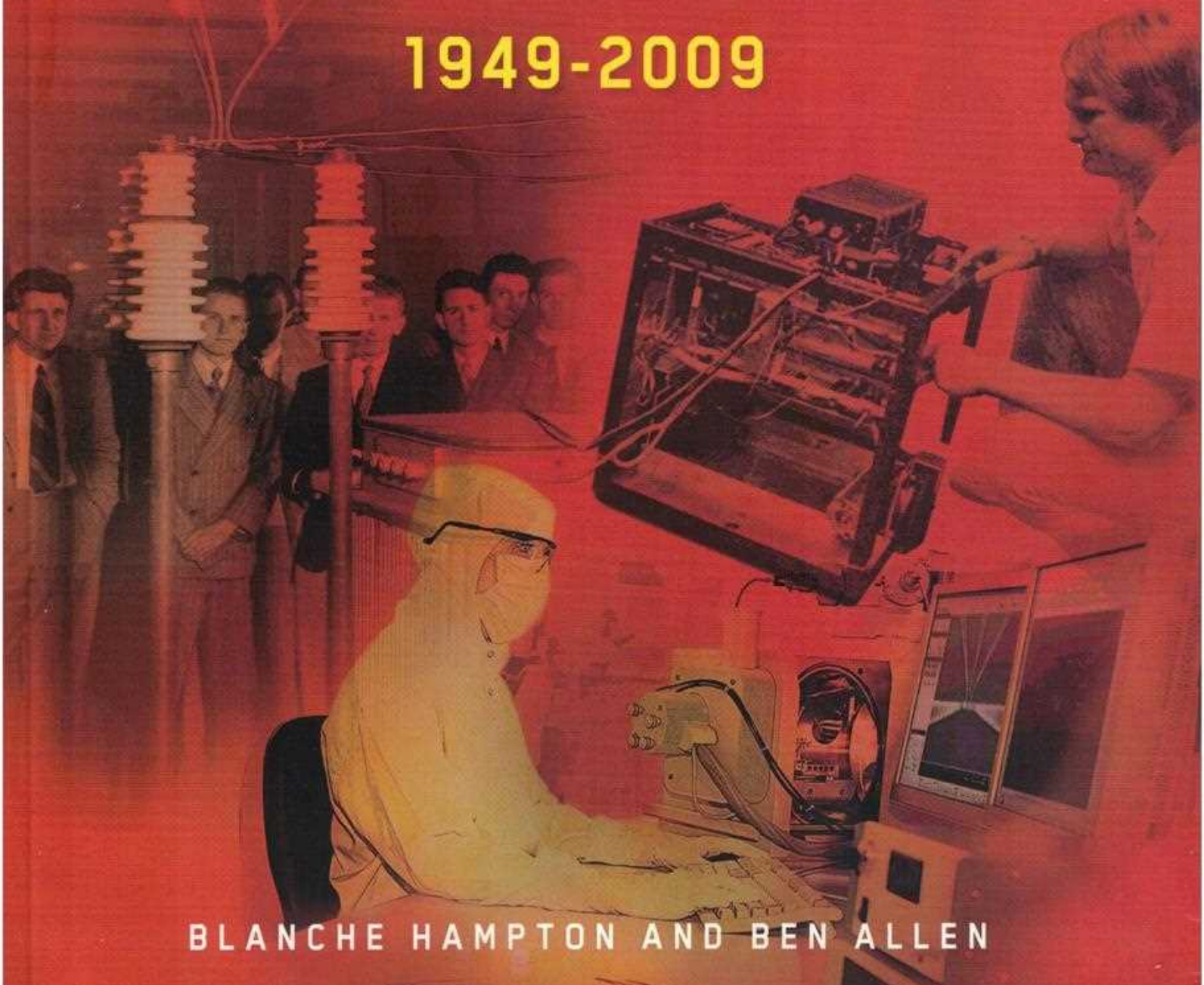
THE HISTORY OF THE UNSW

SCHOOL OF ELECTRICAL ENGINEERING AND TELECOMMUNICATIONS

1949-2009



BLANCHE HAMPTON AND BEN ALLEN

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CHAPTER 4

1969–1978

TECHNOLOGY TAKES OFF

In January 1969 Professor Tom Fink became Dean of Engineering. Professor Philip Baxter stood down as the University's first Vice-Chancellor and was replaced by Professor Rupert Myers in June. It was a time of transition for the University and indeed the world. Only weeks later, the United States landed the first human beings on the surface of the moon.

The Vietnam War was polarising the population of Australia to the degree that it would play a major part, alongside the growing sense that 'change' was needed, in toppling the country's longest running conservative government in 1972. The implications of this would have a significant impact on the University and the society it aimed to serve. These included the ending of conscription and the establishment of free university education; the introduction of the *Trade Practices Act* and the slashing of tariffs; new no-fault divorce laws; the introduction of universal healthcare and legal aid; independence for Papua New Guinea; the establishment of diplomatic and trade relations with the People's Republic of China; and the abolition of the White Australia policy.

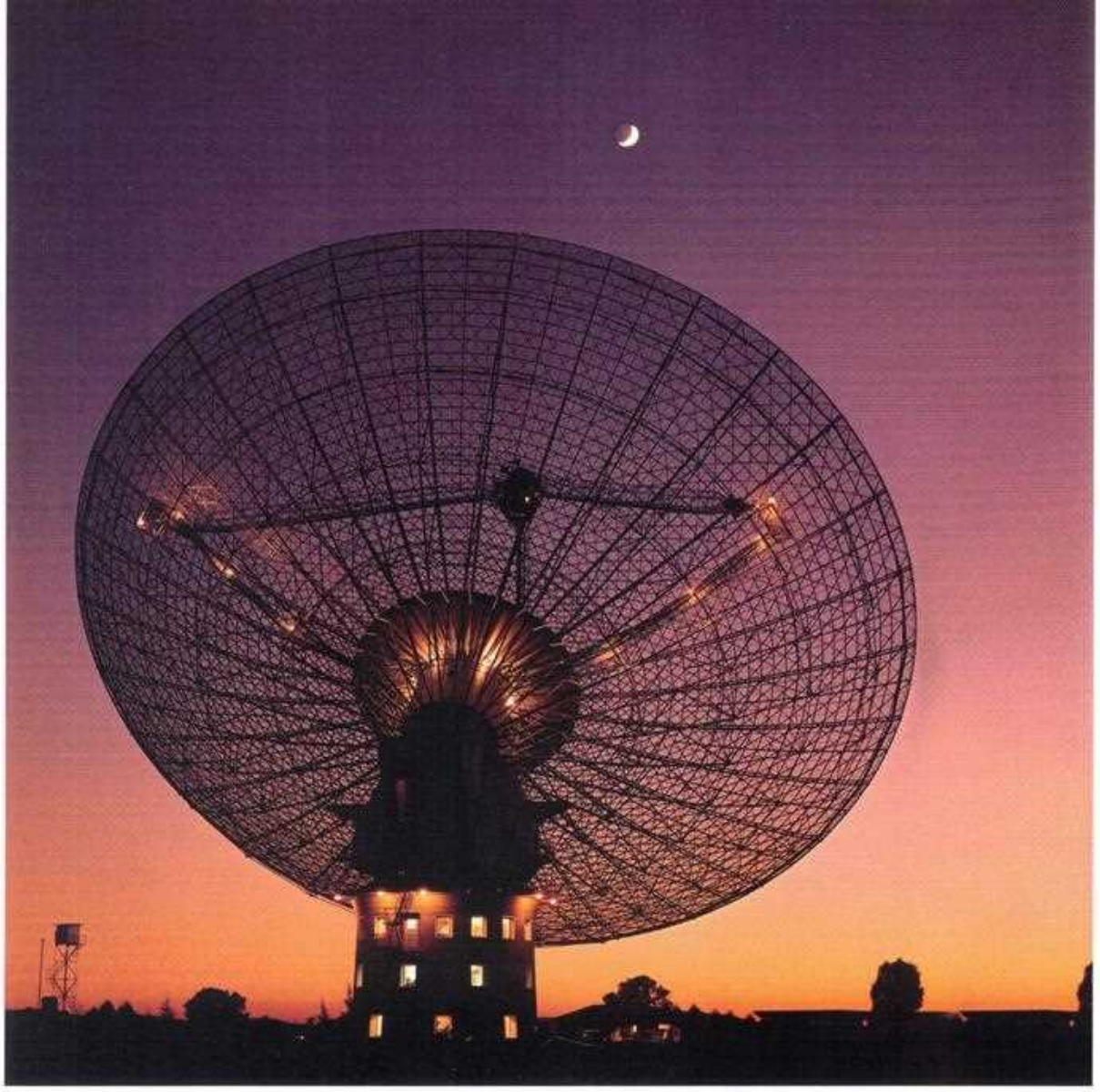
1969
- USA LANDS FIRST HUMAN ON MOON
- PROFESSOR RUPERT MYERS BECOMES VICE-CHANCELLOR
- PROFESSOR TOM FINK BECOMES DEAN OF ENGINEERING
- 14 000 VISITORS ATTEND UNSW OPEN DAY

1970
- FIRST CD-ROM PATENTED
- VIETNAM MORATORIUM MARCHES IN AUSTRALIAN CITIES
- COLLAPSE OF WEST GATE BRIDGE, VICTORIA

1971
- BRITAIN'S OPEN UNIVERSITY BEGINS
- INTEL'S 'COMPUTER ON A CHIP' MICROPROCESSOR
- WORLD'S LARGEST HYDROELECTRIC PLANT, RUSSIA

1972
- WHITLAM LABOR FEDERAL GOVERNMENT
- AUSTRALIA RECOGNISES PEOPLE'S REPUBLIC OF CHINA
- AUSTRALIAN TROOPS WITHDRAWN FROM VIETNAM
- PROFESSOR ANTONI KARBOWIAK BECOMES HEAD OF SCHOOL

1973
- US WATERGATE SCANDAL GOES PUBLIC
- FEDERAL VOTING AGE REDUCED FROM 21 TO 18
- SYDNEY OPERA HOUSE OPENED BY QUEEN ELIZABETH II



CSIRO's Parkes radio telescope, 1969. It played a crucial role in receiving signals during the *Apollo 11* moon landing in 1969, relaying them for broadcast to an audience of 600 million around the world. Copyright CSIRO.

The world was increasingly complex and its interrelated nature was becoming more apparent. There was a rising trend towards interdisciplinary development, visible initially in the nascent discipline of biomedical engineering which was beginning to claim independence alongside its progenitors, the Schools of Electrical Engineering and Mechanical and Industrial Engineering.

And as important as it had been to date, the information revolution was only just picking up steam, with largely unforeseeable consequences. Add to this the end of Australia's long prosperity boom and a global mid-decade fuel crisis, and it was clear that many of the assumptions with which the 1970s had begun would not survive into the 1980s. No university school was untouched by the developments around it.

1974
- CYCLONE TRACY DEVASTATES DARWIN
- AUSTRALIA'S 'LONG BOOM' REPLACED BY 'STAGFLATION'
- UNIVERSITY TUITION FEES ABOLISHED
- OPEC OIL CRISIS

1975
- END OF VIETNAM WAR
- US MILITARY BEGINS USING FIBRE OPTICS
- DISMISSAL OF WHITLAM GOVERNMENT
- OPENING OF HIGH VOLTAGE AND HIGH CURRENT LABORATORY

1976
- CANADA'S CN TOWER, WORLD'S TALLEST BUILDING
- IBM INTRODUCES FIRST LASER PRINTER
- CENTRE FOR BIOMEDICAL ENGINEERING ESTABLISHED
- PROFESSOR MURRAY ALLEN BECOMES HEAD OF SCHOOL

1977
- AUSTRALIAN RELEASE OF APPLE II
- FRASER COALITION WINS FEDERAL ELECTION
- NATIONAL ENERGY ADVISORY COUNCIL ESTABLISHED
- GRANVILLE RAILWAY DISASTER

1978
- JOHN PAUL II BECOMES POPE
- LAUNCH OF FIRST GPS SATELLITE
- FIRST COMPUTER BULLETIN BOARD SYSTEM CREATED
- PROFESSOR RUPERT VALLENTINE BECOMES DEAN OF ENGINEERING

A second antenna was added to the earth station at Carnarvon in Western Australia in October 1969. These satellite earth stations provided an important new dimension in Australia's overseas telecommunications services and by 1974 more than half of Australia's overseas telecommunications circuits were carried via satellite. Satellite technology also began to receive greater attention for its potential to improve services in outback areas.[1]

Within telecommunications research, the advent of solid-state electronics saw a focus on digital coding and transmission techniques and work began on preparing the analogue network for conversion to digital, establishing design rules for the expanded use of Pulse Code Modulation (PCM) systems and developing digital transmission performance measuring techniques and equipment. Optical fibre communication research was taken up with increased enthusiasm nationally from 1971. In 1972 the PMG Laboratories developed a prototype videoconferencing system which was trialled on a satellite link between Australia and the United Kingdom in 1973 and was later installed between Melbourne and Sydney.[2]

Experimental frequency modulation (FM) radio broadcasts were conducted in Australia in the early 1940s, but a 1957 government inquiry into the topic found that there appeared to be little interest. The 88–108 MHz VHF band, used internationally for FM broadcasting, was reserved instead to provide for three additional TV channels from 1961. In 1974 it was decided that following international practice, FM should also operate in the VHF band. The first use of FM in Australia was for public broadcasting by the classical music stations (2MBS and 3MBS), as well as public access radio stations such as those run by the student unions. National stations began broadcasting in 1976 with the establishment of ABC-FM based in Adelaide and in 1980 the federal government began offering a limited number of commercial FM licences.[3]

Early television systems were fully imported, but from around 1970 channelling, multiplexing and line-transmission equipment were all developed and manufactured in Australia. Based on European designs, they were modified to accord with Australian standard practices, with Siemens and Standard Telephones and Cables being the major firms involved.[4]

Facilities for the transmission of data, the Datel service, were introduced in 1969, with options of using the switched telephone

THE IMPACT OF TECHNOLOGY

The 'technology revolution' of the 20th century changed the world in ways few had dreamed possible. While advances in computing have had a huge impact on all schools and disciplines at UNSW during its 60-year history, few can be said to have matched the pace of transformation experienced by the School of Electrical Engineering and Telecommunications.

From its early days, the School's activities reflected the needs of a changing society following World War II and the technologies that would drive those changes. As early as 1950, the School offered a post-graduate course in television to 'men already qualified in communication and general electronic engineering', six years before television broadcasting began in Australia.[5]

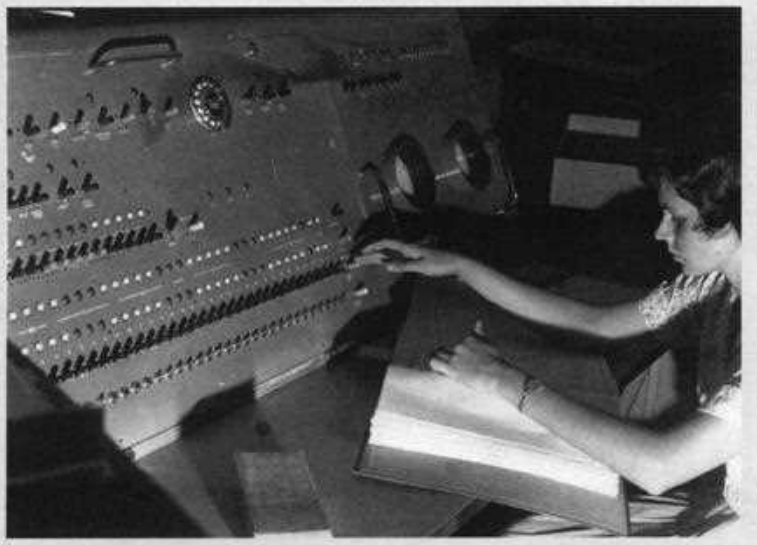
Professor Rex Vowels, the second Head of School (1954–67), was a firm believer in the power of computer technology and did a great deal to drive the University's investment in IT infrastructure. In 1956 he oversaw the installation of the valve-driven digital University of Technology Electronic Computer (UTECOM), which became the responsibility of Electrical Engineering staff. Filling an entire room, UTECOM was housed in the Main Building until its retirement in 1966.

During its life UTECOM was used by UNSW researchers to solve engineering, scientific and mathematical problems and was made available to business and government to perform statistical analyses and estimations in areas as diverse as the Australian economic structure or television and radio audience figures.[6] With its 1500 bytes of RAM, UTECOM was quickly in operation around the clock, with over 70 per cent of its usage being dedicated to industry and government projects.[7]

In the early 1960s the University purchased three IBM 1620 second-generation computers for engineering and science research and an IBM 360/20 was used by the University's administration.[8] Following the installation of an IBM 360/50 in 1966, UTECOM was finally retired. The School established its Department of Electronic Computation in the same year (which became the Department of Computer Science in 1972), headed by Murray Allen, UNSW's first Professor of Electronic Computation and Director of the Digital Computing Laboratory. Under Professor Allen, the School advanced computer science as a discipline distinct from electrical engineering.

The demands on School staff as custodians of the University's computer facilities led to the establishment of a separate Computing Services Unit in the early 1970s, with the IBM 360/50 transferred to the Chancellery to handle administrative tasks.[9]

In the early 1970s the development of UNIX in the United States and its use by staff in Electronic Computation added new capabilities to the Department's teaching and research. Developments in computer-aided design at the time enabled the evolution of Very-Large-Scale Integration (VLSI) of circuits and systems, which had a major impact on other areas of the School's research. Following the establishment of the VLSI and



The complexities of UTECOM were not for the faint-hearted, 1960. Courtesy UNSW Archives.

Lecturer Felix Lewin linking the IBM 650 with the School's analogue computer, c 1963. Courtesy UNSW Archives.

Systems Technology (VaST) Laboratory in 1978, the School co-founded a Joint Microelectronics Research Centre (JMRC) in 1982 with the Royal Melbourne Institute of Technology (RMIT). The Centre's work with photovoltaic technology led to commercialisation opportunities for the researchers' award-winning solar cells.

Computing advancements of the 1970s, due mainly to the availability of embedded computer systems, also revolutionised the electrical engineering disciplines of control, communications and signal processing, along with research into biomedical systems, such as heart monitors and cochlear implants. The impact of computing on power electronics wasn't to be felt until the late 1980s, however, with the parallel development of power bipolar transistors and gate turn-off thyristors which can control and switch high levels of electric current flow with the ease and precision that transistors were able to do in light current electronic systems.

Student interest in the rapidly growing discipline of computer science continued throughout the 1970s and enrolment quotas were introduced in the School to try to control the numbers of students eager to make the most of the School's computer facilities and expertise.[10] The continuing demand for an engineering degree in computing ultimately led to the introduction of a BE (Computer Engineering) in 1989, by which time the School's network of 120 workstation computers made it the largest computer teaching complex of its kind in Australia.

In 1991 the Department of Computer Science became an independent School, and the School of Electrical Engineering shifted its focus to satellite and mobile communications, microelectronics and photonics.

The traditional subdisciplines of electric power and control also began expanding into areas such as renewable energy systems and telemedicine respectively. Since 2002 School staff, along with colleagues in the School of Computer Science and Engineering, have played a key role in National ICT Australia (NICTA), a Centre of Excellence that aims to build Australia's technology sector by supporting research, development and education in information technology. In 2009 Associate Professor Tim Hesketh, former Head of School, joined NICTA as its Education Director.

Not only has technology had an extraordinary impact on the School's structure and research, it has also shaped the learning experience for students. Gone are the days when students relied on 'chalk and talk' lectures, textbook readings and basic laboratory work for their engineering education. The growth of information technology has seen all programs within the School increasingly use Information and Communications Technology (ICT) to develop, deliver and assess course material, while the internet is an indispensable tool for many aspects of research.

Advances in 'e-learning' allow students to download digital recordings of lectures, which helps overcome time constraints and enables greater

From the 1950s, closed-circuit television cameras were used in teaching. Courtesy UNSW Archives.

opportunities to undertake distance education. The School made a significant step in e-learning in 2001 with the establishment of a Virtual Teaching Laboratory (VTL), which uses ISDN-based videoconferencing and web-based electronic whiteboard technologies to deliver interactive lectures to students remotely in real time.

The technology also permits full three-way audio and video communications between the remote lecturer and the students. Inaugural lectures were conducted in June 2001 in conjunction with Imperial College, London (ICL), and Mahanakorn University of Technology (MUT), Thailand, both of which had similar virtual teaching laboratory facilities. In 2003, during a period of leave at the Athlone Institute of Technology in Ireland, Professor Eliathamby Ambikairajah delivered a postgraduate course in Advanced Digital Signal Processing to 30 UNSW electrical engineering students using this technology. In addition, the School's VCPlayer software, developed by Dr Ming Sheng, allows students to view lectures on DVD at their leisure, with the realism of a live lecture theatre. The VCPlayer and the VTL are used extensively within the School and there is ongoing research and experimentation with the learning and teaching methodologies enabled by this technology.

Virtual Teaching Laboratory, 2003. From the Athlone Institute of Technology in Ireland, Associate Professor Eliathamby Ambikairajah (top right video screen) lectures a class at UNSW, using electronic whiteboard technology to facilitate the teaching. Courtesy EE&T.

service for lower speeds, or leased lines for higher speeds. Modems supplied by the PMG were an essential part of the service and by 1973, there were some 2500 subscribers.[11]

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Twenty years after the University's foundation there were still only a handful of female engineering students. Mechanical Engineering had led in 1959 with the first female enrolment, Eleonora Kopalinsky *(BE (Mech) '66, PhD '71)*, but although Electrical Engineering had its first female student enrolled in the part-time BSc (Tech) in 1964, it wasn't until 1969 that Electrical Engineering had its first female graduate, Lee Eng Sim *(BE (Elec) '69)*.[12]

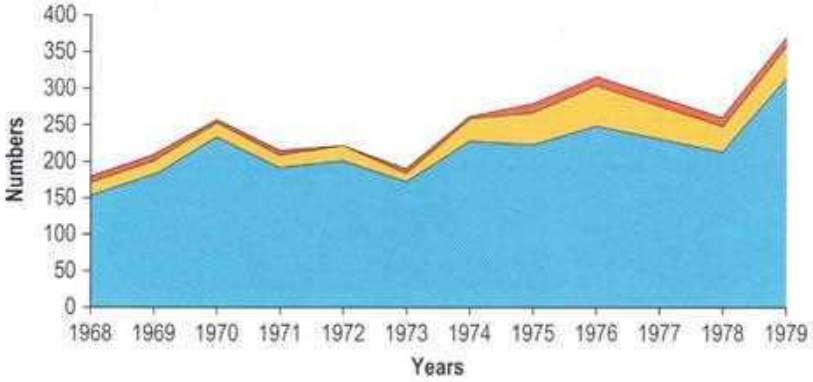
The School's Year One undergraduate enrolments in the mid to-late 1960s remained fairly steady at around 117 full-time and 65 part-time, but along with the other Engineering schools, rose substantially following the University's spectacular Open Day in 1969. The University had previously hosted three Open Days between 1956 and 1958, but the 1969 event was a triumph with over 14 000 visitors touring facilities and watching engineering and scientific demonstrations. The *Sydney Morning Herald* reported that 'the University of New South Wales seems hellbent on eclipsing all records for growth and progress' and that it had hosted the 'most comprehensive open day to be staged by an Australian university'.[13] The result for Electrical Engineering was a substantial increase in enrolments for 1970, with 167 full-time and 67 part-time Year One students.[14]

Lee Eng Sim, the School's first female graduate, 1969. Courtesy UNSW Archives.

University Medallists: 1969–78

Graeme Couch *(BE (Elec) BSc '69)*
August Bertelsmeier *(BE (Elec) BSc '71)*
Priti Hetrakul *(BE (Elec) '71)*
Brian Spalding *(BE (Elec) BSc '73)*
Robert Morris *(BE (Elec) BSc '73)*
Leon Arkinstall *(BE (Elec) '74)*
Laurence Hall *(BE (Elec) '74)*
Fu Yan Cheong *(BE (Elec) '75)*
Nicholas Datyner *(BE (Elec) BSc '76)*
Kevin Hill *(BE (Elec) '78)*
Nguyen Thao *(BE (Elec) '78)*

School of Electrical Engineering commencing enrolments 1968–79



NOTES

1974. Free tertiary education introduced.
Double degree in Arts and Electrical Engineering introduced.

ENGINEERS AT PLAY

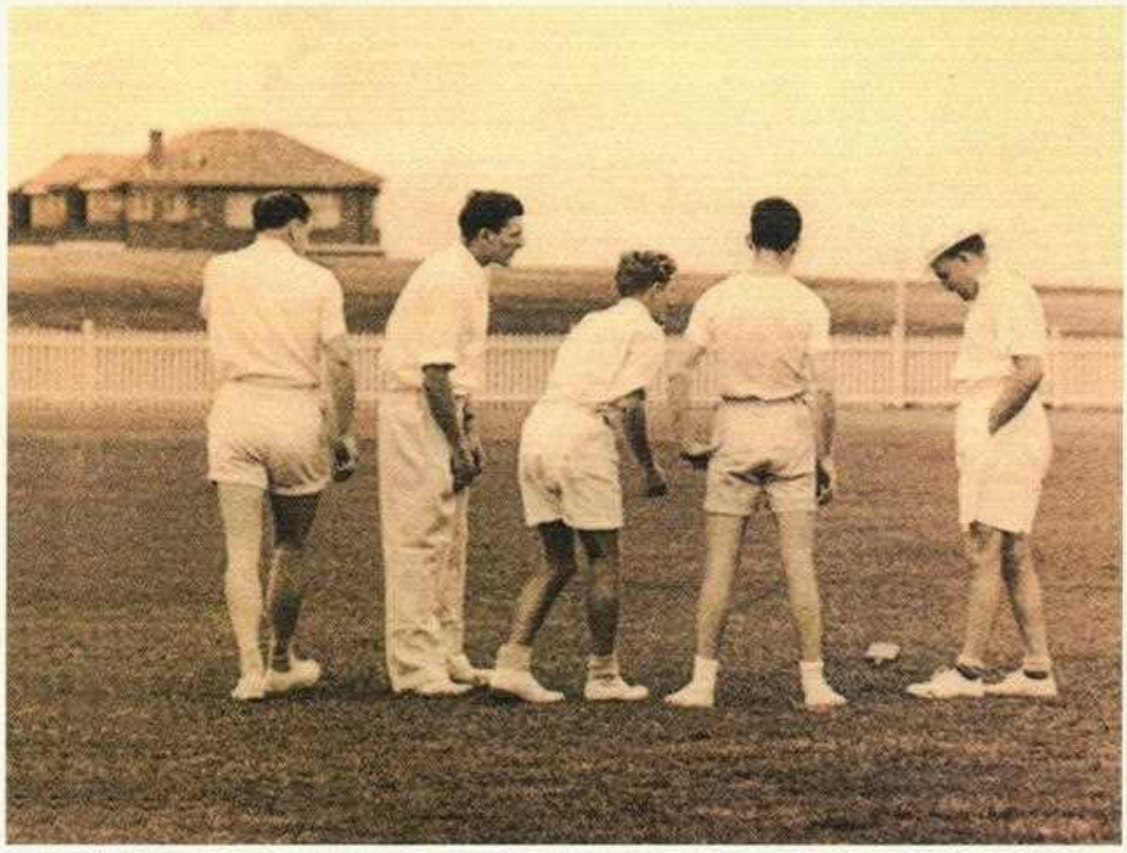
When University classes began at the STC in Ultimo in 1948, a few sports teams were already active at the college, with students holding cricket and rugby union competitions. The following year, the University funded an Amenities Service (later the Sport and Recreation Unit), the primary purpose of which was to manage 'the hire of tennis courts, ovals suitable for cricket, football and athletics, etc, and for the purchase of certain equipment for use by members of the various sporting and recreational clubs'.[15]

During the early years, the weekly academic timetable was adjusted to allow for casual Wednesday afternoon sport sessions, with students enjoying field sports and other activities such as swimming and ice skating. Official sporting clubs were also formed, including the rugby union, cricket, fencing, rowing, rifle shooting and tennis clubs, which enabled students to compete against each other or in local competitions. In 1963 Electrical Engineering Senior Lecturer and sports enthusiast Dr Garth Dewsnap became the inaugural president of the University's baseball club.[16]

The management and coordination of University sport soon became a controversial topic: the Union wanted to control all sporting activities, while the individual clubs sought to establish an organisation dedicated solely to sport, which would coordinate student participation in intervarsity and national competitions.

A valuable advocate for the establishment of an independent sporting body was Electrical Engineering student John Engel *(BE (Elec) '54)* who, as well as captaining the University rugby club, would become the Sports Association's first vice-president. According to the 1954 *Engineering Yearbook*: 'When told that he had not received honours at graduation, [John] mumbled something about "not surprised", and headed for a Sports'

The University's 1953 minor premier Kentwell Cup rugby team, with Electrical Engineering student John Engel as captain (centre row, fourth from left). Courtesy UNSW Archives.



Final-year Electrical Engineering undergraduates challenge the academic staff to a cricket match, 1955. Tossing the coin with the staff captain are (from left) Kevin Cleary, John Crowe, Ron McCarthy and John Coyle. Courtesy Ron McCarthy.

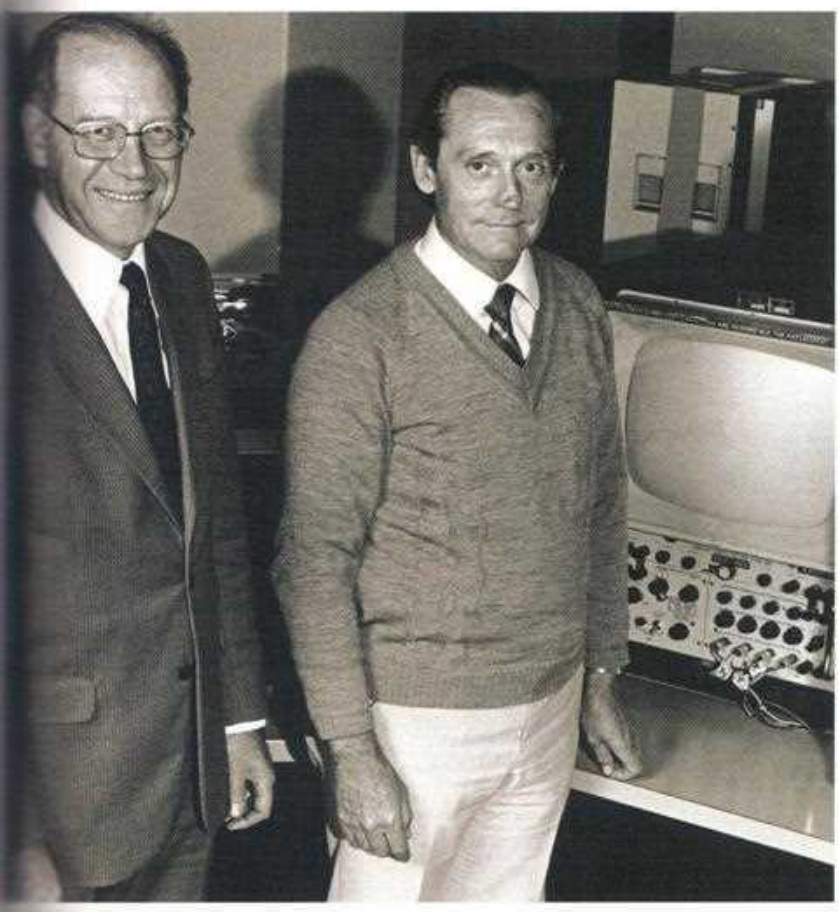
Association meeting with a shot put under one arm and a football under the other.'

Professor David Phillips, the second Dean of Engineering (1952–56), was also a strong supporter of student sport, particularly rugby. After his death in 1962, UNSW's new sportsground at Daceyville was named the David Phillips Field in his honour. Other facilities such as tennis and squash courts were erected on campus over the years and the Village Green sports oval was home to the cricket club from 1968. In 1989 the club took up residence in the Sam Cracknell Sports Pavilion, named after a Student Amenities Officer who had contributed much to the early development of UNSW's sporting culture.[17]

From the mid-1950s, engineering students participated in various inter-school and inter-faculty competitions during the traditional Wednesday afternoon sport sessions. Although these were gradually phased out due to timetabling pressures, students from the various Engineering schools are still able to enjoy some healthy competition at events such as Engineering Student Sports Days. Other activities over the years have provided a chance for Electrical Engineering students to face their teachers on the sports field in cricket matches and golf games. One such event in 1972 was advertised as 'a field study of "reduction of drag force associated with moving golf balls".'[18]

The School has had its share of sporting heroes, including former Head of School Professor Branko Celler who, as a PhD student, was awarded a UNSW Sporting Blue in 1974 for fencing. The School's alumni also include two Olympians: Phillip Cheetham *(BE Hons (Elec) '77)*, who competed in gymnastics at the 1976 Games in Montreal and Mark Carew *(BE (Elec) '76)*, who represented Australia in judo at the 1980 Moscow Games.

In the late 1960s researchers in the School of Mechanical and Industrial Engineering and the Faculty of Medicine had pooled expertise to investigate the lubricating fluids in knee joints. Following on from this, new ground was broken with cross-disciplinary research programs in the emerging area of biomedical engineering, involving Professor Noel Svensson (Mechanical and Industrial Engineering) and Electrical Engineering's Dr Peter Bason from the Department of Communications.[19] Dr Bason had research interests in cardiovascular system modelling and signal analysis and he concentrated on the electrical monitoring of body data, while Professor Svensson focused on orthopaedic biomechanics. In November 1970 some 30 research and academic staff across the University met to consider further collaboration in the field, and over the next three years Professor Svensson and Dr Bason ran seminars demonstrating the range and depth of interests in biomedical engineering at UNSW.[20] As a result of this work, Dr Bason initiated biomedical engineering teaching in the School with an elective course in the Year Four curriculum.



Professor Noel Svensson and Dr Peter Bason beside a computer used for human gait analysis, 1981. Photo UNSW Public Affairs Unit. Courtesy UNSW Archives.

Due in large part to the startling growth of its Electronic Computation Department, in 1969 Electrical Engineering had extended one wing of its building by two floors (with a walkway from the second level to the upper campus) and constructed a new lecture theatre on the lower ground floor.[21] Student enrolment quotas were introduced for the first time in 1971 to alleviate pressure on the School and its equipment. While workshop and laboratory users had trebled in the eight years from 1962 to 1970, support staff had only increased from 25 to 28, leading to major backlogs of work.[22]

New staff at this time included future Associate Professor The Bao Vu (1968–98) and future Senior Lecturers Christopher Phillips (1970–99) and Robert 'Bob' Radzyner (1970–99) in Commun-

ications and David Mee (1971–92) in Control. Bob Radzyner took responsibility for the School's extensive reference library until it was disestablished in the mid-1980s due to the ever-increasing demand for space. He was also the School's Coordinator for the industry-sponsored Co-op Program from 1994 until his retirement.

Future Associate Professors Ken Robinson (1971–91) and John Lions (1972–91) joined the Electronic Computation Department (renamed Computer Science in 1972), as did future Professor Graham Hellestrand (1973–91).* Peter Maxwell (1973–89) would become a Senior Lecturer in Computing. The School appointed its first female Lecturer, Dr Pamela Sallaway, in Computer Science in 1973, although her term only lasted a year.

In August 1970, finding the administrative demands too much of a distraction from his research, Professor Brian Speedy stepped down as Head of School and left the University to pursue defence work with the British Government. Professor Karbowiak was appointed Acting Head of School until the end of the year, followed by Professor Allen as Acting Head until Professor Karbowiak returned from sabbatical in 1972 to assume the headship.[23]

Professor Speedy's departure also left a vacancy at the Head of Control Engineering, which was filled by Senior Lecturer Colin Stapleton until the arrival in 1972 of Professor Neville Rees (Head of School 1980–88). Professor Rees renamed the Department Systems and Control and sought a greater industry focus for its research and improved industry funding.

Dr Bob Radzyner, 1997. Photo Rory McGuire. Courtesy UNSW Archives.

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Faculty-wide, a major Master of Engineering Science (MEngSc) program revision was introduced in 1971, with changes partly driven by rapid developments in manufacturing, energy generation and what was perceived to be the imminent introduction of nuclear power stations in Australia.[24] A series of lectures and discussions were held for students on the interaction of the engineer and society, with topics including 'Management of Human Resources in Industry', 'Science, Technology and Society', 'Why Nuclear Power?', 'Marketing in the Industrial Society' and 'A New Approach to Invention'.[25]

Biomedical engineering research continued to be conducted in the Schools of Electrical Engineering and Mechanical and Industrial Engineering, but by 1973 more integrated arrangements were needed to take the development of the discipline to its next stage.

* Note: Electronic Computation staff transferred to the new School of Computer Science and Engineering in 1991.

EMERITUS PROFESSOR ANTONI KARBOWIAK

(BSc (Eng) '49, PhD '53, DSc (Eng) '68 Lond)

Head of School 1972–76

Born in Warsaw in 1923, Antoni Karbowiak grew up in war-torn Poland and found his way to Britain as a refugee. He had always wanted to be an engineer, and was able to enrol at University College, London, under the auspices of a British Government scheme that enabled Polish servicemen to study in the United Kingdom at the government's expense.[26]

After completing a science degree in engineering in 1949, Antoni Karbowiak began a master's program with a focus on microwave technology, until his professor recommended that he undertake a PhD. By the time he completed his PhD in 1953 on the propagation of surface waves, he had published six papers in international journals. The same year, Dr Karbowiak took a job with Standard Telecommunications Laboratories (STL, now part of Alcatel-Lucent), working with wide-band telecommunication systems. From 1958 to 1963 he led the firm's Microwave Department, after which he instigated seminal work on the development of optical fibres and established STL's Optical Systems Group.

In December 1964 Dr Karbowiak was invited by Head of School Professor Rex Vowels to accept the inaugural Chair of Communications at UNSW. Dr Karbowiak's young colleague at STL, Charles Kao, who inherited the optical waveguide project, went on to win the 2009 Nobel Prize for Physics for this work on optical fibres in communication.

From 1965 Professor Karbowiak led the School's Communications Department for over two decades until his retirement in 1988. Professor Karbowiak maintained his association with STL while building the School's facilities for optical communications research (the first in Australia), an area in which the School would later excel, due in great part to the photonics research of Professor Pak Chu, a 1970s PhD student of Professor Karbowiak's.

Courtesy UNSW Archives.

With the support of the Vice-Chancellor's Unit, Professor Karbowiak also assisted UNSW's student recruitment efforts by running annual Secondary Schools Seminars from 1968 to 1979 to inspire high school students to pursue engineering studies and to introduce them to new technologies.

From 1970 to 1971 Professor Karbowiak returned to Britain on sabbatical, consulting to the British Post Office Research Laboratories (now part of British Telecom) on future communications systems using coaxial cables, waveguides and optical fibres. He returned to UNSW in 1972 to accept the Head of School post, remaining in the role for four years. During that time the School's research developed in the field of digital communication, laying the foundations for the School's more recent work on data communications and networks.[27]

University administration, however, was not a passion of Professor Karbowiak's, and in 1976 he resigned the headship to have more time for research. As a consultant to Telecom, he conducted research into Australia's telephone network, which was in urgent need of modernisation. In 1982, in a government appointment, he wrote the report for the Committee of Enquiry into Telecommunication Services in Australia.

Professor Karbowiak retired in 1987 as an Emeritus Professor, but continued with the School as a supervisor of research students for many years. In 2003 he was awarded a Centenary Medal by the Australian Government for service to Australian society in telecommunications.[28]

OPTICAL FIBRES, 1970s ONWARDS

By Dr Iain Skinner and Visiting Fellow Trevor Whitbread

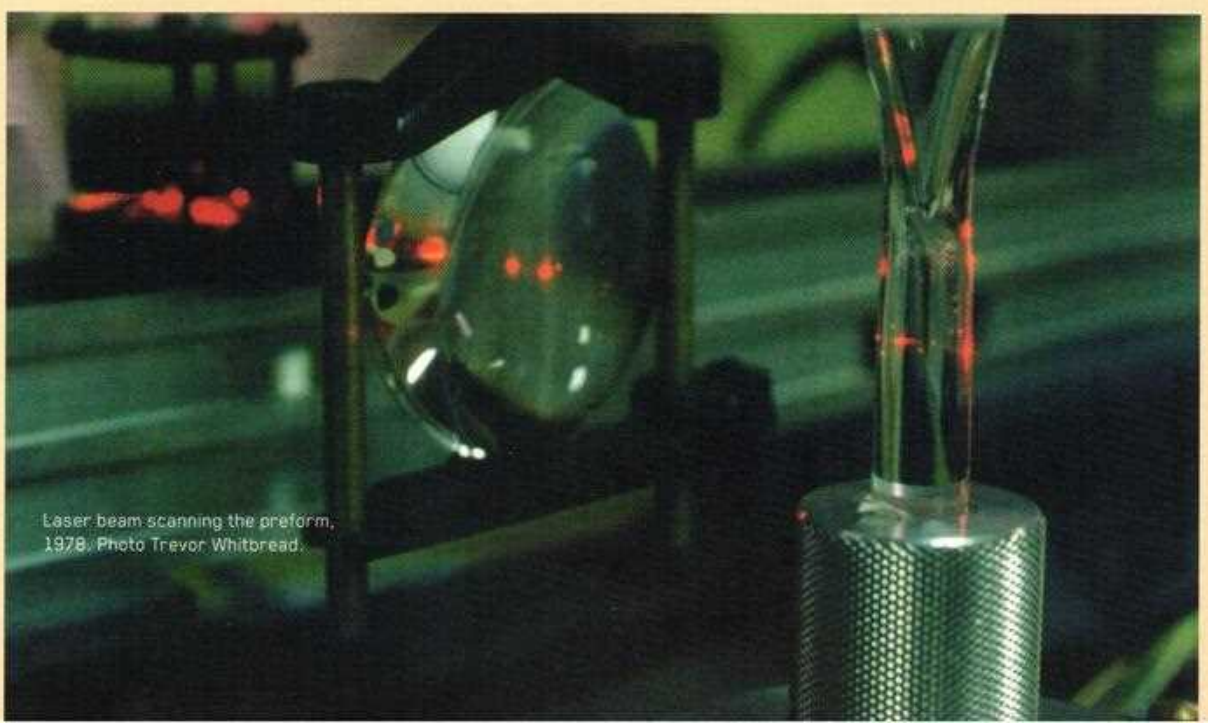
In the mid-1970s telecommunications providers were looking to convert the world's telephony to digital systems and expand the available bandwidth, as demand for services grew. The limits of existing infrastructure were being approached, and optical fibres were the preferred technology for the next generation of deployment.

Significant improvements had occurred in fabrication techniques to ensure the transparency of the glass was good enough for the signal-to-noise ratio to be at a level acceptable for transmission purposes. It was, however, also necessary to be certain of the refractive index properties of these fibres, specifically, how they varied in the cross-section as a function of distance away from the fibre's centre, ie $n(r)$. This is critical as light is guided along an optical fibre by a region of higher refractive index along the fibre's central axis.

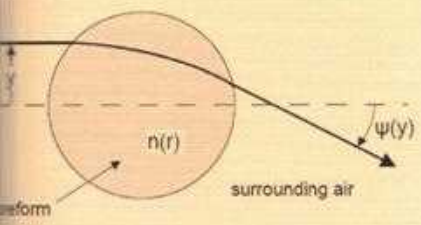
The low-loss telecommunication fibres were manufactured in a two-stage process. First, a 'fat' hollow, silica-glass rod – or preform – was made by depositing successive layers of glass of the required refractive index on its inside. These layers were then fused and a very thin fibre was drawn from this glass preform. It had been established that the refractive index variation in the fibre was simply a scaling of that of the preform so, to ensure the required quality of fibres, it sufficed to measure $n(r)$ of the preform. With its dimensions of a few centimetres, instead of less than 1 mm, this is a much easier task. At that time, preforms could be cut and polished, and then have their end-faces directly measured, but this destroyed the preform so, even if $n(r)$ was acceptable, no fibre could be produced.

Then, in 1977, Senior Lecturer Dr Pak Chu announced in his groundbreaking paper 'Nondestructive measurement of index profile of an optical-fibre preform' a new method to determine the refractive index using simple measurements, by the use of the deflected angle of a laser beam scanned across a cross-section of preform, perpendicularly to its axis. The ray from the scanning laser (solid curve) enters from the left and is offset y from the preform's centre by its higher refractive index which causes the rod to act as a 'lens.' The scattering angle ψ can be measured as a function of the initial lateral off-set. The variables y and ψ are related through an integral involving the refractive index $n(r)$ along the path travelled by the ray. Dr Chu recognised that $n(r)$ could be calculated from $\psi(y)$ using an Abel transform. With the help of Professional Officer Trevor Whitbread *(BSc '68, BE Hons (Elec) '70)*, an automated system was designed to record preform measurements.

The method was extended at UNSW and elsewhere. PhD student Charoon Saekeang *(PhD '80)* showed how to measure the refractive index $n(x,y)$ of a preform with arbitrary cross-section. In 1982 Dr Chu and Trevor Whitbread applied the method



Laser beam scanning the preform, 1978. Photo Trevor Whitbread.



to measuring stress in preforms. A group at Southampton University devised an efficient, automated way to measure the deflection function $\psi(y)$. The resulting instrument, adopted almost universally by the world's fibre manufacturers, is still used. The index reconstruction is still made, however, using the measurement method published first by Dr Chu and which has become the global standard that guarantees the optical fibres in our modern telecommunications networks.

The optical-fibre work of Dr Chu, Trevor Whitbread and others was enthusiastically encouraged by the leadership of Professor Antoni Karbowiak (Head of School 1972–76) who had supervised Pak Chu's PhD. Prior to his appointment at UNSW, Professor Karbowiak had been a member of the British team pioneering work on optical fibres in the mid-1960s and had deliberately sought to establish UNSW at the forefront of research in the nascent discipline of optical communications. This tradition of research in optics still bears fruit. Major current interests are optical fibres made of plastic and used as sensing devices, ie not just carrying but generating signals, and planar (instead of circular) optical waveguides built on diamond substrates, to provide a platform to process signals optically.

In November the Vice-Chancellor, Professor Myers, approved the establishment of a steering committee comprising staff from the Faculties of Engineering, Applied Science, Biological Sciences and Medicine, chaired by Professor Svensson, to consider the future of biomedical engineering.[29]

By September 1974, the University had agreed to the informal establishment of a Centre for Biomedical Engineering under an interdisciplinary committee chaired by Professor Svensson and including Dr Peter Bason as part-time coordinator and Dr Peter Farrell (Chemical Engineering).[30] In 1976 the Centre for Biomedical Engineering, a collaboration between the aforementioned faculties, was formally established to coordinate and foster teaching, research and clinical applications in this rapidly expanding field. First housed in the new Geography and Surveying (GAS) Building, an extension of the Mechanical Engineering Building, the Centre was primarily focused on research, but as it finalised its Master of Biomedical Engineering program and was about to enrol students, it needed a more formal structure and a 'home' Faculty, which became Engineering.[31] Associate Professor Peter Farrell was appointed foundation Director in December 1977.[32]

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The Labor federal government led by Gough Whitlam came to power in 1972, and two years later it abolished tertiary education tuition fees and took over the full funding of universities. This was reflected in the Faculty's 1974 commencing undergraduate enrolments, with an increased intake of 752 students, including 594 full-time students.[33] For Electrical Engineering this marked the beginning of a sustained growth in enrolments that would last for nearly three decades until the fallout from the dot-com crash of 2000.[34] In the meantime, any potentially beneficial period for the tertiary sector was, however, almost immediately dissipated by the global economic recession and increasingly restrictive federal government budgets. Triennial funding to universities was suspended and practically all capital expenditure cancelled. By 1982 it was clear that, in real terms, funding had been progressively reduced since 1975.[35]

Professor Antoni Karbowiak returned as Head of Electrical Engineering in 1972, but 1973 was a difficult year financially for the School. Several years of increasing student numbers, combined with a lack of commensurate growth in financial support to maintain laboratories and equipment, had led to a state where the Year Two

THE GRADUATE SCHOOL OF BIOMEDICAL ENGINEERING

Biomedical engineering began at UNSW in the late 1960s as a collaboration between researchers from the School of Mechanical and Industrial Engineering and the Faculty of Medicine to investigate the lubricating properties of fluids in knee joints. Further research opportunities emerged in cross-disciplinary areas such as artificial kidneys and hip prosthetics, and in 1976 the Centre for Biomedical Engineering was jointly established by the Faculties of Engineering, Applied Science, Medicine and Biological Sciences.

The Centre's aim was to coordinate and foster teaching and research in this rapidly expanding field that applied engineering techniques to clinical problems. Drawing on expertise in electrical, mechanical and chemical engineering, much of the Centre's research in the mid-1970s focused on the performance of artificial kidneys and haemodialysis systems.

Postgraduate teaching and research programs were introduced in the late 1970s, and in 1981 the Centre – the only one of its kind in Australia – was formally established within the Faculty of Engineering. New laboratories equipped for studies of artificial organs (heart, liver and kidney), cardiovascular dynamics, medical instrumentation, biomaterials and pharmacokinetics were opened in 1982.

In the 1980s the Centre's researchers focused on developing novel biomaterials and biomedical devices, and a new computer system enabled many experiments to be automated. In 1991 the Centre was involved in successful applications for two Cooperative Research Centres (CRCs): the CRC for Cardiac Technology, which operated until 1998, and the CRC for Eye Research and Technology, which was absorbed into the Vision CRC in 2003.

Collaborative research programs continued to develop between the Centre's researchers, the medical device and pharmaceutical industries and medical schools and hospitals around Australia, resulting in several commercial successes. Working with the CRC for Eye Research and Technology, researchers produced a breakthrough soft contact lens that could be worn continuously for up to 30 days. Through the CRC for Cardiac Technology, a biostable polyurethane was developed for use in implantable medical devices such as pacemakers and stents.

Dr Nigel Lovell (left) and Associate Professor Branko Celler using a computer card and PC software to monitor electro-cardiographs (ECGs), 1995. Photo UNSW Public Affairs Unit. Courtesy UNSW Archives.

In 1995 the Centre became the Graduate School of Biomedical Engineering (GSBmE), and began offering concurrent degree programs whereby students obtain a Bachelor of Engineering with a Master of Biomedical Engineering over five years. The first two streams of this unique program were in electrical and mechanical engineering, with a computer engineering stream beginning soon after. A chemical engineering stream joined the ranks in 1998, followed by telecommunications and mechatronics in 2001 and software engineering and bioinformatics in 2004. The first concurrent cross-faculty degree program began in 2002 with the introduction of a materials science stream in conjunction with the Faculty of Science.

Today, GSBmE's research focuses on two main areas: cell and tissue engineering, and biophysical monitoring and modelling, which currently includes the development of a bionic eye. Collaboration continues to be integral to the School's work, with expertise drawn from the engineering, science and medical disciplines within UNSW and from institutions around the world, as well as research organisations like the CSIRO and a range of companies with biomedical interests. The School's activities aim to increase our knowledge of biological systems to enable the development of biomedical devices, as well as reducing healthcare costs and improving the quality of treatment for patients.

and Three electronics laboratories, each of which serviced 150 students a year, were considered unfit for teaching. It was fortunate that the University approved a $20 000 grant for their renovation in 1974, along with $7000 for the Electrical Engineering Laboratory, $8000 for Power Engineering and $12 000 for Computer Science.[36] Further urgent upgrades were still needed in the final-year Electronics Laboratory and due to expected increases in student numbers, in the Communications Laboratory.[37]

As with other UNSW schools at the time, the position of Head of School in Electrical Engineering was often shared among the professorial staff, whose main focus was their research and who may or may not have had an interest in administration. Professor Speedy had given up his headship to pursue research and Professor Karbowiak had no greater inclination to the task.

> Professor Vowels asked me to take the headship of the School and I said no. They eventually prevailed on me. It was only for two years and after that it became another two years. [It's] the classic example of how effective researchers are starved by a load of an administrative nature which they are not expert at either. After four years I'd had enough of it and I went back to research again …
>
> When I became Head of School I went to the Dean, Tom Fink, [who] was a very intelligent person, [with] a good understanding of human beings, and he provided finance and I took the academics with me to Leura in the Blue Mountains for a week [to discuss] what needed to be done around the School. Out of that some good ideas came in and [we] implemented them. – Professor Antoni Karbowiak, Head of Electrical Engineering (1972–76), 2008.[38]

The Department of Electronic Computation was renamed Computer Science in 1972. Two years later, in a pivotal moment for computer science globally, Ken Thompson and Dennis Ritchie of Bell Labs in New Jersey published their first revolutionary paper on the UNIX operating system. At that time the Department had a Digital Equipment Corporation (DEC) PDP-11/40 for teaching and administration which came with a standard operating system used by the University's newly established Computer Centre. Recognising the UNIX system as 'too good to be true', Lecturer Ken Robinson wrote to Dennis Ritchie to acquire a copy. It arrived in early 1975 and was modified and loaded on the School's PDP-11/40 over one weekend – a technically difficult exercise. That it was possible to do this so quickly was a testament, according to Emeritus Professor Graham Hellestrand, to the 'clarity and good structuring of the UNIX source code and the leadership of [PhD student] Ian Johnstone'.[39]

From that time the Department had a significant computing resource running UNIX, and as such was the first facility outside the United States to do so. By the end of 1975, the PDP-11/40 – with a computation power of 1/10 000th of a personal computer in 2008 – supported 40 terminals and was being used for teaching and research.

Senior Lecturer John Lions decided to use UNIX for his Year Three Operating Systems course. With PhD students Ian Johnstone, Ian Hayes *(PhD '83)* and others, he worked to annotate large sections of UNIX code in the *Source Code and Commentary on UNIX Level 6* for use as a teaching tool.[40] Although there were legal issues around the publication of these notes in the late 1970s and early 1980s, by 1998, just prior to Associate Professor Lions's death, they were resolved and his teaching achievements over more than 20 years in making the UNIX operating system accessible to students were recognised.

Associate Professor John Lions and computing students Michael Leach and Elizabeth Broderick, 1979. Photo GM Downie. Courtesy UNSW Archives.

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At the end of 1972 Senior Lecturer Arthur Blake retired after 27 years, first with the STC and then with the School. He had been Acting Head of School for two years after Professor Brown's departure in 1951 and from 1967 was Executive Assistant (Undergraduate Studies) to the Head of School.[41] He was succeeded in this position by Senior Lecturer Colin Stapleton. At the time there were more than 40 academic staff and around 60 technical and clerical support staff in the School.[42]

New staff included future Senior Lecturers William Dewar (1973–2002) and Kevan Daly *(BSc '66, BE (Elec) '68, PhD '72)* (1975–2005) initially in Systems and Control, although he later worked in Power Electronics.

The Tyree Chair in Electrical Power, recently established with the support of Tyree Industries, was filled in 1972 by Professor Fred Evans, who came to the School from the University of Sydney. He had worked with the ECNSW in power systems research, but on his arrival at the School was instrumental in expanding the scope of power engineering research into new areas, including high-voltage systems and power electronics.

Tyree Professor Fred Evans, 1979. Photo John Hearder. Courtesy UNSW Archives.

Future Associate Professors Dr Trevor Blackburn (1974–2005), Dr Hugh Outhred (1974–2007) and Dr Ron James (1974–88) were appointed to Electric Power in 1974. Drs Blackburn and Outhred continue their research work in the School today. Following his departure in 1988, Dr James remained an Adjunct Pro-

fessor with the School until 2007. Future Professor Dr Pak-Lim Chu (1975–2001) was appointed in Communications. Senior Lecturer Rudolf Guertler retired in 1976 after 22 years with the School; a year later Associate Professor Richard Huey retired after 27 years.

Dr Israel Korn joined the Communications Department in 1978 as a Senior Lecturer. Even though he retired as an Associate Professor in 1996, he maintained his links with the School as a visiting researcher until 2006. He authored *Digital Communications* (Van Nostrand Reinhold, New York, 1985) and was elected as a Life Fellow of the Institute of Electrical and Electronics Engineers (IEEE) for his contribution to the analysis of digital communication systems in 1994.

Electrical Engineering was still in financial difficulty in 1974, with enrolments outpacing its resources. Its commencing undergraduate enrolments had risen from 173 the year before to 228, with new postgraduate coursework and research enrolments rising from 23 to 34. A double degree in electrical engineering and arts was also introduced in 1974.

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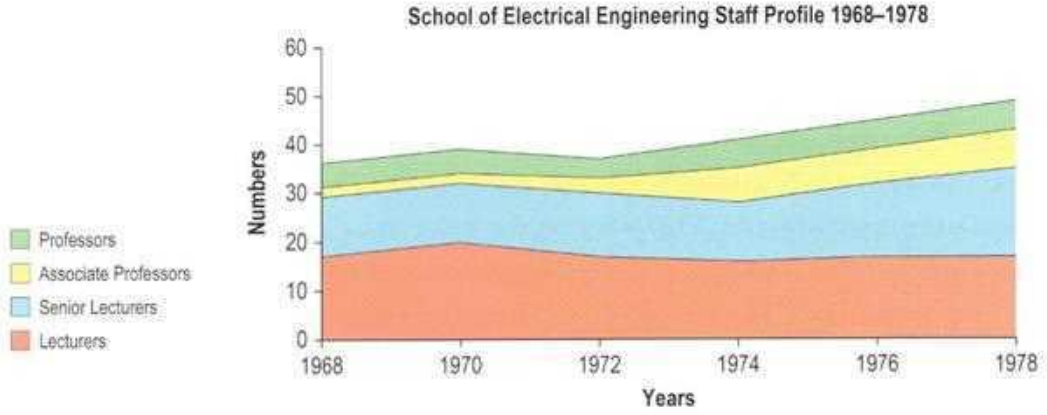
At off-peak times, when the steam-driven coal-fired generators of Lithgow and the Hunter Valley (which provided the main base-load electricity supply for New South Wales) were not fully loaded, they could provide very cheap power for pumped-storage electricity generation by pumping water between the Snowy Mountains Scheme storage dams. The water stored in an upper reservoir could then be released for hydroelectric power generation at the time of highest system demand during the day, when the value of the electrical energy is greatest, and then be pumped back again at times of lowest demand during the night when the electricity cost is low. In



1974 the first major use of pumped-storage hydroelectric power was commissioned in the Snowy Mountains Scheme with 1500 megawatts of generation at Tumut 3 Power Station. This was followed in 1978 when the ECNSW commissioned the 240 megawatt Shoalhaven River Pumped Storage Scheme.[43]

The ECNSW received up to 2.2 gigawatts of daily peak power capacity from the Snowy Mountains Scheme. Its overall power demand was increasing rapidly and so very large base-load generating units were employed in its later power stations at Liddell (1974) and the Wallerawang extension (1976), which were equal to the largest in service in Britain at that time.[44]

In 1975 the establishment of a High Voltage and High Current Laboratory in the School led to the development of new undergraduate thesis topics and a new elective course, along with three new postgraduate courses and new research projects in electric power.

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The 'oil shock' of 1974 occurred when the Organisation of Petroleum Exporting Countries (OPEC) quadrupled the price of crude oil to around US$12 per barrel,[45] signalling sharply to the world that oil was a finite resource and could no longer be counted on for the supply of 'cheap energy'.[46] There was an intensified focus on renewable energy, including solar energy.

There had been very little research on solar energy prior to 1945, but the 1950s saw an increasing interest in the field in academic institutions in the United States, Israel and Australia. By 1970 the Australian solar water heater industry was well established and there were research programs in the CSIRO and in several Australian universities, including UNSW, especially in the Schools of Electrical Engineering and Mechanical and Industrial Engineering. By 1974, although there were no commercial solar water-heating systems on the US market, several Australian brands were already being marketed locally.[47]

It was in the direct conversion of solar energy into electricity using silicon cells, however, that the School was to make its mark. In 1974 Dr Martin Green began working with Professor Lou Davies, continuing his PhD work on the structure of micro-electronic components that combined semiconductors, metals and insulators. In 1975 the Solid-State Electronics Department fabricated its first solar cell in the School's Integrated Circuit Laboratory and Dr Green would go on to establish the discipline

Solar panels at Fowler's Gap used to run recording equipment, 1987. Photo UNSW Public Affairs Unit. Courtesy UNSW Archives.

of photovoltaic engineering at UNSW and lead a world-record-breaking research team in the development of high-efficiency (the percentage of sunlight converted into electric energy), low-cost solar cells.[48]

The global energy crisis of 1973 led generally to a greater interest in alternative energy sources and in 1975 Professor Fred Evans established the Centre for the Study of the Distribution and Utilisation of Electrical Energy with support from industry and various county councils, to investigate methods and means of electrical energy allocation.[49] The National Energy Advisory Council (NEAC) was established in 1977 to advise the federal government on energy matters and the following year the National Energy Research Development and Demonstration Council (NERDDC) was established to make recommendations on the award of federal government grants.[50]

In 1978 Telecom Australia installed 13 transportable solar power packages between Alice Springs and Tennant Creek to provide the 130 watts needed for the 960 channel system. Solar power was also being used for small-scale water pumping, electric fences, small power units (with peak ratings of less than 200 watts) for lighting and electronic equipment.[51]

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In Computer Science in the mid-1970s, Professor Allen and students Wayne Ruting *(ME '73)* and Bob Zeltzer *(BE (Elec) '70)*, with the support of a major Australian Research Grants Committee (ARGC) grant, designed and built the AR-16, an emitter-coupled logic research computer. Lecturer Ken Robinson introduced a teaching innovation, the building of a compiler as a major assessable, practical project in his Programming Languages and Compiling Techniques course.

The concept of including a major project in a course caught on and was used by many staff in succeeding years, including Senior Lecturer John Lions in his operating systems subject and Lecturer Graham Hellestrand in VLSI design courses, as well as in software engineering, networking, and computer organisation and design courses. According to Emeritus Professor Graham Hellestrand, 'These were difficult subjects, but exposure to realistic project work was a great help in encouraging students to exercise critical thinking and originality in problem solving, and inspiring them by being 30 per cent of final assessment'.[52]

PHOTOVOLTAIC ENGINEERING, 1974 ONWARDS

By Scientia Professor Martin Green

Although used in space since the late 1950s, interest in solar cells for generating electricity on Earth was reawakened by the international oil embargoes of the 1970s. UNSW involvement in photovoltaics began in 1974 when Dr Martin Green joined the University and teamed up with Professor Lou Davies, who had an interest in solar cells via his links to AWA (Amalgamated Wireless Australasia). In 1975 UNSW fabricated its first operational cell (microgridded Schottky device).

In 1976 Bruce Godfrey joined the group to research metal-thin insulator-silicon (MIS) structures, the subject of Dr Green's doctoral thesis. Cell output voltage was rapidly improved, provoking international attention as NASA, a pivotal funding agency, had determined that improved voltage was key to improving overall cell energy conversion efficiency (ratio of electrical power out to solar power in).

Dr Green gave the group's first invited plenary presentation at the 14th IEEE Photovoltaics Specialists' Conference in San Diego in 1980. With support from the new National Energy Research Development and Demonstration Council (NERDDC), the group grew and accumulated the equipment and know-how needed to convert high voltage into high conversion efficiency.

Early devices were hybrids of the MIS structure and conventional Positive-Negative (PN) junctions, the so-called MINP, studied by Andrew Blakers. In 1983 these MINP cells set a new world record for silicon solar cell efficiency at 18 per cent.

The growing team then concentrated on the photovoltaic 'four-minute mile', the first silicon cell of efficiency above 20 per cent, long regarded as a practical limit. Team members, including Andrew Blakers, Chee Mun Chong, Mohan Narayanan, Ted Szpitalak, Michael Taouk, Stuart Wenham, Michael Willison and Jianhua Zhao, steadily inched towards this target, producing a batch of 20 per cent efficient cells weeks before the 18th Photovoltaics Conference in Las Vegas in 1985. Associate Professor Green received independent confirmation of this result just hours before flying out to announce it as a conference highlight.

The team worked in two groups: one chased ever-improving efficiency and the other sought simple ways for capturing improvements in devices that could be manufactured inexpensively. Working on the second strand, Stuart Wenham and Associate Professor Green

Solar cell research team, 1985. Clockwise from far right: Stuart Wenham, Jianhua Zhao *(PhD '90)*, Dr Martin Green, Michael Taouk *(PhD '94)*, Andrew Blakers *(PhD '84)*, Ted Szpitalak, Mohan Narayanan, Chee Mun Chong *(PhD '90)* and Michael Willison. Courtesy School of Photovoltaic and Renewable Energy Engineering.

co-invented the laser-grooved, Buried Contact Solar Cell (BCSC) in 1984, since ranked by the Australian Academy of Technological Science and Engineering as one of the 'top 100 Australian inventions of the 20th century'. This cell design became the second internationally to exceed 20 per cent efficiency in 1986.

German firm AEG Telefunken made the first BCSC sales under licence in 1990. These BCSCs powered the Swiss solar car, *Spirit of Biel*, to a convincing win in the 3000-kilometre World Solar Challenge from Darwin to Adelaide. A second licensee, BP Solar, supplied BCSCs in 1991 to Europe's then largest system, a 1 megawatt Union Fenosa system near Toledo. By the late 1990s, BP Solar was Europe's largest cell manufacturer, exclusively using UNSW technology there.

Reduced international funding for solar research during the 1980s, prior to the Chernobyl nuclear disaster in 1986, resulted in many research groups leaving the field. The UNSW group survived but realised that it had to focus on the field's key problems. From 1988 this led to the development of potentially much cheaper thin-film cells and the commencement of an innovative silicon thin-film project taking advantage of the improved light absorption and surface passivation demonstrated in the group's silicon wafer-based research.

The 1990s was a decade of substantial achievement for the group under the umbrella of the ARC Special Research Centre for Photovoltaic Devices and Systems. Cell efficiency improved to 24.7 per cent. Working with the University's commercial arm, Unisearch Ltd, the team fabricated and sold solar cells for six solar cars, including *Honda Dream* and *Aurora 101*, winners of the 1996 and 1999 World Solar Challenges respectively, with proceeds used to procure incubator facilities in Botany.

The buried-contact approach became the most successfully commercialised new cell technology of the decade, with sales under licence reaching $1 billion. BP Solar's Saturn module set new standards for commercial module efficiency that were only recently surpassed. In 1995 the Centre's innovative thin-film 'silicon on glass' approach attracted massive investment by Pacific Power, then Australia's largest electricity utility. The first commercial sales were by CSG Solar in Germany in 2006.

Professors Martin Green and Stuart Wenham have received several local and international awards on behalf of the group. These include the 1990 and 2009 IEEE William R Cherry Awards, received by Professors Green and Wenham respectively. They shared the 1992 CSIRO External Medal and the 1999 Australia Prize. Professor Green received the 1995 IEEE JJ Ebers Award and the 2002 Right Livelihood Award – known as the alternative Nobel Prize.

By 2000 the term of the Special Research Centre had come to an end but two new initiatives emerged. The first was the new ARC Key Centre for Photovoltaic Engineering, directed by Professor Wenham, targeting industrial collaborative research and the establishment of the world's first undergraduate degree in photovoltaics, anticipating the industry's rapid expansion. The second was the ARC Special Research Centre in Third Generation Photovoltaics, directed by Professor Green, which sought to accelerate the development of futuristic photovoltaics for the 2020 timeframe. These two Centres were combined in 2003 within the ARC Centre of Excellence for Advanced Silicon Photovoltaics and Photonics, with Professor Wenham as Director, Professor Green as Executive Research Director and Dr Christiana Honsberg, Professor Armin Aberle, Dr Richard Corkish and Professor Jianhua Zhao as Deputy Directors. In 2006 the School of Photovoltaic and Renewable Energy Engineering was established with Dr Corkish as first Head of School.

The recent photovoltaics boom has seen almost overwhelming international interest in the Centre and its students, graduates and technology. In 2007 its semiconductor-finger technology, jointly developed with China's Suntech Power, went into production, with its similarly developed 'Pluto' technology beginning experimental production in 2008. Centre graduates have spearheaded many international initiatives in photovoltaics manufacturing, most notably Dr Zhengrong Shi *(PhD '92)*, Chief Executive and Chairman of Suntech Power, now the world's largest solar module manufacturer.

Electric vehicle, 1979. Left to right: driver Laboratory Craftsman Warren Potts with Senior Technical Officer Neville Brennan. Courtesy UNSW Archives.

In Electric Power Engineering research, the mid-1970s were spent expanding on and applying the digital protection methods developed by Professor Ian Morrison and his colleagues, with the support of funding from ARGC and the Electrical Research Board (ERB), which also funded work in high-voltage condition assessment in the High Voltage Laboratory. Research in power electronics also began with applications to electric vehicles.[53]

Communications research covered six broad areas. Work in ultra high frequency (UHF) and microwaves included the computer modelling of a trunk waveguide communication system for Telecom. Research continued on optical fibres for wide-band systems and the development of adaptive receivers for digital communication systems. In 1977, Dr Chu published his seminal paper *Nondestructive measurement of index profile of an optical-fibre preform*.[54] The solid-state devices and circuit applications group worked on new types of nonlinear filters and the acoustics group worked on holographic sonar for medical purposes and modelling of the human hearing process.[55]

Control Engineering was renamed Systems and Control in 1972 and aside from general theory research, the applications group continued its work on the Boiler Project and other collaborative projects on fermentation processes (with UNSW Biotechnology), stability studies of boiling channels (with the Australian Atomic Energy Commission at Lucas Heights) and renal dialysis (with Sydney Hospital). The computer-aided design (CAD) group worked on the

development of interactive packages for control system design, single input/single output systems and linear and nonlinear simulation packages. Hardware and computer projects were carried out on the use of microprocessors in real-time situations. The cybernetic systems group worked on a new approach to third-generation industrial robot systems and learning machine simulations. Following its transfer from Communications to Systems and Control, the biomedical engineering group worked on modelling the mammalian arterial system and investigations of respiratory influences on heart rate.[56]

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Throughout the Faculty of Engineering, the exchange of ideas had picked up pace and there were regular graduate seminars across all the Faculty schools.[57] One result was the Faculty's establishment of an Environmental and Interdisciplinary Studies Committee in 1976 to consider the development of such studies in the context of technology in society. A standing committee was then formed to coordinate and stimulate teaching and research in this area and the schools were encouraged to consider how they could develop a core undergraduate course covering environmental and interdisciplinary concepts, as well as ways to incorporate new ideas and techniques within existing subjects.

Under Professor Fink as Dean, interdisciplinary contacts were further encouraged by informal monthly luncheons to which staff of various Engineering departments and from other faculties were invited. It was noted that, 'In a Faculty of over 200 teaching staff, special efforts of this nature are needed to combat natural tendencies towards insularity within sub-groups'.[58] This was a laudable effort to overcome barriers to interdisciplinary activity, but was ultimately limited by reduced funding and increased workloads.[59]

As well as regular graduate seminars, there were increasingly frequent visits from distinguished international academics and more opportunities to sponsor or host specialist conferences for engineers and researchers from Australia and overseas. It was felt that, despite the great effort involved, the 'benefit of interaction with workers outside the University and the stimulation they provide for senior students and staff' made these exercises worthwhile.[60]

To provide a much-needed stimulus to research, in 1976, as part of a University-wide exercise, five special projects were funded within the School with the aim of bringing the research of younger Faculty staff to a level at which they might expect to attract external support for further work.[61] These included projects by Drs Peter Bason, Pak Chu, Bob Radzyner, William Dewar, Tim Hooper and Ron James.

International telephone traffic was growing at about 25 per cent per year in the mid-1970s and a new computer-controlled telephone exchange was installed at the new telecommunications terminal at Broadway, Sydney, to provide increased capacity.[62] The exceptional activity during the 1970s in electronics, digital techniques, satellites and optical fibres would have major impacts on communications technology. It also led to the growing integration of computers and communications, both with computers as integral parts of the communications equipment, and the use of communications to link computers, in the build-up to networks that integrated computers and communications into overall systems.[63]

In 1975 the PMG Department was divided into two statutory authorities, Australia Post and the Australian Telecommunications Commission (Telecom).[64] Work on optic fibres continued and in the same year AWA began to develop a facility to make a solid core cable for Telecom. In 1977 the first of a notable series of Radio Research Board annual workshops on optical communications was sponsored by the School's Communications Department, bringing research workers in the field together to discuss the latest developments in Australia and overseas.[65]

In 1977 Telecom adopted the PCM system as its standard, introducing it progressively into the capital city junction networks. Digital microwave systems on main routes followed, as well as the introduction of digital equipment on existing coaxial cables, rapidly establishing a basic digital transmission system within the existing analogue one. By 1986 Australia had the world's largest digital microwave trunk system, stretching over 5000 kilometres from Perth to Brisbane.[66]

In the late 1970s the INTELSAT and AUSSAT satellite services were used to provide TV program relays to small and remote population centres,[67] and from April 1976, as communications satellites made it practicable to provide large numbers of relatively low-cost international channels, International Subscriber Dialling (ISD) became available in Australia to 14 major destinations.[68]

Telecom made a major leap in network management in 1978 with the establishment of a computer-controlled network monitoring centre. Over the next four years this resulted in the development of a series of network management strategies to cover all peak days throughout the year and all practicable failure conditions. Australia became a world leader in the development of network management, with its procedures being used in the installation of similar centres internationally.[69]

On 1 January 1976 Professor Murray Allen was appointed Head of Electrical Engineering (1976–80).[70] Within Computer Science, the Give system (as in 'give assignments') for the electronic submission and automated marking of assignments was implemented by Ken Robinson, with assistance from Dr David Carrington. This was one of the first such systems in the world and continues to be used by the School of Computer Science and Engineering.[71]

Professional Officer Peter Ivanov (sitting) and PhD student Ian Johnstone discussing the new PDP-11/70 computer in the Department of Computer Science, 1978. Photo UNSW Public Affairs Unit. Courtesy UNSW Archives.

Although there had been considerable hardware innovation in computer architecture between 1953 and 1967, it was the decade to 1975 that saw very rapid developments in knowledge and expertise in computer science, with profound changes in computing algorithms, computing languages and hardware technology.[72] It happened that the University's first computer had been installed under the care of the School of Electrcal Engineering in 1956. The University's primary computing department, the Department of Electronic Computation, was also part of the School so, unlike the case in most other universities at the time, computer science subjects were taught by Electrical Engineering staff – to engineering students, as well as to students from other faculties. Reflecting the unique and evolving nature of the field – as computer science was seen more as a science/applied science hybrid and not really engineering *per se* – the computer science degree program (leading to a three-year BSc) was administered by the Board of Studies in Science and Mathematics.[73] Definitions aside, there was an explosion of student interest in this area of study.

During the mid-1970s, the Computer Science Department was largely responsible for managing its own (and the School's) computing resources. Almost all teaching was done on the Department's equipment and by the late 1970s Computer Science was in the business of mass-producing its own terminals – at considerable savings in capital and maintenance expenditure. Around 1978 a DEC VAX-11/780 was purchased for teaching and research; it augmented the workhorse DEC PDP-11/40.

The Department was responsible for all software maintenance and developed capabilities for the UNIX operating system to help make the sharing of the processor and disk resources highly efficient. This work was also distributed through the worldwide UNIX network to many other universities. At the time the technical support of UNIX within Computer Science was comparable to the best in the world and many UNSW developments were incorporated into the ongoing UNIX source work.[74]

One of the key contributions to the development of UNIX was in the area of resource management and control. As a multi-user, multi-tasking operating system, UNIX has to keep track of user identity

EMERITUS PROFESSOR MURRAY ALLEN

(BE Hons '50 Adel, PhD '59 Sydney)

Acting Head of School 1970–72 and Head of School 1976–79

Born in South Australia in 1927, Murray Allen completed an engineering degree at the University of Adelaide before taking his first engineering job at AWA in Sydney. He left a short time later to become a Research Officer in the CSIRO's Section of Mathematical Instruments. During his seven years there from 1951 to 1958, his work involved early transistor computers and computer hardware, and he rose to the rank of Senior Research Officer. Also during that time, he undertook a PhD at the University of Sydney for which he designed and constructed an Automatic Digital Analyser (ADA) that used solid-state circuitry.[75]

In 1959 Dr Allen returned to the University of Adelaide, this time as a Senior Lecturer in Electrical Engineering, and spent six years in the role. During this time he was responsible for developing CIRRUS, an early example of a transistor computer featuring microprogramming control and multi-programming operation.

In 1964 he took study leave during which he worked as a Senior Research Scientist with the major US supercomputer firm, Control Data Corporation (CDC). While there, he received an offer from UNSW to become Professor and Head of the School's new Department of Electronic Computation (later Computer Science) and Director of the Digital Computing Laboratory. He arrived back in Australia in 1965 to assume these dual roles.

From 1967 Professor Allen continued to work on various computer design projects. In the 1970s he was involved in the design of the Visicom computer (a low-cost tool used for education and research) and its successor, the AR-16.[76] During that time, he also implemented a strong research program covering graphics, computer organisation and architecture, programming and programming languages, operating systems and artificial intelligence.

Courtesy UNSW Archives.

Professor Allen was Acting Head of School from 1970 until Professor Antoni Karbowiak assumed the role in 1972. Professor Allen succeeded him as the School's official Head in 1976, serving until 1980. As Head he oversaw a restructure of the undergraduate program that allowed more flexible pursuit of a BSc, BE or a combination of the two, which he felt 'resulted in high-quality, well-balanced graduates'.[77]

In 1981 Professor Allen was made a Fellow of the Academy of Technological Sciences and Engineering. He also served on the Australian Research Grants Committee (now the Australian Research Council) from 1982 to 1984. After stepping down as Head of School, he continued to lead the Department of Computer Science until he retired in July 1987 as an Emeritus Professor. Since 2003 he has sponsored an annual award, known as the Murray Allen Prize, which is granted to a high-achieving honours student in the School of Computer Science and Engineering.

Professor Allen's most recent accolade was the Pearcey Medal, Australia's most prestigious ICT industry award, which he received in October 2009 for lifelong service to the ICTsector. In presenting the medal, Senator Stephen Conroy, Federal Minister for Broadband, said: 'During his career [Professor] Allen was considered to be one of the world's leading designers of digital computers. As well, he was a major force in ICT education and many of his students have gone on to gain eminence in the industry and academia.'[78]

information. The original UNIX system obtained from Bell Labs in 1975 stored passwords in an encrypted form. The algorithm, however, was well documented and the password file was a 'flat' text file, readable by all users. This presented problems for both security and in slowing down the system while the file, which grew with the number of users, was being searched for user information. Computer Science staff and postgraduates produced a suite of changes to UNIX sixth edition to improve performance, resource monitoring and control. This included a rewrite by Professional Officer Peter Ivanov of the password file and associated library code. The suite of changes was released and distributed as the Australian UNIX Share Accounting Method (AUSAM).[79]

Significant revisions were made to computer training as a result of the development of computer technologies, the miniaturisation of electronics and rise in demand resulting from the proliferation of personal computers from 1977.

In the Solid-State Electronics Department, Professor Davies and Dr Green were researching semiconductors and obtaining promising results with a novel MIS (metal-insulator-semiconductor) solar cell, work which stimulated the establishment of a dedicated Photovoltaic Laboratory in 1977.[80] The same year, Stuart Wenham began his undergraduate degree in electrical engineering, later becoming one of Dr Green's first postgraduate students in what was to be an extremely significant research collaboration in the development of solar cell technology. According to research from the 1950s, a silicon cell that could convert 20 per cent of sunlight into electricity was regarded as an achievable upper limit, and from the late 1970s to early 1980s the research group was aiming to break this barrier and increase efficiency to 22 per cent.

In 1978 the Microelectronics Laboratory was further developed and considerable progress was made by the Integrated Circuit Laboratory in the design and fabrication of specialised integrated circuits for medical electronic applications and pattern classification techniques for the interpretation of Landsat satellite images.[81]

In Electric Power, the main focus of research was on the application of the digital protection work, which now included the involvement of industry in the form of Brown Boveri, which later joined Swedish electric power giant Allmänna Svenska Elektriska Aktiebolaget (ASEA) to form ASEA-Brown Boveri (ABB). In the High Voltage Laboratory, Dr Ron James and PhD student Peter White were developing a world first in applying computer techniques to partial discharge monitoring of high-voltage equipment. Such computer-based systems are now the fundamental basis of partial discharge monitoring systems.[82]

Performing partial discharge insulation tests on generators at Tumut 3 Power Station, 1990. Left to right: PhD student Qi Su, Professional Officer Sai Foong, Ross Tychsen (SMHEA), John Simpson (SMHEA) and Senior Lecturer Ron James. Photo Snowy Mountains Hydroelectric Authority. Courtesy UNSW Archives.

MICRO-ELECTRONICS, 1970–97

By Emeritus Professor Graham Rigby

In the 1970s the School of Electrical Engineering showed great foresight when it established research laboratories to investigate the physics and technologies of semiconductor devices, integrated circuit design and fabrication.

The early development of these laboratories can be credited to Professor Lou Davies, who held a joint appointment as Professor of Solid-State Electronics and as Chief Scientist at AWA Ltd. There were three largely independent projects: Dr Martin Green developed a laboratory for the fabrication of photovoltaic devices, Dr Peter Ladbrooke established a smaller laboratory to study carrier behaviour at semiconductor surface layers and Dr Richard Vaughan established the 'Clean Room' as the first Australian university laboratory capable of making silicon integrated circuits (microelectronic devices).

In late 1981, UNSW won a joint bid with RMIT in the Commonwealth Centres of Excellence Program for a Joint Microelectronics Research Centre (JMRC) under the recently appointed Professor Graham Rigby. Two Associate Directors were appointed: Dr Green and, in Melbourne, Dr Jim Williams.

The UNSW component focused on three themes: photovoltaics, silicon device processing and the computer-aided design of microelectronic systems. The first two built on established strengths and, of these, the Photovoltaics Group under Dr Green became the largest and most successful, with the world-first achievement of a 20 per cent efficient cell in 1985. Another research direction was the reduction of manufacturing costs, and the development of a thin-film silicon-on-glass technology resulted in the formation of the Pacific Solar company to put the low-cost technology into production. In 1991 the Photovoltaic Group applied successfully to be a Centre of Excellence in its own right and the new Centre for Photovoltaic Devices and Systems was established under Professors Martin Green and Stuart Wenham. The Centre is now a School and has become one of the best-known UNSW facilities in the world.

Dr Chris Horwitz with his hand on the Electro grip control box, 1989. The small device standing on its side on the box is the wafer holder, which the manufacturer incorporates into its wafer-processing production line. Photo UNSW Public Affairs Unit. Courtesy UNSW Archives.

During the first years of the JMRC, more equipment was added to the original Clean Room, which was upgraded with improved air filtration and water purification. It successfully fabricated working integrated circuits (ICs) using bipolar technology and was also able to make the research samples needed by Dr Ladbrooke and others. To move into newer complementary metal-oxide-semiconductor (CMOS) technology, it was necessary to acquire an ion implanter. This large machine – probably the heaviest item of equipment installed in the School – enabled devices to be made which were of greater relevance to research.

Next to the IC Laboratory, Dr Chris Horwitz set up a laboratory for the plasma processing of semiconductors. Plasma processing provides a modern alternative to etching silicon with wet chemicals. Many research papers were generated from this work and Dr Horwitz later commercialised some of these innovations in the USA.

At the instigation of IBM, a research association was formed with the JMRC in 1983; this involved visits to the IBM research laboratories and the donation of research equipment.

Near the end of the 1980s there was a change of direction for the IC Lab, as it became obvious that a university laboratory could not fabricate integrated circuits with the performance necessary for research. The IC Laboratory was redirected to the fabrication of samples for more fundamental studies and also to support recent interest in micro-electro-mechanical systems (MEMS). This work was led by

Technician Jeff Lean is the cooperative 'patient' as research student Branko Celler (right) demonstrates equipment he devised for predicting normal and anomalous beating of the heart, with Dr Peter Bason looking on, 1976. Photo UNSW Public Affairs Unit. Courtesy UNSW Archives.

Communications research focused on the solution of problems in modern communications systems with funding from the RRB. The ARGC, RRB and ERB also funded optical fibre research. The acoustics group investigated new forms of hearing aids and the signal processing group worked with the School of Surveying on the development of a microprocessor-based system for high-resolution, low-cost automatic surveying data acquisition and processing, with the aid of an ARGC grant.[83]

In Systems and Control, new research included simulation studies and control design for industry (supported by industry) and nonlinear filters for improved noise performance funded by the RRB. The cybernetic engineering group worked on the development of a third generation industrial robot. The biomedical group pursued its major project on human gait analysis and the electric vehicle group focused on control and optimisation.[84]

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From 1976 to 1978, the School's undergraduate commencing enrolments remained at record highs, averaging 232 new students each year.[85] Postgraduate coursework programs were similarly popular with an average of 52 commencing enrolments a year. Postgraduate research commencing enrolments had plateaued in 1975 and remained at around 11 new students a year. This was, however, in the context of an economic slump that lasted until the early 1980s. The resultant government funding cuts across the entire university sector affected a general freeze in 1978 on any new staff positions, causing the School serious hardship.

Professor Chee Yee Kwok and continues using the more recently established Semiconductor Nanofabrication Facility (SNF).

The circuit design aspects of microelectronics were then supported by a new service whereby designs from research groups around the world were merged into a single large-scale chip design, which was fabricated by a commercial foundry. The electronic circuit group in the Centre pursued research in low-power analogue design, analogue-to-digital data conversion and low-power digital systems. The ability to fabricate working ICs via this method became popular with students, and dozens of student designs were also sent for fabrication in the 1980s.

Computer-aided design (CAD), the JMRC's third research area, took several forms: using computer simulation of designs in progress; the layout of components on a silicon chip; and the design of large systems on silicon (under Professor Graham Hellestrand from Computer Science). The advent of Very-Large-Scale Integration (VLSI) meant that building up a system as large as a microcomputer or a mobile phone controller could not be handled by starting at the circuit design level. Under Professor Hellestrand's leadership, a large research group evolved, which developed software intended to be a generation beyond what was currently in use. After the JMRC ceased operation in 1992, Professor Hellestrand established VaST Systems Technology Corporation, first in Sydney in 1995 and then in the United States in 1998.

1969–1978

THROUGH STUDENT EYES

With 10 faculties and 51 schools, UNSW had truly come of age by the 1970s. The campus buzzed. Along with the annual Foundation Day flour fights between engineering and medical students, there were frequent outdoor concerts and spirited debates between the editorial staff of the left-wing student publication *Tharunka* and 'the establishment'. In the late 1960s and early 1970s particularly, students worldwide were gaining much attention for their protests against the Vietnam War and, in some cases, for their advocacy of the free-love movement. Students at UNSW also had the chance to enjoy the presence of Ian 'The Wizard' Channell, the University's resident philosopher-cum-performance artist.

A Teaching Fellow in the School of Sociology, the Wizard was recognisable for his long hair and beard, outlandish costumes and public orations about magic, philosophy and sociology. In 1969 he was named 'Gandalf, the Wizard of Oz' by Vice-Chancellor Baxter in an attempt to form a 'bridge between officialdom and student power',[86] and in 1970 the new Vice-Chancellor, Professor Rupert Myers, recognised the Wizard's valuable effect on student morale and the campus atmosphere by appointing him as 'The Wizard of World University Service (Australasia)'. The Wizard appeared at festivals and other 'happenings' around the country until he settled in New Zealand in 1973. There, he became known as 'The Wizard of New Zealand' in 1992.

The Electrical Engineering Society (ELSOC) was an important social network for many students, and hosted frequent barbecues and the annual dinner. At the 1972 dinner, for example, guests were treated to a four-course meal and unlimited drinks for the low price of $3.75, as well as enjoying an after-dinner competition in which 'Speakers on any funny, quasi-technical subject from amongst both the students and staff (would) be enthusiastically received'.[87]

As UNSW's academic reputation grew, it increasingly became the preferred choice for many students looking to gain a first-rate engineering education. Scientia Professor Stuart Wenham *(BE Hons (Elec), BSc '81, PhD '86)*, Director of UNSW's Centre of Excellence for Advanced Photovoltaics and Photonics, recalls:

> My father had gone to Sydney University, but that was a long time ago and I remembered him advising me that if I was interested in engineering ... the University of New South Wales was the university that really stood out in Australia as being the leader. So in terms of choosing UNSW I had no hesitation; that was just my first choice.

Like many engineers, Stuart Wenham decided to study engineering because, he said, 'I liked working with my hands, I liked the idea of making things work'. Former Head of School, Professor Branko Celler *(BSc '69,*

College common room, c late 1960s. Courtesy UNSW Archives.

Library Lawn, c 1970s. Courtesy UNSW Archives.

BE Hons '72, PhD '78), had similar interests from a young age, though electrical engineering was not his most obvious academic path:

> I was a bit of a crazy-type inventor, even as a kid. I had my own chemistry set for a while. I wanted to do aeronautics initially because of my interest in rocketry and astronomy, but I realised there wasn't much opportunity in Australia for aeronautical engineering and I thought electrical engineering would give me great flexibility.

View along the Mall from Anzac Parade, 1972. Courtesy UNSW Archives.

Graduation, 1974. Left to right: Paul Poynton, Peter Magill, Bruce Lewis, John Burton, Lesley Tyler, Paul Weirick and Mick Schrume. Courtesy Lesley Tyler.

Dr Sitthichai Pookaiyaudom *(BE '72, PhD '76, DEng (Hon) '09),* who in 2009 was awarded one of UNSW's first honorary Doctor of Engineering degrees, arrived in Australia from Thailand under the auspices of the Colombo Plan, which meant the choice of university was made for him. His decision to study electrical engineering, however, was his own. 'I always wanted to be an engineer since I was very young,' he said. 'My father was a technical man and I have never

View from the Civil Engineering Building towards Anzac Parade, *c* 1970s. Courtesy Dr Russell Burdon/UNSW Archives.

The swelling numbers at the Central Lecture Block, 1971. Courtesy UNSW Archives.

wanted to be anything else. I chose electrical engineering, because in those days, the area of electronics was booming. Solid-state electronics was the most exciting area, and to study solid-state electronics you had to do electrical engineering.'

Dr Pookaiyaudom had previously spent his last year of high school in the United States, and arriving in Australia altered his preconceptions of what to expect from a Western country. 'In America things were a bit more modern, the look of the city, etc. Australia was a bit more English-like I suppose. So the first few months were a bit of a shock, but I was here for seven years for both my degrees and I got to like the place.'

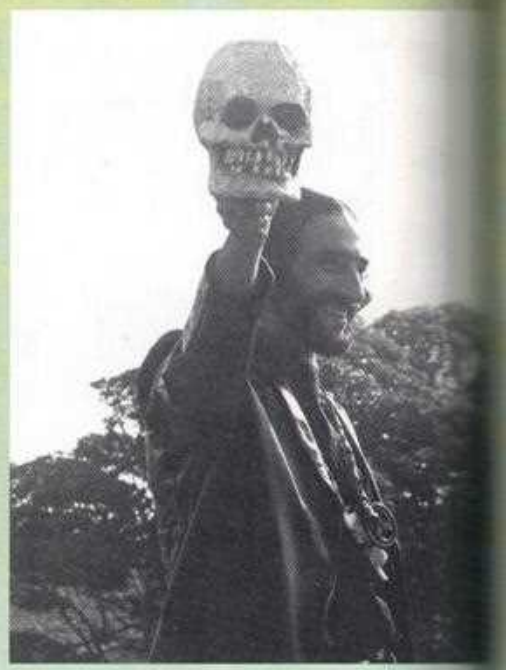
In the 1970s the School was building its research expertise, and its academics inspired many students of the time to pursue careers in similar fields. 'Most people liked electronics, information theory and control, and Associate Professor [The Bao] Vu's lectures in antennas and propagation were also quite interesting,' said Dr Adrian Ankiewicz *(BSc '73, BE Hons (Elec) '75, PhD '79 ANU)*, now part of ANU's Optical Sciences Group. 'I did my honours thesis on an optical fibre project, which started me on a long career on guided wave optics research.'

Kevin Bloch *(BSc '79, BE Hons (Elec) '81)* has fond memories of Associate Professor John Lions – 'I will never forget his amazing "no-advice-of-exams-so-you'd-better-be-ready" Unix course' and also Head of School Professor Murray Allen:

> Professor Allen was instrumental in helping me enter Australia from Rhodesia (now Zimbabwe) as a foreign student. Soon after starting at UNSW, I was advised that my scholarship application to Princeton University was successful. This was a difficult decision to make having just arrived in Australia with no permanent resident visa and not sure which country would be home. Professor Allen provided excellent counsel. He was a mentor to me and a real gentleman.

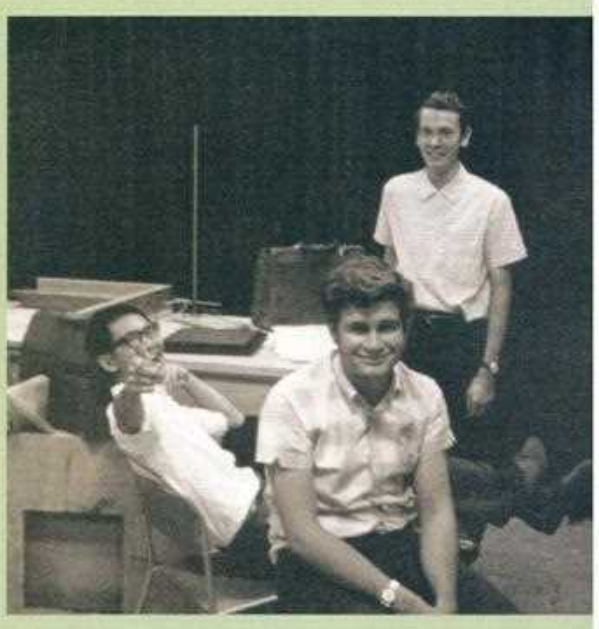
For David Coleman *(BE (Elec) '78)*, it was his thesis supervisor, Senior Lecturer Felix Lewin, and the brave new world of computers, which made a lasting impression:

> Felix was a great guy to have as supervisor, especially working one-on-one in the lab, which contained his beloved PDP-8 computer. Microprocessors were



The Wizard, a familiar figure on campus in the 1960s and 1970s. Courtesy UNSW Archives.

The flour fight – a time-honoured rivalry between Engineering and Medicine students, 1974. Photo Sir Rupert Myers. Courtesy UNSW Archives.



Practising photography in the physics lab. Left to right: Chee-Yee Kwok, Brian Douglas and Wilfred Bleeker, 1989. Photo Neil Simpson. Courtesy Professor Chee-Yee Kwok.

only just beginning to take hold and he encouraged me to pursue the application of one of them in my thesis. Computing in those days was so primitive compared to now; most desktop or laptop PCs have many times the power of the room-sized computer that used to service the entire Electrical and Mechanical Engineering schools.

I used to detest any subject that had a software component because of the time waiting in queues for a terminal or for a batch job, to produce my printout. So many days wasted going into uni to get a batch result to find the Elec Eng computer was down. Most, if not all, of those computer projects could be done on the average PC these days – at home!

Thanks to Scientia Professor Stuart Wenham, Professor Branko Celler, Dr Sitthichai Pookaiyaudom, Dr Adrian Ankiewicz, Kevin Bloch and David Coleman.

Staff and students enjoying lunch together. Professor Murray Allen (centre) hesitating unwisely amid hungry students, 1976. Courtesy UNSW Archives.