BIOGRAPHICAL
MEMOIRS

Edward George Sydney Paige. 18 July 1930 –– 20 February 2004

Eric A. Ash and E. Peter Raynes

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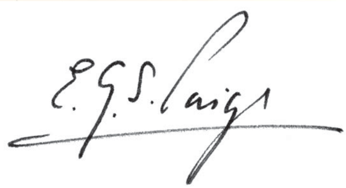

EDWARD GEORGE SYDNEY PAIGE

18 July 1930 — 20 February 2004

Elected FRS 1983

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Professor E. G. S. Paige was an applied physicist who spent the first half of his career at the Radar Research Establishment, Malvern, where he made major contributions to the understanding of transport properties in semiconductors. He is, however, particularly celebrated for his work there on acoustic surface waves and their use in electronic systems. In a later period while at Oxford he developed an innovative class of optical systems based on the use of programmable phase plates.

Early years

E. G. S. (Ted) Paige's career embraced a remarkably wide range of themes within physics. In pursuit of his research objectives he showed equal facility in and sympathy for the pure as for the applied. He was bilingual in theory and experiment—perhaps trilingual if we add his enthusiasm for directing his researches to novel applications. And it all started in a thatched cottage, reputedly of sixteenth-century vintage, in Northiam, a village on the border between Kent and East Sussex. Mains water arrived when Ted was five years of age, and electricity somewhat later. He had a happy family upbringing, with parents who were encouraging and supportive but who had little contact with the world of learning or with intellectual pursuits. His father was the stationmaster at Northiam village—employment by the railway service was a family tradition traced back to the earliest days of rail.

Ted was an only child, and in his early years he liked to spend much of his time alone. He developed a passion for bird watching, which he sustained throughout his life. He developed a

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spontaneous interest in the natural world, based on what he could discover by his own observations, and this was enhanced when he managed to acquire a microscope.

As a child Ted suffered periodically from chest complaints necessitating visits from a doctor, which were not readily affordable by the family. Ted remembered his mother's explanation of how they coped: 'She told me that we were unable to pay the normal doctor's bills but he lowered the charges, balancing it by charging well off people more.' He added that he saw this as the source of his subsequent socialist leanings.

School career

Ted attended Sandhurst primary school in Kent from 1935 to 1941. He remembered the disruption caused in his school by the arrival of children evacuated from London—to be safe—although within a year most of them had, perhaps unwisely, returned to London. (One of us (E.A.A.) had the reverse experience of evacuation from London and returning in time for the onset of serious hostilities.) It was towards the end of this period that the evidence of his innate abilities first appeared. There was at that time an examination, somewhat similar to the '11+', which still obtains in part of the country. Success in this led to an Assisted Places entry into Rye Grammar School, where he remained until 1949. The school had been relocated to Bedford, again to escape possible bombing in Rye, which meant that Ted was accommodated in a succession of local billets. During that period Ted developed the ambition to make the navy his career. He joined the Sea Cadets, and he planned to go to Dartmouth on leaving school. However, he then discovered that his choice of career involved a good deal of regimentation, which he found less than appealing. Matters came to a head when Ted refused to participate in 'church parades', and this led to a mutual parting of the ways. Ted remained throughout his life of an agnostic disposition.

During his time at Rye Grammar School, Ted developed an increasing interest in science. He performed some experiments on his own—including the making of explosives, happily with no dire consequences. At this time there were no plans other than his leaving school at the 'School Certificate' stage. However, his headmaster had spotted Ted's abilities, and suggested to him and to his parents that he should consider staying on in the sixth form. This was absolutely new territory for both his immediate and more distant family—but it happened!

So Ted embarked on his sixth-form work initially focused on biological studies. That choice was dictated by the fact that at that moment there was not a single teacher for the physical sciences in that school. However, quoting Ted, 'by great good fortune a master, Mr Leslie Elliott joined the school' so that Ted could include physics and chemistry in his studies. Elliott did more than teach—he inspired. He got his students to broaden their reading, and to build things such as hi-fi amplifiers*. Elliott also suggested that the next step should be to go to a university—an even more dramatic departure, as seen from within the Paige family. This required good exam results in Higher School Certificate. They were good enough to earn a County Scholarship, but even so it was not at first clear whether Ted would win a place at Reading University to read physics†. He did, but modestly explained 'only as a result of someone dropping out in the last few weeks before the start of term.'

* Ted wondered why some bikes had external three-speed gears and others internal hub three-speed gears, and further why not combine them and make a nine-speed bicycle? He did!

† This was still during the immediate postwar era, when places were preferentially allocated to returning veterans.

University education

Undergraduate studies

Ted Paige's undergraduate career (1949–52) involved studies in physics, chemistry and mathematics, but culminated in 1952 in a first-class honours degree in physics. This also earned him a British Association for the Advancement of Science Exhibition, enabling him to attend the British Association meeting that year. He was fully confirmed that physics was to be his life. Ted Paige was launched on his career!

During his time as an undergraduate, Paige took on a summer job in an electronics factory. He discovered that he was not keen on working in industry—perhaps an echo of his experiences as a Sea Cadet. So there was both push and pull to persuade Ted to embark on postgraduate studies and towards achieving a doctorate.

Postgraduate studies

Paige embarked on his research career under the tutelage of Dr (later Sir) William Mitchell (FRS 1986). Indeed, Paige was Mitchell's first doctoral student. It turned out to be a most fruitful collaboration leading to distinguished research—and a lifelong friendship. The theme was radiation damage in quartz effected by X-rays and by neutrons. The interest was not so much in quartz as a material, but rather the fact that it is optically transparent over a wide wavelength range—from the onset of infrared absorption at 2.7 μm to the electronic absorption edge at 0.14 μm. This gives the possibility of using optical absorption spectroscopy over a broad wavelength range as a tool for examining the nature of the defects—atomic and those due to trapped charge carriers. Quartz was in effect the laboratory for studying a fascinating and highly complex branch of defect physics. One of the key results that emerged was that optical absorption in the visible part of the spectrum was attributable to aluminium impurities. The fact that the absorption was anisotropic clearly demonstrated the interaction between the defect and the crystal lattice.

Reading the papers that emerged from these researches (1–3, 5, 6)*, one notes that there is never any reference to any possible applications. This was of course long before the emergence of optical fibres—where radiation damage in some situations is of great importance. The motivation was to understand; it was pure science. Ted received his PhD (4) in 1955—preceded by matrimony. Ted married Helen (*née* Gill) in 1953—and they had a long and happy life together, with four children (two daughters and two sons) who were a great source of joy. Family life meant a great deal to Ted and provided a steadying influence to the inevitable highs and lows of a research career. Throughout his career Paige developed trusting professional relationships, and together with Helen, a keen hostess and wonderful cook, he welcomed his colleagues, research students and their partners into the family home.

By this time the fact that Dr Paige had the potential for great achievements in research became clear to all those who encountered him and particularly to those who were hoping to employ him. He had the opportunity of taking on a Post-doctoral Fellowship at the National Research Council in Canada or a Civil Service Commission Junior Fellowship in a UK government research establishment. He opted for the latter, and after a tour of the establishments he chose the Radar Research Establishment (RRE) in Malvern, Worcestershire. Subsequently he regarded this as an inspired choice.

* Numbers in this form refer to the bibliography at the end of the text.

Radar Research Establishment, Malvern

Paige took up his Junior Research Fellowship in 1955 and remained at the RRE for 22 years. His promotion through the ranks was rapid, becoming a Deputy Chief Scientific Officer (special merit) in 1973. He had six months' leave of absence in 1966 to take up a Visiting Professorship at the Technical University of Denmark in Copenhagen, where he gave a postgraduate course on solid state plasmas—his first experience in a formal teaching role.

The RRE was the key laboratory for a range of defence projects, with a primary focus on radar, electronics, computer hardware and software. Much of the activity was targeted on specific identified defence requirements. However, there were sections that were, to a considerable extent, insulated from the pressures of immediate need. Here there was recognition that giving freedom to highly talented individuals can be enormously fruitful. There is no doubt that the Physics Group at the RRE did indeed fully justify the faith in this philosophy.

It was in this group—and within it the Transistor Physics Division—that Paige started his career at the RRE. The division was led by Dr (later Professor) Alan Gibson (FRS 1978) and included several luminaries in the field. The RRE was recognized as one of the foremost electronics laboratories in Europe.

In this period the emphasis of the research was on understanding the detailed physics of carrier dynamics in germanium—at that time the material on which transistor technology was based. Central to the many phenomena studied was the recognition that at high fields the current voltage characteristics became nonlinear (non-ohmic); that the carrier distribution deviated from the Maxwellian; that the carrier temperature could exceed that of the lattice (hot electron effects). Ted invented an ingenious method for measuring the electron temperature by using the change in velocity-field curves in response to the application of mechanical stress (7, 8). In a series of subsequent papers (11, 13, 14, 19) he was able to obtain information on the shape of the non-Maxwellian velocity distribution. The understanding of the dynamics led to the introduction of a new concept—that of an energy relaxation time (as distinct from a momentum relaxation time)—and the realization that this could be deduced from measurements using microwaves (12).

One area of research on which Paige embarked during this period was to measure and understand the magnitude of the drift mobility of minority carriers in germanium at low temperatures. Here there was a specific 'applied' motivation. If the mobility was to increase with a decrease in the temperature—as might have been expected on the basis of normal scattering processes—it could be advantageous to operate germanium transistors at low temperatures, thereby achieving an enhanced high-frequency performance. Disappointingly, the drift velocity was much lower than had been predicted. Ted proposed that this could be due to scattering of the minority by the majority carriers (9)—an explanation that was widely recognized as valid.

The phenomenon needed to be grasped theoretically. This led to a collaboration with Dr Tom McLean and resulted in a detailed comprehensive theory (10). Paige regarded himself as the junior partner in that enterprise, but attributed his ability subsequently to grasp problems in a rigorous theoretical approach to what he learned in the joint work on this remarkable paper.

Paige's involvement with germanium over many years produced a total of some 20 papers. He was seen as one of the acknowledged experts in this field. It led to the invitation to write a definitive survey on the electrical conductivity of germanium in *Progress in semiconductors*.

This is a monumental work (15), grasping the entirety of the subject at that time, and including several original contributions from his own work and that of his colleagues. It was a scholarly work with the emphasis firmly on the fundamental physics. There was no attempt to embrace technology and applications. Its impact was perhaps somewhat dampened by the fact that, when it appeared, silicon had become the lodestar of the electronic world (although in more recent time germanium is making a comeback in the form of SiGe alloys).

Up to this time, Paige was not overtly concerned with finding 'useful' applications for his work. On one occasion he was heard to say that should he want to create something practical he would go home and build a piece of furniture. However, at just about this time he became intrigued by the fascination of physical phenomena that could lead very directly to applications. This change of philosophy arose perhaps from embarking on a new area of semiconductor physics, based on acousto-electric effects in semiconductors such as cadmium sulphide.

The link to the previous work on germanium was the observed non-ohmic behaviour; however, in cadmium sulphide (16) this had a totally different origin. What was novel and exciting was that in these materials it was possible to obtain amplification (17, 18). This led to what was perhaps the first direct application of the phenomena to the realization of an acousto-electric device—an oscillator (20). Such oscillators were demonstrated to work at frequencies up to 500 MHz, with the prospect of extending this into the gigahertz range. Moreover, the oscillators could be frequency-modulated. The extension to gigahertz frequencies was achieved in a different semiconductor, zinc oxide (21). This device also provided a means for generating acoustic waves at gigahertz frequencies.

This work was exciting, both in the observation of new acousto-electric phenomena and in the promise of leading to applicable devices. At this time silicon transistors had not yet conquered the gigahertz frequency ranges. But when they did, the competition against acousto-electric devices was not sustainable.

Surface acoustic waves

Although acousto-electric devices failed to find a role in the development of electronic systems, passive piezo-electric resonators had been widely used ever since 1920 as frequency control elements and as narrow-band filters. These elements used acoustic bulk waves, they were constantly developed and improved, and they provided the most stable available frequency standards until the arrival of atomic clocks. In the late 1960s several groups began to realize the potential of a different acoustic mode propagation—acoustic surface waves—originally discovered by Rayleigh in the context of seismic wave propagation. Several laboratories on the international scene embarked on research into such acoustic surface waves—in France at Thomson CSF, in Norway at the radar research laboratory, at Stanford University, at University College London, and at the Academy of Sciences in Russia. Some of this early work was presented in a special issue in 1969 of *IEEE Transactions on Microwave Theory and Techniques* (Haddad (ed.) 1969).

The application of surface acoustic waves was a surprising twist in the story: it turned out that acoustic waves on their own, without any entanglement with electrons, could perform a whole series of functions in electronic signal processing. It was the recognition in particular that surface acoustic waves could be harnessed to such tasks that stimulated the interest and the need to embark on a new research direction.

Paige, together with Dennis Maines, already a member of his group, recognized the potential of this new field and, significantly for a laboratory within the RRE, its bearing on advanced radar systems. In very short order, Paige put forward proposals for funding, formed and led a group of 15 researchers. The speed with which this was done bears witness to both Paige's growing managerial abilities and the imagination and flexibility of the RRE management at that time.

The team that Ted assembled was remarkable in the quality and diversity of talents it included—Graham Marshall, Meirion Lewis and Dennis Maines, all of whom grew to gain international recognition, as indeed did several of their colleagues. Paige ran this team for the decade 1967–77. It was recognized as a key source of invention in this field, undeniably the best in Europe and arguably the best in the world. Apart from being foremost a first-rate scientist he was a respected and effective group leader. He was fair and democratic and distributed credit among the team whenever possible. Yet this collegiate approach in no way detracted from his effectiveness as a leader, fighting battles where appropriate, and standing his ground when necessary, in a polite but firm manner.

The great merit of surface acoustic waves (SAWs) is that they propagate on the surface of a crystal and are therefore accessible. Electrodes deposited on the crystal surface can be devised to launch and receive the waves, and during their transit influence their progress. The simplest SAW device consists of an interdigital transducer to launch waves separated from a similar transducer to receive them. The distance between the two transducers determines the delay experienced by a signal in traversing the structure. One of Maines's and Paige's first inventions in this field, probably stimulated by his earlier interest in oscillators, was a SAW oscillator consisting of an amplifier connecting the input and output transducers of the delay line (20–22). The frequency of oscillations depends on the path length, but also on the temperature. It turned out that the oscillator, in addition to being a component in its own right, can be the basis of a sensor as well as a method of measuring the temperature sensitivity of the crystal parameters.

The stream of innovation that flowed from this group includes a remarkable invention—the 'multi-strip coupler' (23, 25). It was a joint triumph by Marshall and Paige, with Marshall being responsible for the basic idea and Paige contributing the understanding and detailed analysis of how it performed. Most advances in a growing and highly competitive technology, if not made by one person in a particular laboratory, will almost inevitably, and with little delay, be made elsewhere by someone else. In science and technology one is fortunate to win by a head. But, just occasionally, there is an inventive step that deviates so far from the established path of progress, is so radical and unexpected, that had it not been for the inventors the possibility that they uncovered might have lain dormant for a long time. The multi-strip coupler is a plausible candidate for such special inventive status.

In its simplest form the multi-strip coupler is a means of displacing a SAW signal from its propagation path to an adjacent track. This is effected by an array of electrodes disposed normal to the propagation direction. There is an immediate improvement in performance. One of the problems with the standard interdigital transducer lies in the fact that in addition to launching a SAW, it also tends to generate, though at a low level, other modes of propagation such as acoustic bulk waves. These, sensed by the receiving transducer, can distort the desired performance characteristics of the device. The multi-strip coupler transfers the SAW signal but will not transfer such other spurious signals. In this simple embodiment the multi-strip coupler can be regarded as a mode filter. It turned out that the multi-strip coupler formed the basis of a veritable Pandora's box of innovative SAW devices (26–29).

Just one example is the unidirectional transducer. The basic interdigital transducer can efficiently transform electrical to SAW energy. However, it is bi-directional—half of the acoustic energy will go in the forward direction and half in the backward direction. For a simple delay line, therefore, only one-quarter of the input energy will be received. By using an ingenious configuration (24) involving the multi-strip coupler it is possible to arrange for the transducer to radiate in only one direction. Delay lines can therefore avoid the penalty of a factor of four.

Years later, SAW filters found usage in mobile phones—as they do to this day. An important design criterion in this mass market is cost, and this is dominated by that of the crystal itself. Just as in microelectronics, where the area of silicon that is needed for any function is crucial, designs sought to minimize the area of crystal needed. This played against the use of multi-strip couplers, which, although they had been almost universal in the earlier mobile phone filters, tended to be avoided in later versions.

Throughout the period of exciting new developments in SAW technology there was the fear that all this analogue ingenuity might be swept aside by the ever-increasing potential of digital electronics. Paige gave an invited review lecture on this topic in 1972, 'Against the digital tide'. Now, one-third of a century later, SAW devices continue to have important roles, particularly in two major areas of application. The first, as already mentioned, is in filters, notably intermediate-frequency filters for mobile telephones, and in commercial TVs. It has been found that it is possible to design the performance of such filters with exquisite precision—appropriate amplitude and phase characteristics in the pass band and very high attenuation in the stop bands. The RRE group contributed greatly to the emergence of this field through in-house research but also through collaboration with several industrial companies. The ease of manufacture of these filters—usually a single stage of lithography suffices—makes them extremely cheap.

The other major area of application is radar signal processing. A fundamental problem with radar systems is that for precision in target location one would like to use very narrow pulses. But to achieve a long range, one also needs the pulses to be powerful. The highest energy pulses that can be generated are, however, limited by the peak power capability of the transmitter. It is this quandary that led to the invention of pulse compression radar, in which the transmitted signal is a *coded*, long pulse, which on reception can be compressed into a short pulse. The basic idea goes back to the early days of radar*. It turned out that both in generating an appropriate coded waveform and in compressing the signal reflected from the target, SAW devices come into their own. This formed the key mission of the RRE SAW group (31, 32) and was the stimulus for its formation by Paige.

The simplest form of coding is to generate a linear frequency-modulated pulse. One can use a simple SAW dispersive delay line to launch the waves, and a similar structure can then be used to recompress the pulse at the receiving end. The compressed pulse will have a $(\sin x)/x$ form. The secondary peaks on either side of the maximum have an amplitude of about one-fifth of the main peak; such 'sidelobes' will give rise to spurious effects. They can be drastically reduced, albeit with some broadening of the main peak, by including a filter function in the compressor device.

The selection of the coded waveform, and the filter functions needed to compress them optimally, form a large field of endeavour with an extensive literature. There is no doubt that

* And a good deal further back than that if we include bats, which use very similar principles in their version of sonar—for mainly comparable reasons.

the RRE group were foremost in developing this field. Much of this work was classified, but we do know that Paige and his team had a major role in the design of the pulse compression filters that were incorporated in the Nimrod fleet of aircraft. This work earned the Royal Signals and Radar Establishment (into which the RRE was subsumed in 1976) a Queen's Award for Technological Achievement in 1989.

The key tool for realizing the required sophisticated filter functions was the design of the extended transducer structures, both transmitting and receiving, disposed on a common propagation path. An alternative concept (Williamson & Smith 1973) incorporated a pair of reflecting grooved arrays so that the acoustic beam was reflected through a right angle, and by the second array in the counter direction but displaced laterally. It turned out that this arrangement offered some major advantages but involved difficult and expensive technology in ion milling the array grooves. Paige decided that one might be able to reap the advantages of the concept without resorting to the mechanical loading of cut grooves, but instead using the electrical loading arising from the deposition of thin metal strips in the reflective array. This brought the concept back to one of the key advantages of SAW technology—devices that could be manufactured in a single stage of lithography (30, 33, 34, 36).

There are some problems in the use of the metal strip reflectors, in that in addition to performing their function of reflecting the SAWs they can also generate some spurious waves. It turns out that if one replaces the metal strips by metal dots, some of these problems can be overcome. It was a theme pursued by Paige, both while still at the RRE and in the next phase of his life, in Oxford.

Wider horizons

Paige remained a dedicated 'hands-on' researcher throughout his career, an activity that proceeded without any detriment to other enthusiasms—above all, of course, to his wife, Helen, and to their growing family. Towards the end of the 1950s he was being drawn into a range of professional tasks that extended beyond his immediate RRE responsibilities. This included some teaching at Birmingham University and seminars in the Physics Department of Oxford University.

Paige developed close links with several university groups, first of all in the field of acousto-electronics. The liaisons extended to groups in France, and for some period there were regular Anglo-French consortia meetings, with the British contingent led by Paige. When it emerged that SAW technology was of more immediate interest, Paige in 1970 set up the UK SAW liaison group, which flourished for most of a decade. It was a fruitful venture, engendering good collaboration between university, industry and government groups. Naturally there was a measure of competition, as is inevitable in a fast-moving field. This stemmed also from the fact that most of the work was supported by the Ministry of Defence, and the control of the very substantial funding involved was in Paige's hands. It was a responsibility in which he enjoyed the total trust and confidence of the various participants, not infrequently thereby influencing the thrust of the proposed researches.

In managing the liaison group Paige achieved a remarkable degree of collaboration between all members including the universities and the companies involved*—GEC, Marconi, STL, Plessey, Philips, MESL/Racal. The research themes were divided between these companies,

* Sadly including names that now have a place only in history.

subject to the agreement that all intellectual property generated would be freely available to all participants. This was at the time seen as somewhat revolutionary; it was not easy to negotiate—but it worked. Paige was also drawn into other decision-making bodies, notably those of the Science Research Council.

In 1977 Paige was invited to apply for the Chair of Electrical Engineering at Oxford. He found this possibility intriguing but had some concerns with a move that would take him from a physics to an engineering environment; from a focus on research to one in which teaching would have an equal role; from a government establishment to a collegiate university. A factor in his decision making was the somewhat bizarre fact that in the Scientific Civil Service there was mandatory retirement at the age of 60 years. In the end Paige took the plunge and, for the remainder of his career, was glad that he had done so—as, indeed, were his new colleagues in Oxford.

Oxford, 1977–97

Paige adapted rapidly to the academic environment. His transformation to a professorship was much aided by the fact that he was a brilliant teacher, applauded by students in both the department and the college. He also rapidly adapted to the need to compete for research funds. He succeeded in gaining adequate support for his own research interests but also, on a wider scale, for the Electrical Section within the Engineering Science Department. Although he was not head of department, apart from a short period as acting head in 1984, Paige had a lasting influence on the department. He saw electrical engineering at Oxford as being rather overshadowed by the other engineering subdisciplines, and he decided to do something about it. He brought in G. G. (later Sir Gareth) Roberts (FRS 1984), who at that time was Director of Research at Thorn-EMI, as one of the first visiting professors at Oxford. For several years Roberts ran an active and successful research group within the department. Paige was also concerned to invigorate electrical engineering with new areas already blossoming elsewhere. In the late 1970s he initiated the introduction of information technology into the department, and 10 years later he introduced optoelectronics. Both areas are flourishing.

Initially Paige's researches were a direct continuation of his previous developments of SAW technology and in particular reflective array devices in which the reflecting elements were metallic dots rather than metallic strips (35, 37–43, 48). The reflection mechanism was based on the electrical loading induced by the dots. The dots were 'thin'—so the mechanical loading was negligible. This retained the key advantage of the SAW devices—that they were produced by means of a single stage of lithography. The dot arrays proved to involve great complexities in analysis and design and were certainly highly appropriate for academic research.

Interdigital transducers on a crystal surface launch SAWs. However, for certain crystal cuts they will generate a bulk wave, which on account of its source is nevertheless predominantly associated with the surface. These are known as 'surface-skimming bulk waves'. They have certain advantages over pure surface waves, and Paige and his group in the RRE and later in Oxford analysed their propagation and the manner in which they were reflected by crystal edges. This work, too, proved to be fruitful and has led to a distinct class of devices that have a role in signal processing.

By the early 1980s Paige perceived that the interest of the research community in SAW devices was increasingly focused on meeting exacting specifications with known devices, which did not seem a sufficiently promising and exciting field for doctoral students. In 1986–87 Paige spent a sabbatical year at Stanford, with Professor J. W. Goodman. He used this period to embark on studies and researches in optical signal processing. On his return to Oxford he made optical signal processing the focus of the researches that he conducted with his students.

By the early 1990s Paige was opening up an important new field using a ferroelectric spatial light modulator (SLM) in a novel phase-only mode. Amplitude modulation had been the conventional mode of operation of SLMs, and the fast switching speed of ferroelectric liquid crystals had made them popular electro-optic materials in these devices. Paige realized that, by simply reconfiguring the polarizers, the ferroelectric liquid crystal SLM could be converted into a powerful new electro-optic component, the programmable phase-only modulator (44, 45). Within a few years a wealth of developments and applications were found by Paige and his group, making his last years before retirement both productive and intellectually rewarding.

The original binary device was quickly extended to produce modulators with four-level and eight-level modulation (46, 51), and computer-controlled feedback was incorporated to optimize performance. Early applications included a new technique of determining wavefront aberration (47, 50) and a novel optical pattern recognition correlator (55). Other applications followed, including the focusing of light for submicrometre lithography (49, 52, 53), but it was the creation of three-dimensional images by configuring the phase-only SLM as a Fresnel zone plate that gave Paige much satisfaction. He collaborated with an experimental psychologist he had met in St Johns to study three-dimensional vision when a subject was presented with depth cues (54). This interdisciplinary activity, fostered over college lunch, epitomized what Paige thought should happen in a collegiate university.

Paige retired from Oxford in 1997 but remained active and productive as an emeritus professor (55, 56), helped in this by the award of a Leverhulme Fellowship.

Haemochromatosis Society

In 1996 Paige was diagnosed with haemochromatosis—a genetic disorder causing the body to absorb an excessive amount of iron from the diet, which afflicts about 1 in 300 in the UK. In 1997, on his official retirement from the chair at Oxford, Paige joined the Haemochromatosis Society and became a director of the society in 2001.

The figure of 1 in 300 victims is an estimate based on inadequate statistics, particularly with regard to difficulties of diagnosis at an early stage of the disease. Paige decided to conduct some statistical research to obtain more reliable figures. He wrote reports for the society on how to obtain better estimates and how to gauge the extent to which the disease is underdiagnosed. He produced more detailed analyses on geographical distribution, using membership of the Haemochromatosis Society as a basis. He investigated the nature of the replies to a questionnaire received from patients that enabled members of the society to compare their experience with that of other haemochromatosis sufferers. He fostered the contact between the society and the medical profession and encouraged the initiation of research. He performed these tasks with the same objectivity, critical sharpness and total commitment that had previously informed his work in physics. One of his colleagues remembered a conversation with him in which he expressed concern that he might be spending too much of his (retired!) time on his beloved photography rather than doing more for the society. That says a lot about the man and explains the flow and warmth of the letters of condolence received from so many members of the society.

On 20 February 2004 Ted Paige died from liver cancer, which was the result of haemochromatosis.

Honours

Fellowships

1967 Fellow of the Institute of Physics
1978 Fellow of the Institute of Electrical Engineers
1977 Fellow of St John's College, Oxford
1983 Fellow of the Royal Society
1997 Leverhulme Emeritus Fellow

Honorary appointments

1966 Visiting Professor, Technical University of Denmark, Copenhagen
1986 Visiting Professor, Stanford University, USA

Awards

1973 Ministry of Defence Wolfe Award (with others)
1978 Rayleigh Medal of the Institute of Acoustics
Duddel Medal of the Institute of Physics
Hewlett Packard Europhysics Prize (with others)
1979 J. J. Thomson Premium of the IEE (with Gunton)
1989 Queen's Award for Technological Achievement (to the Royal Signals and Radar Establishment, Malvern)

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Most important to us were the several discussions that we were privileged to have with Ted Paige's widow, Helen Paige, and their daughter Sadie Paige. They were able to give us marvellous new insights into the nature and character of a most remarkable man.

The frontispiece photograph was taken in 1985 and is reproduced by courtesy of the President and Fellows of St John's College, Oxford.

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