurity could ruin a circuit. The processing of silicon and germanium, aluminium and phosphorus, and of their compounds, are prominent in the records; chemical etching, the silane process for the manufacture of high purity silicon and the vapour-grown deposition of Si and germanium, all attest to the new dynamism in semiconductor research. Resistivities of above 1000 ohm-cm were achieved in 1959 for silicon [1], another STL 'first' in an impressive and growing list in the materials field. Indeed, STL licensed the silane process to Du Pont of America, evidence of its maturity in this field.

Crystal growth and refinement

The late 1950s and early 1960s were fruitful years in the materials R&D sector, seeing substantial progress in the science, and the recording of several STL 'firsts'. The Czochralski method of crystal growth, whereby a seed crystal is pulled from a melt of the same material at a higher temperature to form a large crystal, was being refined for silicon growth. Germanium was already being grown by this method at STC's Ilminster plant, but the growth of silicon was a more formidable task. The Czochralski process is in wide use today in semiconductor manufacture.

The 'silver boat' refining technique, another STL 'first', was the metallurgist's answer to the problem of melting various materials (e.g. silicon) at very high temperatures without being contaminated by the container through contact with it. The name of Henley Sterling deserves special mention here for his inventive and innovative work [2][3], for which he duly received an ITT award. The years 1961 to 1970 were to see some important patents registered by Henley and his colleagues and international recognition of their achievements.

Civil aviation takes off

Much was needed to be done in the civil aviation industry where new landing aids, radar and navigation equipment were required. Great strides had been made in the war years; this had to be applied to the civil industry and developed. Also, the international nature of the business called for expert representation at national and international decision-making discussions. The propagation of microwaves through the troposphere needed to be better understood, and to this end the systems planners carried out a number of propagation tests in the UK and Europe.

In spite of the apparent irreconcilable differences that existed between East and West, suppressed in the common interest during the war years, science would see to it that countries of the world were inevitably drawn closer together by means of the new air routes and communication networks. In this it would be aided and abetted by international business interests.

First PCM infiltration

The commitment to PCM transmission for telephony throughout the 1950s involved theoretical studies and demonstrations of PCM transmission over microwave radio links for the longer distances, and over balanced line pairs for local and subscriber lines.

An enormous undertaking, the conversion to digital transmission from analogue required a critical examination of every aspect of 'traditional' telecommunications practice. Techniques of analogue (voice) to digital conversion, and the reverse, would call for special study; also, digital modulation methods, e.g. pulse amplitude, pulse density and pulse width modulation (PAM, PDM, PWM), with their respective advantages and disadvantages. Digital multiplexing: time division and frequency division (TDM and FDM) being the immediate and principal ones, which would, as in the analogue case, permit the sharing of a common channel or highway by two or more (usually many more) signal sources. Finally, the digital switching of circuits would present special problems. The whole subject is rich in possible trade-offs and performance penalties to achieve the right balance of technical maturity, cost and quality of service.

In the transmission sector also in the 1950s, digitizing and coding methods for television over long-haul waveguide were being examined. But by the end of the decade this form of signal carrier was being overtaken by the more flexible (electrically as well as physically) coaxial cable and attention was being transferred accordingly. The coaxial waveguide was seen as the solution to the problem of providing increased bandwidths for the projected new digital services. It dominated research in the 1960s, from waveguide design and fabrication to system planning, installation and the short and long-term economics.

An area of study of particular importance at this time was the digital repeater. Not only would this 'rejuvenate' attenuated and distorted signals, but it would largely eliminate noise that had accumulated over the previous length of line. Messages would thus be re-transmitted in virtually the original form. This was a particularly powerful argument in favour of digital working over analogue. Susceptibility to noise is directly proportional to the operating bandwidth, and as wider bandwidths are the key to greater diversity of services (data, video, TV, etc.), the signal-to-noise parameter is as fundamental as in the analogue case.

All of this work would of course have been carried out in close cooperation with the 'customer', who at this time could have been an ITT associated company, an STC division, the UK Post Office, or sometimes all three together. These would in tum have contractual obligations to their customers, the PTT (Post, Telegraph and Telephone administration) in the country concerned, and so to the general public, the ultimate customers.

Two notable achievements constituted milestones ln the evolution of PCM ln the l950s: time-division multiplex (TDM) switching system in 1955-56, and in 1959 a 24-channel PCM system installed in Madrid in cooperation with the resident ITT company, Standard Electrlca S.A.

PART II – MOVE TO HARLOW

Upheaval

By the late l950s the demands on the company R&D facilities and its growing prominence as a research centre for ITT, gave some urgency to a review of alternative sites for a new purpose-built laboratory environment. Sites in the Enfield area were first considered, and plans drawn up for local council approval. However, after much debate the present-day site was selected in the countryside at Harlow and the formalities completed. The move took place in 1959, some 500 members of staff making the move. The new laboratories were officially opened by the late R A Butler (later Lord Butler of Saffron Walden), then the Lord Lieutenant of the County of Essex.

1960 saw the company settling down at London Road, Harlow. For what was planned as a 'house-warming' party, an Open Day was held to show off the new building and demonstrate a cross-section of STL's activities and achievements. Open Days became a regular feature, and apart from enabling the laboratories to show off their wares were a useful means of demonstrating local community spirit.

Specialised groups and services

The MEC

1960 saw the setting up of the STL Materials Evaluation Centre by Dr Ken Batsford, who over the previous six years had been busy in crystal silicon and germanium research and vapour-phase deposition. The new MEC was equipped with the latest measurement and assessment instruments available at the time for surface and bulk materials analysis and other work: x-ray diffraction, electron microscopy, ultra-violet, visible and infra-red spectroscopy. Such instrumentation would be augmented and updated over the years.

'Physics of aging' and accelerated life testing programmes were established. The MEC was to flourish, and later, under Ruth Billington, would maintain its position as a world leader in materials analysis and reliability work. Neither should the reservoir of personal knowledge and experience be overlooked which was on call to MEC's customers.

Van de Graaff

Also in 1960, a Van de Graaff particle accelerator was installed at London Road to mark the beginning of radio-chemical research into the effects of atomic radiation on the properties of materials and to further STL's work on the chemical analysis of materials. The equipment was switched on by Sir John Cockcroft, the distinguished atomic scientist. The Van de Graaff accelerator is widely used in medicine, throughout industry and other areas of science, its great utility being through its ability to produce beams of both positive and negative charges at high energies and densities for materials surface and interior analyses.

The HP Lab.

A rather unique 'first' for STL was the setting up in a commercial environment of a High Pressure Research Laboratory, to be supported later by the Science and Engineering Research Council (SERC). This was ln 1961. With a capability of handling pressures of 100,000 atmospheres (approximately 600 tons/sq in) and above, and temperatures up to 2000°C, the primary tasks for the new laboratory were the syntheses of new materials and using the high pressure variable to determine the band structures of gallium arsenide (GaAs) and other related compounds. A secondary function was the production of artificial (industrial) diamonds, used in instrumentation for the calibration of pressure and temperature. This was the first industrial laboratory of its kind, and the support from SERC was perhaps an acknowledgement of the standing of STL in fundamental materials research.

The mechanical background on materials established in this laboratory was later to become key to STL in establishing and holding its advanced position in all types of cable development especially underwater cable engineering.

The names of Drs David Pitt and John Lees are permanently associated with the HP Lab., the former achieving the distinction of being awarded the DSc degree by Glasgow University for his work in this and other fields [9]. The Oilcon oil-in-water monitor, to be mentioned again later, was a product of his inventiveness. John Lees was to continue running the HP Lab. under a later arrangement with the SERC, while managing STL's advanced cables research programmes [7].

Semiconductor Laser Group

A semiconductor laser group was set up at about this time, to build up a substantial inventory of theory and practice. The absolute dependence of optical fibre communication on the laser as a source of the light carrying the digit streams, and the increasing use of the laser as an engineering tool, ensured that laser technology became and remained one of the cornerstones of work at Harlow. Mr Peter Selway was one of the pioneers of this distinguished group, and his subsequent career with STL to a position of leadership in STL's work in optoelectronics, of which laser technology became the major part, reflected STL's own rise to pre-eminence in the subject.

PCM Laboratory

To further the exploitation of PCM techniques already established, a PCM laboratory was set up under Mr. Kenneth Cattermole to study data transmission and regenerator units over PCM channels. Ken Cattermole [24] was a young but close associate of Alec Reeves. An acknowledged authority in telecommunications transmission, he was one of several people at STL who were establishing its international standing in so many fields. He later became Professor of Telecommunications at Essex University.

The Overall Systems Planning Group

Another active group was the Overall Systems Planning Group, as it was now called mentioned earlier in connection with the Enfield days. Its mission since it was transferred to Harlow in 1963 was to provide a system focus for switching transmission, voice and recording techniques in telecommunication systems: the forerunners of modern integrated systems. Their work complemented the ongoing research and development in the laboratories and provided 'customers' for a number of subsystem and component achievements. The team included reliability, maintainability and system modelling specialists. This highly experienced team of planners and consultants was to remain together into the 1980s when its members were distributed among other STL divisions as both the name and role of STL were revised to meet the needs of the times.

Looking overseas, strategic studies of microwave radio propagation via line-of-sight and tropospheric links, in Africa, North America and Europe, and the anticipated introduction of PCM worldwide, were to exercise the systems planners. Plans for national and NATO networks were provided, as well as major contributions to CCITT and CCIR Study Groups looking into standard formats and protocols to meet the requirements of future international networks. The work of the planners did much to enhance the prestige of STL both within and outside of its parent grouping, STC and ITT, locally and internationally.

The Acoustics Group

An Acoustics Group was set up at STL to provide a comprehensive service to ITT companies and to national PTTs across the world, including the UK Post Office. The work encompassed the evaluation of speech performance of telephone sets [18], tests of telephone handsets, and the design and evaluation of transistor circuits for the new generation of handsets, including a unique design of 'hands-free' telephone.

This group designed the circuit for the first all-electronic subset, completed in 1975 [19]. Speech recognition and analysis, requiring highly sophisticated research tools and techniques, were also important, receiving support from the Government's joint Speech Recognition Unit.

The Acoustics Group was involved in justifying a decision to adopt 19.2 kbit/s (now 16 kbit/s) CVSD (continuously-variable slope delta modulation) speech for military tactical communication systems, instead of PCM which required four times the bandwidth. In this connection many hours were spent analysing tapes to confirm that user intelligibility and recognisability requirements could be met in a codec (coder/decoder) no larger than a matchbox. Through its contributions to the CCITT the Group established STL’s international credentials in matters audio.

VPE, plasma deposition and a world record

Another product of STL work on III-V semiconductor compounds was the vapour-phase epitaxy (VPE) of aluminium-arsenide [6], which was to be a key technique in the fabrication of light-emitting diode sources for optical fibre communication. The first preparation of silicon nitride films in 1965, to become widely used in the semiconductor industry, was the outcome of work on glow discharge/low energy plasma deposition techniques, very much an STL development. Published papers on the physical properties of amorphous silicon attest to the original work in this field, and for which 'Rab' Chittick [5] deservedly received international acclaim. He was also responsible for much original work on the physics of failure and the non-destructive screening of materials. Extensions to work on radio-frequency melting techniques and the 'silver boat' saw the achievement in 1967 of ultra-high-temperature Czochralski growth of zirconium diboride (ZrB2) - melting point 3450°C, probably a world record [4]. Finally, 1969 saw the publication of the first account of the doping and photoconductivity of amorphous silicon [5].

Corporate Matters I

In 1962 Mr. J.D. Clare succeeded T.R. Scott as Managing Director, a position he was to hold until March 1965, when he took up an appointment outside the Company.

STL was at this time still primarily an ITT laboratory, funded by ITT via the ITT R&D Case System, involving an annual Business Review session at the ITT Europe Headquarters in Brussels. Consequently, although there were close ties with STC in relation to its business commitments to the UK Post Office, to the various government departments and to ITT, STL had its own case to answer with ITT and its subsidiary companies in Europe. The Question of STL’s primary allegiance was at times an uncomfortable one which called for considerable diplomacy, and this problem would persist.

John Clare saw his main task as being to establish STL as <u>the</u> principal research centre for ITT in Europe, for which the ground had by now already been well laid. Whether this was more of a personal ambition than corporate ITT policy is a matter for conjecture, for there were powerful rival claims to fame (and funding) from across the Channel, in Paris and Stuttgart from LCT and SEL (Standard Elektrik Lorenz A.G.) respectively.

The TXE 'switches' and System X

In 1963 the Post Office had announced its decision to replace the old mechanical Strowger telephone exchanges with new electronic ones, employing the latest technology and anticipating future traffic needs. STC, an equipment supplier to the Post Office of long standing, had a heavy commitment to this major and complex undertaking. Work on the TXE series of exchanges was launched and in due course a series of demonstrations and trials marked the milestones in their evolution, leading to the TXE4 - which switches analogue speech signals, using reed relays - being eventually (1973) adopted by the Post Office as the cornerstone of its UK network, and entering service in 1976.

STL was also supporting the development of ITT's own digital exchange, based on its ITT3200 computer, employing 'distributed processing' and constructed from modular units in its structural philosophy to allow rapid expansion of services. Software control was to be the key feature. However, System 12 was more than a decade away from commercial exploitation at this time.

The next decade would also see a start made on System X for the UK Post Office, an all-electronic digital telephone exchange for the 1990s, which would integrate telephone, telex and data services. However, System X would eventually become a product of a GEC-Plessey joint venture and STC would make its exit from this particular stage.

1964 saw the start of a massive Post Office programme of conversion of the public trunk and junction networks to digital working, with the first installation of PCM in the UK.

John Clare vacated his position of Managing Director in March 1965, his place being taken by Mr. S.B. (Jock) Marsh, from the Telecommunications Research Establishment (TRE), later to become the Royal Radar Establishment (RRE), then Royal Signal and Radar Establishment (RSRE).

PART III - TOWARDS THE OPTICAL SPECTRUM

The potential of using the optical spectrum or light, as a carrier of information had been a subject of speculation and modest experimentation by scientists for many years. A qualitative study had been made in the late 1940s by A.A. New of STL. Indeed, Alec Reeves is on record as having regarded the future of digital (PCM) and optical techniques as inextricably associated [24].

Back in 1880 Alexander Graham Bell had produced his 'Photophone', based on his discovery in 1873 that the electrical conductivity of selenium increased with the intensity of the light that fell on it. He saw that if light could be varied in intensity by the sound of a voice, the light could be beamed over a distance to affect selenium as the variable-resistance element in a telephone transmitter. So speech could be transmitted without wires. "The greatest invention I have ever made; greater than the telephone", he said. However, Photophone had a range of only a few hundred feet, and only then if not obscured by obstacles, fog, rain, etc. .... It was not a success.

It was the celebrated paper by Kao and Hockham [14], published in 1966, that really set the scene for all subsequent developments ln communication practice. It effectively laid down the necessary and sufficient conditions for a viable system based on the optical fibre waveguide. It also told us what the reward would be: an enormous increase in information-carrying capacity. Managing Director Jock Marsh quickly grasped the potential of this new communication medium and gave the idea great moral support. However there was by no means overwhelming financial support for starting the new revolution, and most of the early work was organised by Charles Kao himself who was at the time managing an optics laboratory at STL. There was much theoretical and experimental work to be done and clearly an economic case would have to be made for the enormous investment in R&D that would be called for over many years. The problems were clearly understood.

The broad technical issues

In engineering terms a target threshold of attenuation (or power loss down the fibre, expressed in decibels per kilometre) of 20 dB/km had been generally accepted for the silica fibre if the new system was to be viable. Fibre produced commercially for other purposes was exhibiting 500-1000 dB/km and the challenge for the materials scientists at that time was formidable indeed. Apart from the purity aspects, the fibre had to be produced in commercially practical quantities, again no easy task. While it was to take only four years to achieve the 20 dB/km in the laboratory, reproducibility presented serious problems. In the event, through the use of the new vapour deposition of glass of the highest purity, commercial fibres of one-quarter the target figure were achieved.

Compatibility between the various elements of the new communication system was obviously paramount. Reference to the graph of attenuation versus wavelength for silica fibre showed there to be three 'windows', at about 850, 1300 and 1550 nanometres (nm), at which attenuation was at an appropriate low level. These three figures were to dominate system specifications henceforth [14] and the achievement of these levels of attenuation was among the 'necessary' conditions for the use of optical fibre waveguide for communication purposes. It should be noted in passing that Corning Glass reported 20 dB/km in 1970, but at 630 nm so outside the three useful windows for optical waveguide purposes.

There was another important factor: optical fibre of the time was neither very strong nor flexible. Some form of protection was required if it was to withstand installation and working stresses, even in its eventual cabled form. Surface defects (scratches and alien deposits) which caused loss by light reflection, refraction and scattering, had to be eliminated. The subsequent development of protectively coated and clad optical fibre, and the light guidance this provided through the lower refractive index of the cladding material, was a further vital step in assuring the viability of this form of waveguide.

Charles Kao was not purely a theoretician; understanding the physics and chemistry involved he had much to offer towards the practical realisation of his and George Hockham's proposals. He suggested for example the use of plastic coatings for the fibre. Unfortunately, there appears to have been little support for optical cable development initially, and this had to await support from the Government Directorate of Components, Valves and Devices (CVD) from 1970. With the modest funding that became available a rugged cable unit was eventually produced. This comprised four fibres plus strength member enclosed in a plastic sheath, a design which was to survive to become a standard element of the sophisticated multi-unit cables of the future.

However, fibre and cable for submarine systems would need special protection to give the essential long life (25 years was the datum) and to guarantee the utmost reliability. This required extensive research into new protective and sealing materials and methods, and consideration of the severe physical conditions of cable laying from a ship. Accelerated life testing techniques had to be devised, and 'mechanisms of failure' studies carried out. In economic terms, one important factor in long-haul (land-line and submarine) trunks had always been the number of intermediate repeaters required to rejuvenate attenuated and distorted signals. A high proportion of system costs is expended in these complex units, and it was foreseen that the number of repeaters for optical fibre trunk routes could be reduced relative to coaxial once the levels of distortion and attenuation of the optical signals were reduced in their passage through the waveguide. (The term 'regenerator' was to be used ln future for digital repeaters, since in reconstructing the weakened pulses accumulated noise was cancelled out, another of the advantages of digital working.)

But there were many other factors to be reconciled: laser light sources consistent in size and power output had to be matched physically and optically, to the fibre, as had the photodiode detectors at the receiver for converting the light pulses to electric currents.

The associated electronics would have to match the characteristics of the optical elements. To be practical, lasers were required to operate at room (about temperature ta, achieved 20°C or 63°F), and in continuous wave (cw) mode. In the event, both were achieved by 1970, a great achievement, marking another key milestone and fulfilling another necessary (but not yet sufficient) condition for the viability of optical fibre communication. All the many facets of communication were having to be examined afresh: this had been done in theory for the most part, but practice was another matter.

Navaids and satellites

Throughout the 1960s, research on microwave landing aids, advanced radar and navigation systems, together with the signal processing and embedded software for them, were enhancing STL's reputation and STC's prospects in its military and civil navaid businesses. STC had supplied radar components for UK defence since the war years, and had acquired skills in the design of low-noise quartz crystal oscillators (used as frequency sources for radio transmitters and for 'clock' purposes in synchronised networks etc.) which were to enable STC to enter the Rapier surface-to-air weapon system market in 1970, with STL support. This work was to continue, if on a modest scale, through the 1980s as Rapier was revised and updated. It also fostered work on high frequency quartz devices and the development of new processing routes, thus enabling STC to achieve a world position in quartz technology.

A controversial topic was the Doppler (STL/Plessey) vs Scanning Beam (USA) aircraft approach and landing-aid system rivalry, the first associated with the name of Charles Earp [16], mentioned earlier, which was to end in disappointment for the Doppler group when the Scanning Beam system was adopted by the ICAO in 1976. Largely through the personal initiative of Charles Earp, the Scanning Beam system did eventually incorporate a number of important features of the Doppler system. However, in the more general field of radio direction finding, the commutated antenna direction finder - another Charles Earp invention is still in use 25 years after its introduction.

Another increasingly important subject was adaptive antennas. By the late 1980s a substantial body of knowledge had been accumulated on these sophisticated 'sensors', which are able to adapt or modify their reception capability in specific directions. They are thus able to cancel ('null') or minimise unwanted signals and interference (for example, enemy jamming). Adaptive antennas were obviously of great interest to the military. They call for great sophistication in antenna design, in the associated electronics, and in signal processing [13].

GPS

With the launch of the USSR Sputnik satellite in 1957, and subsequent rapid build-up of the 'space race' throughout the 1960s, satellite communication had been emerging as a subject of particular poignancy. At STL, satellite communication for telephony and TV transmission, and for meteorological data collection and transmission, became a topical if not major area of study for the STL transmission and planning groups. Much of this work was funded by the European Space Research Organisation (ESRO).

Studies of receivers for the International Global Positioning Satellite (GPS) were begun in 1967, under the name of Navstar which would run into the 1980s [22]. STL's experience in microwave antenna design, radar and signal processing would hold it in good stead for participating in this new global technology.

Towards the micro-miniature

In June 1967 a new research block had been added to the laboratory, opened by the Rt. Hon. Edward Short, P.C.M.P., Postmaster General. This was necessitated largely by the great expansion in materials research.

Great progress had been made in the 1960s in tailoring semiconductor components to give specific electronic properties. This was largely the domain of me chemists with their sophisticated instrumentation and procedures, and clinically pure surroundings. Their work included the epitaxial growth of crystalline compounds onto another (by definition maintaining crystalline near-continuity at the interface), ion implantation, and etching and annealing techniques.

For the military, only state-of-the-art components and modules would satisfy the stringent demands of the planners, bent on keeping the West ahead of the opposition where quality and superior technology might outweigh a deficit in quantity. In technical terms, the challenge was that forthcoming generations of military equipment would demand high circuit component densities, long operational lifetimes, high reliability, and repeatability in quantity and quality. These were the 'necessary and sufficient conditions' for good relationships with the military! The work was performed under the close scrutiny of the various military agencies and successive Ministries (Supply, Aviation, Defence), including the Directorate of Components, Valves and Devices (DCVD), under the sponsorship and guidance of government research establishments such as the RAE, RSRE and AWRE.

The evolution of the microprocessor was to revolutionise the computations of war, and together with miniaturised components would be providing combat pilot and field commander alike with back-up potential undreamed of in the Second World War, only twenty-odd years before.

Gallium arsenide (GaAs) was the key compound material, with its high operating speed, low power consumption and other properties, as compared with its nearest practical alternative, silicon. Its radiation resistant properties were also a special attraction to the military in this nuclear age.

The middle-l960s also saw the first Gunn-effect power source realised by epitaxial methods. Of 2 to 3 millimetres dimensions, it typically produced several milliwatts of power at 1 GHz. The concept here was of a negative-resistance effect in a bulk semiconductor which gave rise to domains of high electron density drifting through the material at speeds of typically 100 km/s and frequencies ln the 1 to 30 GHz range, depending on the dimensions and other characteristics. This power source was complementary to another bulk-effect device, DOFIC, or Domain Orientated Functional Integrated Circuit, associated with the name of Charles Sandbank (later to become Head of Research for the BBC) and which was intended to replace conventional circuits with a single piece of semiconductor. DOFIC did not mature; it is understood to have been too complicated a concept to be pursued to a practical outcome.

Network fabrication on substrates was greatly facilitated by the introduction of spark engraving of circuit patterns, and of the masking patterns used in material liquid- or vapour-phase deposition. Spark engraving greatly reduced the costly large-scale drawing and photo-reduction processes previously used, and allowed economic batch production to be introduced.

Ceramics and plasmas

Among the less well publicised groups of the middle 1960s was the Ceramics group, concerned with developing high precision thermistors (a negative-temperature-coefficient resistor widely used for temperature measurement and control), and thick film hybrid integrated circuits.

STL's reputation in this wide field, which included work on bulk-wave (as distinct from surface-wave) quartz devices owes much to Dr Peter Graves, who joined STL in1964 and, apart from his personal contributions, has since this time managed a team which has included internationally-known chemists and metallurgists.

The name of Rudolf Heinecke deserves special mention here. It was at this time that he and his team were developing the complementary technology of thin film and surface deposition and etching, the use of plasmas for etching, and the liquid-phase chemical vapour deposition (LPCVD) process for depositing aluminium, silicon and other films. He was to further distinguish himself in the 1980s by inventing the use of pulsed plasmas for the deposition of surface coatings and chemical etching. His techniques were to become widely used in the semiconductor industry. The great advantage of his pulsed plasma technique was that processing could be performed at room temperatures instead of the typical 350°C temperatures of the previous methods.

VLSI and the real-time revolution

The penetration of large-scale integration (LSI) then very-large-scale integration (VLSI) into electronic equipment design and fabrication, with diminishing feature sizes and greater packing densities, eventually led to a decision to set up a VLSI Design Centre to provide a design and consultancy service of chip design and fabrication for ITT units in Europe.

Custom (specific to application) design, was being applied mainly to telephone speech networks and switching circuit components, and was one of three possible approaches to the design of integrated circuit chips. Another was the semi-custom design of uncommitted logic arrays (ULAs), in which wafers of semiconductor were pre-processed with fixed or standard logic arrays and then 'customised' for a specific function at the final interconnection stage.

The third approach was to use standard cell libraries. These contain details of all major logic functions required to produce LSI chip layouts quickly. VLSI design was to become the essential 'enabling' fabrication technology for all future micro-systems as operating frequencies moved up the electromagnetic spectrum, and dimensions reduced to micrometres.

Complementary to the evolution of VLSI, computers had for several years been penetrating into all areas of research in the laboratories (in common with all other areas of human activity). Logarithm tables and slide rules were fast passing into antiquity. Initially used for solving mathematical equations, by about the middle 1960s computers were being applied to more varied aspects of laboratory work, as a research tool and for 'number crunching' generally. Mathematician George Boole (1815 - 1864) would have been impressed if not astounded at the use being put to his Boolean algebra of noughts and ones only!

The outstanding fact was that engineers would be able to undertake tasks which they would previously have deemed impracticable. Long and complex calculations, which would have taken many man-hours, would become the work of seconds and minutes using this wonderful new tool. The potential seemed almost unbounded, and the writing of software programs, compilation and other coding instructions, was occupying a young, dedicated, and mathematically talented group. This software would be running on purchased machines, typically IBM mainframes and Hewlett-Packard office calculators with graphical printouts.

The dominance of the computer would be profound. Computer-aided design engineering and manufacture (CADEM) was the generic title. Specific tasks such as the testing of relay contacts, system design simulation and modelling, management planning, and the preparation of graphics for printed circuit board (PCB) design, would all become to a greater or lesser extent automated.

Design simulation and modelling, and later animation would have a profound influence on the whole approach to system design in the future removing the costly 'long-hand' calculations and largely trial and error routines of the past.

Most important of all, calculations and responses to stimuli would be done in 'real-time'; the time between detecting an error and applying a correction would be virtually zero, or control would be near-continuous. The importance of continuous real-time control cannot be overstressed; the space programme of later years would have been impossible without it (the shortest time interval between error detection and corrective action in this case being determined more by the distances involved and the velocity of light than by the limitations of the computer/communication technology). The real-time revolution would have a profound influence throughout industry and the services, from factory floor to aircraft cockpit.

Software specialists were becoming prominent throughout the labs at this time, engaged in writing the 'embedded' (specific to application) programs and looking at old practices from a new angle. Elsewhere, but mainly at the universities at this time, and with whom strong links were being forged, 'software science' was emerging as a professional discipline alongside the traditional ones.

STL would in due course be making its own contributions to software methodology

Jock Marsh

The 1960s could be described as the years of consolidation. Firstly, substantial work had been done in establishing digital practice using PCM over balanced copper-pair cable, circular waveguide and, latterly, coaxial cable.
Secondly, great strides had been made towards providing the materials and components satisfying the conditions for optical fibre communication viability. One might be excused for adding that STL had continued to uphold its reputation as a centre for innovative solutions to new problems.

In 1963, Jock Marsh had moved to STC headquarters to become full time Technical Director, STC, which post he was to hold until his death in l980. He had occupied the chair at STL during some important as well as difficult times, and the enhancement of STL's standing as a source of innovation and quality in science is due in no small measure to his leadership. In 1982, the first 'S.B. Marsh Memorial Scholarship Award' scheme was launched by STC in recognition of his unique place in its history.

Corporate Matters II

Following the departure to STC House of Jock Marsh, the laboratories were reorganised into three directorates: Telecommunications & Electronics, headed by Mr Desmond Ridler, himself one time Technical Director, STC; Materials & Components, headed by Dr Joe Evans; and Administration, headed by Mr Tony Young.

Traditionally a focus of attention of cost-conscious business units, less appreciative of its science than of its cost, it was at this time that STL received one of its periodic reviews, which in effect meant a reappraisal of its role, inevitably resurrecting the sensitive issue of its primary allegiance with regards to ITT and STC. Essentially, the issues have remained fairly constant over the years: (i) the direction of and support for long-term (strategic) research; (ii) STL's primary obligation (to ITT or STC) for short-term R&D services. Two further possibilities have lain just below the surface: (iii) that R&D should be in-house, carried out by individual units to meet their specific requirements; (iv) STL should be as far as possible self-supporting.

The relative strengths and weaknesses of the latter two possibilities will not be gone into here, although it may be said that they will have modified any tendency towards over-confidence by STL management.

Altogether the decisions reached at these appraisals tended to depend on the current or short-term status of the ITT and STC economies, which was not entirely satisfactory for a research organisation if it was to pursue long-term scientific objectives. STC was in any case one of the associated companies of ITT at this time, and had no overriding claim on STL allegiance.

At this time, Advanced Development Support Centres were being set up by ITT ln the USA for such key technologies as Materials, VLSI, GaAs and Programming, and STL would inevitably be working closely with them.

The setting up of a Basic Software Control Centre at STL under Mr. Tim Denvir in 1972 to supply and maintain support software primarily for the ITT3200 computer (running the System 12 distributed control exchange) was further confirmation of an ITT policy of setting up Control Centres to support key technology programmes. There would be others.

Demonstrations and installations

On the commercial scene, the 1970s began with STC acquiring the company Submarine Cables Ltd, by so doing becoming the sole manufacturer of undersea cables in the UK. The world's first 1840-circuit (coaxial) submarine cable was laid between Spain and the Canary Islands the same year.

In the laboratories, a 75 Mbit/s optical-fibre subsystem was demonstrated on the bench, and the following year (1971) saw demonstrated the first direct modulation of a semiconductor laser at 1 Gbit/s, an important step.

A digital video link at 120 Mbit/s was demonstrated the same year. The first optical fibre cable was demonstrated in 1973.

From the PCM-coaxial cable work of the late 1960s Europe's first digital line system, a 120 Mbit/s coaxial link between Guildford and Portsmouth, was inaugurated in 1974. It became fully operational ln 1976. A 2x400 Mbit/s system was installed in Bologna University, and over the four years 1973 to 1977 a 30-km 565 Mbit/s coaxial cable link was designed and demonstrated.

By the middle-1970s the credibility of the optical fibre waveguide had been established beyond doubt, and numerous trials systems were at an advanced state of readiness for state-of-the-art demonstrations. However, in laboratory and development unit alike the momentum of work on PCM over coaxial cable for long-haul and submarine systems, and on line-pairs over local networks, would be maintained for some years yet. There would be no quick and easy transition: the scale of the transformation was far too great.

Long-haul waveguide was for some years considered to be the technology of the future for transmission routes, and telecoms companies throughout the world were making major investments in it. STL had a comprehensive research programme in support of ITT, from the basic design and construction of the waveguide to the transmission, planning and economics of complete systems. 'Doc' Foord was responsible for much of the waveguide design work, and had been so since the Enfield days. Many of STL's most experienced engineers were involved ln the complementary transmission studies, and one should mention the name of Mr. Harry Grayson, one time head of an electronics systems group, dedicated to LHWG transmission development. However, the long haul waveguide was to be overtaken by a later technology: optical fibre.

1976 saw ITT setting up Europe's first commercial optical fibre unit at Harlow: another significant milestone. 1976 also saw completion of the installation of a 34 Mbit/s optical link in Colombo House in London, begun in 1975, and a similar system delivered to Standard Elektrik Lorenz Stuttgart, West Germany (another subsidiary company of ITT) for trials. An unfortunate episode was the litigation, begun in July 1976, between ITT and Corning Glass over an alleged infringement by ITT of Corning patent rights in respect of fibre manufacture. Three US patents were involved. This litigation gave rise to a thorough records and archives search on both sides of the Atlantic for evidence in support of ITT's denial of such an infringement. The case went on until July 1981 when ITT made an out-of-court settlement and completed a licensing agreement with Corning. This case was perhaps part of a settling down process, as rival businesses staked out their claims in this new territory of optical fibre communication.

Of particular satisfaction to all concerned was the establishment in 1977 of a 140 Mbit/s 850 nanometre wavelength optical fibre link over 9-kilometres between Hitchin and Stevenage in Hertfordshire, and the subsequent support to STC and the Post Office in extensive trials of this 'first' during 1978 [21]. This was probably the most important demonstration to date in the evolution of optical fibre communication. The cable design and installation techniques had been studied under contract to the Post Office over the previous 18 months and an experimental 1 kilometre length of cable had been installed at the P.O. Research Laboratories at Martlesham Heath, Suffolk (1976-77).

But already the various technologies (fibre, cable, lasers, detectors etc.) were looking at the longer 1300 nanometre wavelength 'window' where the fibre attenuation is lower and regenerators may be more widely spaced, among other advantages.

1977 also saw the demonstration of a 140 Mbit/s landline optical fibre system to BTM (Bell Telephone Manufacturing Company, another ITT subsidiary); of a 560 Mbit/s fibre system.
Finally, 1979 saw the advanced preparation in hand for a trial, on Loch Fyne on the west coast of Scotland, of the laying of the world's first under-sea optical fibre cable. The trials eventually began in February 1980, the first of a series extending over almost the next 10 years, covering long-term reliability, personal and mechanical handling, cable and fibre splicing and connection, and the close examination of the stresses and strains associated with cable laying.

Cables for the military

In 1976 the Ministry of Defence decided to explore the potential advantages of using optical fibre cables to replace the copper HF quad cables used in the PTARMIGAN tactical communication system being developed for the British Army. Apart from greatly improved ease of handling in the field, these cables offered the chance of escaping the bandwidth restrictions imposed by quad or coaxial cables. All the potential rigours of battlefield conditions were taken into account - EMP (electromagnetic pulse), ECM and ECCM (electronic countermeasures and counter-countermeasures), general immunity to interference and intrusion; special rugged connectors, fibre splicing equipment for field use, and cable design for field conditions. In the event, despite a successful 'B' model field trial and design review, procurement was deferred on the tactical grounds of risk to the fielding date for PTARMIGAN.

Such pioneering work at STL, in cooperation with STC transmission and ITT Cannon (GB), provided a unique data bank of knowledge and experience in optical fibre practice and established STC as a state-of-the-art optical communications supplier to the military.

In the early 1980s this also provided the vital credentials for STC's successful bid for a FOTS(LH) - Fibre-Optics Transmission System (Long Haul) - contract from the US Army which took the development of tactical cables and components a significant stage further.

An acknowledgement

In connection with the demonstrations and trials so briefly mentioned above and anticipating others to follow, it is appropriate here to acknowledge the part played by the management and engineers responsible to their companies (STL's immediate customers) in bringing these and other systems into the public domain from laboratory model, breadboard or demonstrator stages reached within the laboratories. It was usually a long road, frequently running into problems; encompassing advanced engineering design, design for production, product planning to manufacture, installation, trials and commissioning. The enormous amount of documentation involved must be appreciated too.

On the other hand, it would be wrong to suggest that there is ever a distinct cut-off date, when researcher hands over to developer, and turns to other work. Transfer of the technology developed in the laboratories will have begun many months earlier, almost at the start of the research programme, with participation in progress and other meetings, document exchanges, and at the appropriate stage, introductory training if necessary. Later, STL staff would be on-call to assist ln any development problems arising.

Sensors

Studies of plasma etching for making semiconductor devices had yielded a dry etching technique subsequently used throughout the semiconductor industry. Plasma etching owed very much to STL's Rudolf Heinecke [10] previously mentioned, and recipient of the first Joe Evans Creativity Award. Results from work going back to the 1960s on metal-organic chemical vapour deposition (MOCVD) - in particular making epitaxial cadmium-selenium junctions using organo-cadmium compounds ~ were similarly adopted by the industry.
The first attempts at micro-machining silicon using selective etches and photolithography gave rise to a thin-silicon resonant pressure sensor which was patented in 1978 and subsequently enabled a robust altimeter to be realised. Sensors were destined to become very important in the 1980s as a by-product of optical fibre and materials research for communication. Detailed studies of light propagation down the fibre had yielded a number of intriguing 'effects' which STL scientists were

quick to exploit. In most cases the sensor function depends on a change in phase, a change in state of polarisation, attenuation or deflection of light caused by the particular effect being monitored. Optical fibre waveguide plus silicon sensor had proved to be an eminently suitable combination for 'hostile' environments. Systems commonly used the Hall effect, a widely used principle based on 'traditional' electro-magnetic interaction.

A prime example of STL's work on sensors was the STC 'Oilcon' ballast monitoring system [20][28], which was the concept of STL's David Pitt, taken up for development by ITT Conoflow, Dortrecht, and for which the early electronics were designed by STC. Oilcon was to become a major business in the 1980s for STC International Marine, with worldwide sales. David Pitt also played a major coordinating role in the development through to manufacture over the years 1977 to 1980.

Controlled Release Glass

Another well-known figure of this time was Cyril Drake, who in 1976 published a paper on 'controlled release glass' - a water soluble glass - and its possible applications [8]. Made up of physically harmless oxides of sodium, calcium and phosphorous, the degree and in particular the rate of dissolution in water could be varied by varying the mixture, dissolving as readily as sugar or slowly over a period of years.

The important feature of this discovery was that materials could be incorporated in the glass and released in a controlled way as the glass dissolved. If the material was an antibody, for as the glass dissolved the antibody would be left behind in the host to perform the function. The following ten years would see application of CRG to medicine, agriculture and horticulture worldwide.

Cyril Drake later joined a Pilkington company, taking with him his talent and experience. Controlled release glass was outside the immediate range of Company interests.

Liquid crystals

Another emerging technology was that of liquid crystal displays (LCDs), already widely used in primitive form in digital watches and calculators. An LCD cell provides a very-large-scale rapid (and bi-stable) change in molecular orientation as a voltage pulse is applied, to give a positive dark or light image (the familiar 'on-off' or '1-0' duality of the digital world). An array of these cells, controlled by digital drive circuits, can be arranged to form a slim picture-like screen or panel on which letter or figure patterns and displays may be constructed by suitably switching the individual elements (pixels).

Liquid crystals combine the properties of being able to flow like a liquid while retaining the anisotropic (directional) properties of solid crystals. Their birefringence (or double refraction) is the fundamental property for practical use. There are three main categories: smectic (after the Greek word for soap); nematic (after Greek for thread); and cholestoric, from the fact that these phases commonly contained cholesterol. The first two are named after their appearance.

The important feature of these displays is that they are bi-stable, in that they maintain their present status without fading until positively charged in the other status. A prototype at this time (1976) was a 20x30 cm display. The 'flat panel' has been under development since, seen as an eventual replacement for the bulky cathode-ray tubes used in visual display units and TV sets, and for widespread use in information displays in public places such as airports and railway stations.

'Doc' Foord, mentioned previously in connection with his early cable design work, has related how in 1956/7 he proposed to the Managing Director, T.R. Scott, a project to develop a flat TV screen.

The screen would comprise a sandwich of thin semi-transparent films, including a photo-luminescent layer and a two-dimensional matrix of conductors switched to produce a scanning effect. Passed to Alec Reeves for comment, the latter is understood to have turned down the idea on the grounds that new components and switching technology would be required, making the project a long and costly one. He was evidently right. The same argument could perhaps have been put forward for PCM ......…

The Professors

STL has over the years built up a reputation for finding solutions to problems. We consider here the problems that sometimes arise in manufacture, for example a component failure during a production run. It may be a problem associated with a batch of components or with an isolated one. Either way it has to be tackled and solved quickly.

Such problems referred back to STL will come under the scrutiny of one or more specialists in the sciences involved, and if necessary, individuals will be called from their project work to form a 'think tank' for the duration of the problem.

Such people will be of a high academic attainment, and with a record of successful projects behind them they are held in great esteem. On occasion we regretfully lose them to academia, and Appendix H serves as a reminder of past colleagues who have gone this way to take up professorships or posts of similar distinction.

Special cases are the Visiting Professorships, and in this respect the name of Professor C.H.L. Goodman will be familiar to present and past members of staff. Colin Goodman has been influential in the direction of materials research at STL for many years, and through his work in organising local symposia he has played an entrepreneurial role in the dissemination of state-of-the-art information. The subject of superconductivity would in due course exercise his talents.

'Radio on a chip'

The 1970s were important years for STL work in digital radio. A work package of the PTARMIGAN programme was devoted to the development of an SHF radio for battlefield conditions; while progress towards the miniature all digital radio was illustrated by the hand-held Radio Pager - the 'VHF radio on a chip' as it became popularly known - another STL 'first'. The design involved breaking away from the traditional approach to radio receiver design and the use of VLSI for the miniature circuits [26].

STL's Ian Vance in due course received deserved recognition for his design of the Zero-IF circuit, at the heart of the pager, and for his contribution to the whole development. The manufacture of the pager by STC resulted in a substantial order from British Telecom in 1980 and to further enhanced versions being developed for the marketplace. The STC Wide Area Radio Pager was to win for STC in 1982 a Design Council Award for excellence in design.

It was also an exemplary example of laboratory-to-market progression. Ian Vance's subsequent award of the MBE in the 1989 New Year's Honours List for this and later contributions to industry won the universal approval of his colleagues.

Cable TV trials debut

Throughout the latter half of the 1970s STL's network and switching expertise was being used to assist STC engineers in evaluating the merits and competitiveness of the emerging Cable TV, a subject of growing political as well as technical interest. The reception of multiple channels via

Cable TV was seen as a potential rival to direct-satellite TV. A field trial of Cable TV was held at Milton Keynes in 1981. This form of TV distribution was to be a subject of political and commercial debate for several years, but was to lose the limelight as satellite and local radio rose to prominence.

Some fell by the wayside

It would be unjust and inappropriate to overlook the mounting number of projects which caused some stir at the time - patent activity, publications and demonstrations - but did not fall within the business domains of ITT or STC, so for these or other reasons did not prosper.

- Ferrodot. A forward-looking development at the time, and one which could have filled a niche, was the Ferrodot 'percussionless' printer. There were high and low-speed versions, and desk-top and public displays were designed. Ferrodot was capable of printing 10 000 characters a second, with a potential for 60 000 char/s. An important feature was a complete absence of moving parts, and it was this that secured its place in the MALLARD switched network military programme. The work received ITT support over the years 1963 to 1969 with some government funding in the later years, and a proposal was submitted for its development by ITT Creed. Some work was done in conjunction with STC Monkstown. In the end it appears to have foundered on foreseen maintainability problems, and magnetic powder handling and deposition problems. Two STL names are prominent in the Ferrodot story: Henley Sterling and Arthur Brewster.

- The evanescent-mode waveguide filter, which proved to be more rapidly evanescent than George Craven [15] could reasonably have anticipated.

- The STL Low-Light-Level TV Camera - based on the 'image intensifier' or 'light amplifier' principle - had been developed. It was not taken up although low-light-level (infra-red) cameras have subsequently been adopted by the armed forces for night-time viewing and range finding. This also was the work of Derek Mash, mentioned earlier.

- The 'Solar Eyeball' was designed to track the sun in its passage across the sky as the heat energy is converted into electricity using solar panels. The means of tracking the sun was another invention of Derek Mash and the design principle quite unique. Presumably intended for countries where sunshine is the norm, the project ran into difficulties not entirely attributable to the British climate.

- 'Radiating cables', another project of the 1970s, involved cables with slot orifices in which the consequent leakage of electromagnetic radiation could be used for communication purposes. Typical uses would have been communication with trains and with cars, since the cable could have been laid alongside railway tracks and motorways.

- The Free Space Optical Link. An 'optical-fibre to free-space converter', for use in inaccessible places (across rivers, etc.) where the laying of cable is not practicable. This system used some of the new semiconductor diodes and detectors, and is understood to have been taken up outside of the Company. It was designed by Arthur Brewster, whose name has already been mentioned in connection with Ferrodot.

- The Radio Lighthouse, a system of position determination for small craft in local waters, where the bulk of the electronic equipment (the 'lighthouse') is on shore and only a simple low-cost receiver is required on board, was designed at STL by Dr Rolf Johannessen [17], who was one of the principals involved in the Radiating Cables work mentioned above. Although trial systems were set up on the French and Belgian coasts to cover the Dover

Strait area, and in Scotland, the situation seems to have stagnated and it is thought that the role of the Radio Lighthouse would be performed via global satellites as GPS matured.

It would of course be wrong to associate these projects with failure. They in fact represent the very essence of research endeavour: original thought, innovation (frequently in opposition to conventional thought and practice), design skill and single-mindedness. It has been said that in research two in ten success rate is commendable. It has also been said that if a research organisation has a 100% success rate in its projects then its management must stand accused of playing safe! On the other hand ln the private sector at least, the bogey of 'return on investment' or 'cost effectiveness' has to be placated.

Being outside of the main focus of company strategy, such innovative work by individuals becomes particularly vulnerable at times of business retraction and realignment.

It may be of interest to add here (although not in the same category as the foregoing) two cases of 'what might have been'. The history of science by definition abounds with such cases.

- Alec Reeves ln the 1940s while working at the ITT Paris laboratories had noted negative resistance effects in doped germanium diodes. Pursuing this line of research could have led to his inventing the transistor - but Bell got there first.

- Another potential 'first' was missed when the novel idea of using hydrides as intermediates to achieve high purity was being explored with germanium as well as the dopants arsenic, lead, boron and phosphorous. However, it is thought that a policy decision to concentrate on pure silicon prevented STL chemists developing epitaxial deposition ahead of the opposition in the USA [12].

Some unquantifiable return on investments in these isolated projects would be forthcoming from published papers, demonstrations and displays, and for a number of years such STL achievements were in one form or another demonstrated at the Institute of Physics' Annual Exhibition, held at Alexandra Palace, north London.

Another popular annual event, providing an opportunity to display laboratory achievements to local people, was the Harlow Town Show, another entry in the STL appointments diary at this time.

STL scientists and engineers were also contributing regularly to the ITT Technical Journal 'Electrical Communication' and to other prestigious scientific and technical journals. Publishing on average one paper or article per working day, and on average making 150 patent applications every year, was evidence enough of STL's standing in materials and systems research for telecommunications.

PART IV - CORPORATE UPHEAVAL AND THE AFTERMATH

In 1979 the Post Office had split into two, to form separate postal and telecommunications businesses, and British Telecom (BT) was formed out of the latter, to become a public limited company (PLC) in 1984. The new arrangement marked the opening of a new age of competitiveness in the telecommunications business.

The following year, management changes within ITT took place which were to be but the first of a series of events which, over the following seven or eight years, would see the transformation of the traditional, and possibly complacent, STC, and the demise of the name Standard Telecommunication Laboratories Limited. Fortunately, the initials 'STL' would survive and this would be of considerable help in maintaining continuity with long-standing customers within the ITT family as well as outside, during the difficult times ahead.

STL-STC-ITT: a sensitive relationship

ITT had been sole owner of STC for more than 50 years, but ln 1979 it had reduced its holdings to 85% by public offers of its STC shares, and in 1982 similarly reduced them to 75%. Again in 1982, ITT offered a further £40 million of its shares to the British public, by so doing reducing its shareholdings in STC to 35%.

The problems which arose in the early 1980s, especially after 1982, in the business relationships between STL, STC and ITT, had their origins, at least in part, in the great diversity of interests acquired by ITT during the 60s and 70s under its charismatic Chairman and Chief Executive, Harold H. Geneen. ITT had purchased or otherwise acquired controlling interests in businesses ranging from bakery to bathroom accessories, car hire to hotels, insurance to machine tools, as well as in a wide range of 'consumer products'.

All of this in addition to its principal civil telecommunications and defence businesses in the USA.

There were accordingly areas of concern to ITT in which STL could and did provide essential and much valued R&D services, especially in material sciences and materials evaluation and diagnostic services. In addition, as the principal R&D company for ITT Europe, STL had obligations to the ITT European companies through a General Relations Agreement (to be mentioned later); and there was the collaborative work with the Advanced Product Development Groups in the USA.

In spite of its close proximity, physically and temperamentally, there were no special obligations to STC. There was bound to be a certain emotional affinity, but as far as R& D services were concerned, the latter was one of the ITT European companies being served by STL with no special claims to allegiance. Accordingly, as the ties between ITT and its European interests were slackened, there was an inevitable period of readjustment for STL as it turned towards STC and began to adjust to a new more independent STC strategy. These will have been sensitive days for the STL management, and all the old questions as to the role of the separate research organisation will have received a new airing; in short, STL had to argue its case afresh.

Such were the broad issues which were to exercise STL management in the early 1980s.

'Technology Transfer'

Following an internal reshuffle in ITT early in 1981, with repercussions at ITT's Europe HQ in Brussels, Dr 'Jack' Shields became resident Managing Director at STL. He had been Executive Director, Research Programmes, at Brussels. Mr 'Bill' Forster was then Technical Director, ITT Europe, and nominally Managing Director, STL, following the departure of Jock Marsh.

Under Jack Shield's leadership a greater emphasis was to be placed on the transfer of technical information from the laboratories to ITT companies. Not new in principle, 'technology transfer' was to be done on a more systematic basis in future. Milestones would be agreed for the year and progress on them reported regularly. Problems would then be reported upon and tackled in good time, before they reached Red Flag status. In future, Technology Transfer would feature prominently in management's planning.

Bill Forster was soon to depart to an appointment at ITT's headquarters in New York, and Mr R.A. (Bob) Palmer became the Executive Technical Director in Brussels. Regular monthly letters from Jack Shields to Bob Palmer in Brussels and STC Chairman and Chief Executive Sir Kenneth Corfield in London were evidence of a continuing duality of STL's allegiance at this time.

In support of and to give emphasis to the new policies, the laboratories were reorganised into two directorates, 'Technical Programmes' and 'Technology Transfer', with Mr Desmond Ridler and Dr Ken Batsford the respective Directors.

The General Relations Agreement referred to earlier had for many years been in operation between STC and ITT, which, in common with similar agreements between ITT and its other subsidiaries, had governed the exchange of technical information, intellectual property rights, patent rights and other issues. Most of the mainstream work at STL, as well as the so called 'blue sky' research, had been supported by ITT. [An unfortunate term, and essentially relative, 'blue sky' applied to the work of individuals whose inventiveness needed an opening but whose ideas were well outside (or in advance of) the main thrust of Company interests. The term was also applied by some to those projects the aims of which were not fully understood. It would necessarily have been funded under local arrangements.] Such work, strictly limited as it was, became an early casualty in a later and strongly market-orientated STL.

Joe Evans

An event which was to sadden many people throughout the whole ITT corporation, and particularly his colleagues nearer home, was the death in 1981 of Dr Joe Evans, leader of STL Materials and Components research for many years. A very popular figure, Joe Evans enlivened many an otherwise mundane meeting, both at home and in Brussels, with his humour and obvious high intelligence. It was fitting that in his memory an annual 'J Evans STL Memorial Award' should be initiated in 1982. The first recipient was Rudolf Heinecke, who was to go on to further distinguish himself in his field of plasma processing and deposition of materials.

The New Marketing Philosophy

With ITT's further withdrawal in 1982, a revised General Relations Agreement was to be negotiated, for clearly with ITT now a minority shareholder its relationship with STC/STL had taken a significant turn. The GRA was revised later that year.

Sir Kenneth Corfield, Managing Director of STC since 1970, had become Chairman and Chief Executive, STC in 1979. Very much an innovator and entrepreneur in his own right, Sir Kenneth was a great supporter of a strong R&D support facility, and at STL for a while there was a degree of optimism in the air. The slackening ties with ITT were no doubt a source of invigoration and optimism in the higher echelons; but to the people in the laboratories a 'wind of change' was about to manifest itself; closer ties with STC business units were to be the basis of STL's future R&D policy. Any residual suggestion of a university atmosphere in the labs was to be finally swept away and laboratory management would in future have to embrace a strong marketing strategy.

New Threats and New Associations

The intervention of government in business affairs has always been a subject of controversy. However, formidable competition foreseen from the USA and Japan, already much in evidence, and the risk of Europe falling behind in areas vital to its future independence and competitiveness, led to a new spirit of European cooperation in which national governments played key supporting roles. Similarly, cooperation between companies within individual countries was also to be encouraged.

The publication of a Japanese national programme for a six-to-seven year Information and Manufacturing Technology programme, in which plans for '5th generation computers' and 'robotics' respectively were openly discussed, is thought to have had some bearing on this new willingness to cooperate between erstwhile rivals.

'Pre-competitive' research programmes were set up (1981-82) under new collaborative agreements between companies, and involving the universities, the results to be shared and freely circulated. The competitive element would be introduced in the later 'implementation' stages. Schemes of particular importance were the European Strategic Programme of R&D in Information Technology (ESPRIT); the Basic Research in Industrial Technologies for Europe (BRITE) programme; the Joint Optoelectronics Research Scheme (JOERS), and the DTI-sponsored Alvey programme for British businesses. The titles speak for themselves; they covered three broad areas of technology - computers, computer-aided design, and optoelectronics. Encompassed by these three areas, 'intelligent' terminals, the man-machine interface, and 'knowledge-based' systems' were to be key topics of the future as man and computer converged towards the Information Society.

Software comes of age

For two decades, software engineers had been constructing software programs using the same fundamental approach: that of composing high-level language statements and putting them together. Meanwhile, the complexity of the system they were asked to construct was continually on the increase, so that reliability and 'correctness' were becoming increasingly critical issues as 'embedded' software became a part of an expanding range of applications. A different approach was needed.

To advance the technology of software development, it was necessary to consider constructing software out of modules, which would be reusable in the sense that their development costs could be spread over many instances of usage, and greater reliability would be assured. The approach could be likened to that employed for electronics hardware: semi-custom LSI chips are large-scale, reusable designs of components with which engineers construct circuits, instead of designing components afresh on each occasion.

Another aspect of the new approach, again bearing a close analogy with electronics hardware and VLSI, was to be to construct support software using a 'library' of Abstract Data Types, so as to be able to insert, catalogue, search and retrieve software modules for particular usage. Integrated Programming Support Environments would unify the whole process of software evolution throughout its life cycle: the Vienna Development Method and Ada (the latter introduced by the US military) were being developed and applied to software general development.

Formal Methods of system specification were being developed to overcome the problems of ambiguity and the clarification of customers' needs. These are based on mathematics and allow precise descriptions and properties of data, the operations that can be performed on the data, and the states that the computer system can be in.

One obvious problem was that few customers were likely to be sufficiently familiar with the mathematical interpretation of their requirements. To overcome this, the mathematical symbols would be annotated with structural English text to interpret the specification, and computer-based tools used to animate the specification. The customer could then verify the functional properties for himself. A close partnership between customer and systems analyst would be paramount.

Looking ahead, considerable research, development and education will be needed before the Formal Methods approach becomes of common usage. In the meantime, specifications will continue to be a mixture of diagrams, text and mathematical symbols, and programmers will continue to run the risk of delivering systems that do not quite match the customer's requirements.

The name of Tim Denvir has already been mentioned in connection with the software centre for the ITT3200 computer software development. To a contemporary of his at the time, Mr Bernie Cohen, we owe STL's growing reputation in software science. In the main, this work, which amounted to several years of research (the fruits of which would ripen in the rather remote future) was partly or wholly funded under one of the EEC ESPRIT collaborative schemes. Another important project of the early 1980s, also under ESPRIT, was Software Program Management and Maintenance System (SPMMS), which was intended to formalise another aspect of the software life cycle.

Martlesham-Ipswich and 'coherence' trials

Another technical milestone had been reached in 1982 when the Martlesham - Ipswich Monomode Experiment (MIME), which had been set up by British Telecom, demonstrated the suitability of single-mode fibre for landline trunk links.

While multi-mode fibre (100 - 200 µm typical diameters) was easier to splice and join, generally easier to handle, propagation problems such as transient mode changing, resulting from the multi-mode nature of the light [23], and which causes pulses to 'merge' and become indistinguishable at high bit rates, led to this demonstration using the much finer (6 to 8um typically) single-mode fibre.

The 62 km link was later used by British Telecom for experiments in coherent transmission, which was one of the emerging technologies for further advances in communication. Coherent transmission (and reception) would provide much greater sensitivity in the reception of signals, permitting greatly increased distances between regenerators; indeed, these expensive units would be dispensed with altogether on shorter routes.

STL had been anticipating coherent transmission for several years. Richard Epworth [23] in the transmission laboratory had demonstrated the use of the laser local oscillator (employing the heterodyne principle from traditional radio practice), operating in phase with and of the same wavelength as the transmitted carrier wave, being a means to much greater sensitivity and selectivity.

The STL laser group, now with its international reputation well established, had also been anticipating the emergence of coherent transmission, and was developing its range of 'single frequency' distributed feedback (DFB) lasers to provide the local oscillators for the coherent systems and for STC's optical fibre transatlantic (TAT) cable system.

Corporate Matters III

In July 1983 Mr B D ('Bernie') Mills took over as Managing Director. With a background of long service in senior positions with STC, and sensitive to the need for closer, more direct cooperation between STL and the STC development and manufacturing companies, Bernie Mills set about the task of organising the laboratories accordingly, a task which was to take up a major part of 1984.

A merger of STC and ICL, which took place in September 1984, was seen to present new and great opportunities for both parties. Although marred initially by a general depression in the electronics industry, to which STC was particularly vulnerable, and marked by a sharp drop in sales of components (a substantial investment had recently been spent on building a special components assembly plant at Foots Cray in Kent) and high interest rates, this new partnership was seen by many to be a 'natural', with the prospect of a synergy of ICL computer mainframe/office terminals and STC advanced network technology. Representatives from the new alliance would in future go out together to grasp new opportunities which might well be denied to their companies in isolation.

Future products would be 'networked systems', a synergy or bringing together of ICL mainframe, desk-top and other 'personal' terminals, and STC networks: a timely arrangement under the circumstances, since STC had recently launched its new and versatile PDMX (programmable digital multiplex) unit, already being introduced in a new City of London optical-fibre-based communication complex. The PDMX would have wide applicability to ICL interests.

However while the prospects for the merger looked bright at the tactical level, strategically STC was about to enter a period of depression and declining confidence, both of its shareholders and the public at large.

For in order to meet what amounted to a state of crisis following a sharp drop in profitability, a major restructuring of STC PLC took place under its new Chairman, Lord Keith of Castleacre, and a drastic programme of staff reduction and redeployment took place (1985-86).

Major changes took place, from boardroom downwards, leaving a much trimmer organisation better suited to meet the foreseen challenges of home and abroad that undoubtedly lay ahead. STL took its share of the trimming down process with a programme of redundancies and early retirement, involving in all about one-hundred people.

At this time, marketing considerations prompted two new 'private ventures': one was between STL and an American company, LSI Logic, and the other between STL and a new company Image Displays Ltd. The first was a reciprocal arrangement by which STL would be supplied with LSI chips in exchange for a guaranteed STL participation in the research and development. The second was an agreement over the R&D, manufacture and marketing of liquid crystal display panels for which the new company had been formed.

In October 1985, Bernie Mills retired and was succeeded by Mr P I Cropper. Previously Managing Director of IDEC, a major systems engineering company of STC, and with a background of senior positions in ICL of over ten years, Peter Cropper brought with him timely and valuable knowledge of ICL business philosophy and methods, and an appreciation of the potential of the recent STC/ICL merger.

As part of a new restructuring programme, the Company name 'Standard Telephones and Cables Limited' became 'STC PLC'. 'Standard Telecommunication Laboratories Limited', reorganised to include an ex-ICL systems engineering and software contingent, became STC Technology Ltd, the effective date being 25th November 1986. In addition to the main complex at London Road, the new 'STL' occupied an ICL site at Newcastle-under-Lyme where the systems engineering contingent was housed.

The systems planners disperse

A casualty of 1986, after some 40 years as a coherent entity, was the Systems Planning group whose members were dispersed among the technical divisions. The divisional manager of the Systems Planning Division in its final years, Mr. Geoff Dawson, had first joined STL in 1946, had been

Chief Engineer of STC's Microwave Systems Division, and had held senior management positions at STL since 1967. He was therefore well qualified to head this team of professional engineers, most of whom had themselves held senior management positions within ITT and elsewhere. In view of his association with the subject it was appropriate that he should have been invited to deliver, in March 1981, the Memorial Lecture '50 years of cross-channel microwaves' at the IEE, Savoy Place, London.

Timely new orders

STC's sensitive situation in the business world could in no way affect its status in its primary business of telecommunications networks and services which had been built up over 100 years [31].

Under the leadership of Lord Keith, and with Mr. Arthur Walsh as Chairman of the Board, STC's recovery was greatly aided by important orders from British Telecom and the Ministry of Defence. 1985 saw STC winning 85% of the year's submarine cable projects open for international tender, including the first submarine optical fibre cable link between the UK and Denmark, and a PTAT-1 contract for a 7000 km transoceanic optical link from the UK to Bermuda and New York [25][27][29][30].

STL shared the satisfaction in these business successes, not only from having taken part in the R&D and development, but also from the new feeling of confidence in the future which these successes helped to engender. It must be said that the mainstream R&D work during periods of trial and tribulation went on much as before, but within different organisational structures.

As part of the restructuring programme, STC had in 1986 disposed of some of its components businesses, so that there was a need for reliable sources for components. This was satisfied in one important instance by the joint ventures between STC and LSI Logic Inc. previously mentioned, the latter to supply 1.5 nm CMOS and bipolar/CMOS (BiCMOS) devices of original STL design. Such joint ventures secure access to large-scale component production facilities without exposure to the risks of the mass market.

In 1986 also, a further programme was launched, Research & Development in Advanced Communications in Europe (RACE), which was a further step along the road to a European identity in science and technology, and a further answer to the foreseen threat of USA and Japanese dominance in the advanced technologies of the 1990s.

In November 1987, the integration of ICL and STC was further enhanced when a directorate of Corporate Information Systems was formed, and Peter Cropper was appointed to head the new organisation. The setting up of the new directorate was seen as a practical demonstration of the STC PLC commitment to Information Systems.

Peter Cropper was succeeded as Managing Director by Dr Eric I Risness, CBE, from a distinguished career on the military procurement side of the Civil Service, who would cast an independent and pragmatic eye over the affairs of his new charge.

A New Optimism

The 1980s had on the whole proved to be difficult and unsettling years, and as 1988 dawned there was a real need for a period of stability.

ITT had finally bowed out of STC affairs in October 1987, selling its remaining holdings to Northern Telecom of Canada. The ramifications of the subsequent purchase by STC PLC of the Northern Telecom's UK subsidiary early in 1988 have yet to be fully assimilated.

Business opportunities are seen for STC in North America and for Northern Telecom in Europe, each using connections established by the other.

At the close of 1988, and to this brief history, and as STL prepares to celebrate 30 years at Harlow, it is perhaps the continuing convergence of STL and ICL business interests that is having the most immediate impact.

In Europe, the 'opening of frontiers', at least in the commercial sense, planned for 1992 for EEC member countries, is the latest challenge for the STC PLC Group, as for the country as a whole. With ICL connections and experience already in Europe, and its own achievements behind it, there is every reason for confidence. In the West at large, a massive merger and restructuring movement is under way among the major companies as they prepare themselves to compete in a greatly expanded market of 300 million people. Of more direct and immediate interest, the enormous investment required for the emerging integrated services networks is beyond the capacity of any one company, and this fact alone is a further incentive to merge and collaborate among those whose business is Information Technology.

Further afield, a continuation of the current trend towards detente in East-West relations promises to provide business opportunities on a scale as yet impossible to predict, and a continuation of the current easing of military confrontation, already much in evidence, will have its repercussions.

Last words

As far as STL is concerned, adaptation to new circumstances is not an unfamiliar exercise, so we may be sure that whatever the future holds for STC PLC as a group, STL will be there in its supporting role, confident to refer the inquisitor to its track record for its credentials, as a supplier of state-of-the-art technology and as a centre for innovation and diagnosis.

ACKNOWLEDGEMENTS

[LIST OF PRESENT AND EX-COLLEAGUES WHO HAVE PROVIDED INPUTS, MORAL SUPPORT ETC.]

APPENDIX I: WORLD 'FIRSTS' AND KEY PARTICIPATIONS
[Later notes to be added]

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22. First NAVSTAR receiver operational in Europe, 1977

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C. Other References

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APPENDIX II: PROFESSORSHIPS AND OTHER DISTINCTIONS ATTAINED BY STL STAFF

Their STL colleagues at the time shared the satisfaction of the following in their elevation to the professorial and other posts of distinction noted.

E.A. Ash	Professor, Telecommunications	??
K.W. Cattermole	Professor, Telecommunications	Essex
B. Cohen	Professor, Software	Surrey
C.H.L. Goodman*	Visiting Professorships	Chelsea College
	Physics and Chemistry of Solids	Warwick, then King's
G.A. Hockham	Professor, Electrical Engineering	Queen Mary College
C.K. Kao	Professor, Electrical Engin'g	Chinese Univ. of Hong Kong
	Chief Scientist, ITT	ITT Roanoke, USA
G. King	Professor, ??	
L. Lewin	Professor, Electrical Engineering	Colarado
G.D. Pitt	Visiting Professor, Physics	Surrey
C.P. Sandbank	Head of Research	BBC

* STL staff

APPENDIX III – AWARDS

[To BE COMPLETED]

Company Awards	First Recipient	Year
Harold H. Geneen Creative Management Award	D.G. Pitt	??
Sir Kenneth Corfield Prize for Innovation (??)	P. Barton	1982
Joe Evans Memorial Award	R. Heinecke	1982
STL Creativity Award	R.V. Latin	1982
STL Programme Management Award	D.W. Wright	1987

National/International (award related to their work at STL)

MBE (New Year Honours)	I.A.W. Vance	1989
	A.H. Reeves	
	C.K. Kao	
	G.A. Hockham	
	C. Earp	

APPENDIX IV - TECHNOLOGY FOR THE 1990s

It would be appropriate to end this account with an outline summary of some topics of particular relevance to the 1990s.

[The following notes are virtually off the cuff and will need to be 'strengthened'! Illustrations will supplement the text.]

WDM

The wavelength-switched network concept or 'wavelength division multiplex' (WDM): A single fibre carries a number of optical carriers of different wavelength, each providing a channel for analogue or digital information, i.e. voice, data, video, TV. At the receivers, optical detectors separate out (demultiplex) the different channels to provide the carriers for individual services. The light in the fibre, at the individual wavelengths, may be provided by an array of (near) single-frequency distributed-feedback (DFB) lasers.

[The principle takes us back to our school days and early physics lessons. White light - containing all colours of the spectrum - introduced through one surface of a prism emerges split up into all the constituent colours, red - orange - yellow - green - blue - indigo - violet. Let us call these colours 'modes'. We may suppose then that these individual colours are used as independent channels of communication. Neighbouring channels would need to be kept isolated to avoid mutual interference The prism acts as a wavelength (or colour) demultiplexer]

The principle has already been demonstrated in the laboratory: In 1987, demonstrations of an optical fibre link carrying three television channels were made to senior BT management, one in the presence of the Prime Minister, Mrs Margaret Thatcher.

Coherent Detection

Related to WDM and the basis of the new family of optoelectronic components for the 1990s, coherent detection techniques, employing a laser version of the local oscillator used in radio communication, are now being studied for optical communication. They are distinguished by the great improvements in sensitivity and selectivity that are possible. Essentially, coherent detection relies on subtle changes of phase rather than polarity of the incoming signal. The local oscillator, in phase with the carrier signal and of the same wavelength, effectively raises the threshold of the modulating (message) signal above the background noise level.

One important outcome of this work will be that for optical fibre systems, repeater spacings, currently some 50 - 60 km, will increase to 300 km and beyond, and repeaters will be dispensed with altogether on many of the planned routes. Ultra-narrow linewidth lasers, operating in the 1.5 μm window, are being developed for use as transmitters and local oscillators for these coherent systems.

Digital Radio

STL's radio work is being applied on an increasing scale to the civil field, particularly in local and cellular radio. Refinements of the Radio Pager receiver have led to the world's first single-chip display pager as noted previously. The 'cordless telephone' is currently under development, and a second-generation cordless phone (CT-2) is the subject of an important programme for British

Telecom, with multi-million pound sales prospects as it becomes widely available to the general public in the 1990s. It is a rival system to 'cellular radio'.

VLSI

It is of course VLSI which is making it all possible. VLSI techniques are continually being refined and updated. The present generation packs some 100,000 to 150,000 transistors on a chip less than one-half inch square: their successors will approach one million with predictions of 10 million over the next decade.

BiCMOS technology, or the merger of bipolar and CMOS circuits on the same chip, is a great step forward. It was the design of Dr Peter Scovell that overcame the apparent incompatibility between the digital and analogue elements that required their isolation on separate chips. Their respective advantages can now work together in close proximity (micrometres) over a wide range of applications: e.g. digital working into the subscriber's handset and pilot headsets.

Sensors

Sensors, based on the interruption, deflection or dispersion of light carried along optical fibres, or on sensitive silicon structures using optical fibre for transmitting information and control, have become a major business prospect. The oil-in-water monitor, marketed as the STC Oilcon monitor, pioneered at STL, has already been mentioned. A laboratory prototype down-well pressure and temperature sensor is being developed which uses a resonant silicon element which is excited into resonance as a function of the physical property being measured. Pressure and flow measurements at well-heads may be made from remote gas and oil platforms, where the only connection between platform and well-head is an optical fibre cable. Power may be transmitted down a control fibre to open and close a valve.

The term 'sensor' is currently being applied to a wide range of products, from radar antennas to robots, from space satellites to car instrumentation. The common factor is in the use of semiconductor optical and optoelectronics components, realised by VLSI and controlled by (micro)computer. A specific example is STC's reflectometer, which detects breaks (or lesser discontinuities) in fibre waveguide from the light reflected back from them. The reflectometer uses coherent technology to achieve the high sensitivity required to detect minute reflections. There is enormous business potential in sensors for the 1990s.

ISDN

Integrated Services Digital Networks (ISDN) combine traditional voice transmission with the capacity to store and exchange data. The alliance of STC and ICL is being given practical form in a business partnership to develop an STC PLC prototype ISDN product family. This involves networking ICL professional workstations with STC's 144 kbit/s transmission system at the heart of which is its new Programmable Digital Multiplexer (PDMX). Variations of the ISDN concept are already being considered in many areas, including the military. The prospect of truly wideband services, i.e. voice, data, video, TV, over a common network via optical fibres, with teleconferencing a regular feature, will approach reality as the technology matures, but is still some years away.

Superconductivity

A subject deep in speculation, and in which heavy investments in research is being made by the three rival groups, Europe, USA and Japan, is that of High Temperature Superconductivity, where the 'high' temperatures of interest are currently in the 70 K (-200°C) region. A small group is at work at STL monitoring the literature and carrying out modest experimentation on this fascinating subject.

The ramifications of achieving zero electrical resistance at or close to room temperatures (about 20°C) will be revolutionary, but it is generally acknowledged that such an attainment is as yet many years away. [One is reminded that optical-fibre communication has been on its way for over 20 years and it has still not reached the subscriber.]

[THIS APPENDIX TO BE REVISED!]

List of Proposed Illustrations

(not finalised and not in order of presentation)

Fig. No.	Brief Title	Format
Frontispiece:	Enfield and Harlow 1988	(comparison)
1.	A H Reeves (& PCM background)	all on one page?
2.	Photographs of Managing Directors	photograph
3.	K C Kao/G Hockham	photograph
4.	C Earp	photograph (?)
5.	Radio valve & LED comparison	?
6.	Early semiconductor diode	schematic
7.	Lab at Enfield (1950s)	photograph
8.	Ultra-clean lab at Harlow	photograph
9.	High Pressure Lab	photograph
10.	Materials Evaluation Centre	photograph
11.	O.F. pulling tower	photograph
12.	Acoustics Lab	photograph
13.	O.F. fundamental wavelength/attenuation	graph
14.	O.F. waveguide/ray diagram	diagram
15.	O.F. Cables: landline and sub-sea	structure diagrams
16.	Early laser	diagrammatic
17.	Gunn diode/oscillator	photograph?
18.	Doppler/MLS	photograph/schematic?
19.	Quartz crystal oscillator(s)	photograph
20.	GPS	principles/schematic
21.	Hitchin-Stevenage P.O. link	map & photo
22.	Loch Fyne	photograph
23.	Si pressure sensor	photograph
24.	FOG	principles
25.	Liquid crystal display	principles & photo
26.	Radio pager	photograph
27.	Radio Lighthouse	map of Dover Strait
28.	DFB and ridge lasers	schematic/photos?
29.	Wavelength-division multiplex	principles
30.	Spatial light modulator	principles
31.	Grating multiplexer	principles
32.	VLSI	typical chip (photo
33.	VLSI Design Centre	photograph
34.	A 'networked' system	principles

Other illustrations

	Organisation chart March 1966	In hand - some familiar names here!
	Synthetic crystal growth	photograph(s)
	STL divisional structure	1988-89 (including photos of directors?)

OTHER TOPICS TO BE MENTIONED IN FIRST EDITION

Conference Centre

Annual Cricket

Supporting services:

Financial services?
Restaurant - Malcom Napier
Library services (opening at Enfield already mentioned)
Site Services - Arthur Brown
Model Shop (already mentioned at Enfield)
Personnel Dept. (already mentioned at Enfield)
A&SC (Arthur Brown, Vi Maile)