PETER JOHN BELL CLARRICOATS
6 April 1932 — 17 January 2020
Peter Clarricoats made fundamental contributions as a microwave engineer in the fields of applied electromagnetics for microwave and optical waveguides, and microwave antenna feeds. Peter was also a pioneer of optical fibres, and established the theory of electromagnetic propagation on dielectric and ferrite structures. In the course of this, he discovered that such structures can, under some conditions, support ‘backward waves’ and that guides can propagate complex modes. Over 40 years of his academic career, Peter Clarricoats had numerous notable achievements, including pioneering designs for shaped reflectors, reconfigurable reflectors and especially corrugated horns for microwave antennas. The latter are now universally used in satellite ground stations and in spacecraft. He published what became standard reference texts on corrugated horns for microwave antennas, microwave horns and feeds.

He served as vice-president of both the Institution of Engineering and Technology and the International Union of Radio Science, and from 1998 to 2000 was chairman of the Defence Scientific Advisory Council. He was appointed a CBE in 1996. He is the recipient of the 2001 Distinguished Achievement Award of the Institute of Electrical and Electronics Engineers Antennas and Propagation Society, and in 2015 he received the Sir Frank Whittle Gold Medal from the Royal Academy of Engineering.

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Early life and academic career

Peter John Bell Clarricoats was born on 6 April 1932 to John and Cecilia Clarricoats in Southgate, London. He was the youngest of three children; his two older sisters were Joan and Pamela (figure 1). His father was Secretary of the Radio Society of Great Britain, a contributing factor to Peter’s interest in all forms of telecommunications. He grew up during the Second World War, and when the blitz started his father moved the Radio Society headquarters to their home. It was here that Peter practised his Morse code by listening to the (coded) Enigma transmissions on his father’s radio. His teaching career started early: by the age of 10 he was teaching air corps students Morse code!

He attended Minchenden Grammar School and then went on to study electrical engineering at Imperial College, London, where he obtained his BSc in 1953 and subsequently his PhD in 1958.

After a short spell in industry following his graduation in 1953, Peter started his academic career in 1959 as a lecturer at Queen’s University Belfast, and initiated the university’s microwave research. In 1961 he moved to the University of Sheffield. He was subsequently
appointed as a professor at the University of Leeds in 1963, making him the youngest professor in his field at the time. In each university he started research groups in microwave engineering, which still thrive today. Peter was extremely productive during the early years of his academic career, with many single-authored papers covering a broad range of ferrite research, from theoretical calculation to the development of measurement techniques, and finally applications of ferrites to both passive and active microwave devices. He went on to carry out research on circular waveguides, optical fibres and antennas, making several pioneering contributions.

In 1968 he made his final academic move, to Queen Mary College (now Queen Mary University of London) and founded the Electromagnetics and Antenna Group, which went on to make significant contributions to antenna and microwave research. He was head of the Department of Electronic Engineering between 1979 and 1995 and served as Dean of Engineering between 1977 and 1980. He was also a College governor from 1986 to 1991.

FAMILY AND INTERESTS

Peter Clarricoats was supported by a loving family and was very happily married for over 50 years to his second wife Phyllis (figure 2). He had five children, two step-children and 11 grandchildren. He was a passionate sportsman and loved squash, badminton, rock climbing (which he said he was ‘no good at’) and walking. After tearing both his cartilages and breaking his patella tendon playing tennis with his wife on holiday, he was forced to reduce his sporting activities and took up reading history as a pastime. He was a great lover of classical music, particularly that of Sergei Rachmaninov. He will be fondly remembered by his family and friends for his great sense of humour and his penchant for mixing knock-out drinks, including whisky with red vermouth or Drambuie (figure 3). These were, as one can imagine, fearsomely potent.

SCIENTIFIC AND ENGINEERING CONTRIBUTIONS

Microwave ferrites

Peter studied at Imperial College and received his PhD from the University of London in 1958, with a thesis entitled ‘Properties of waveguides containing ferrites with special reference to waveguides of circular cross-section’.

Microwave magnetic materials have long been a subject of interest as their potential applications operate either near the natural resonance, as absorbers or electromagnetic interference shielding materials, or above and below resonances, as low-loss, high permeability materials in non-reciprocal devices, allowing only unidirectional flow of a microwave signal. These ferrite non-reciprocal devices include circulators, isolators, phase shifters and filters, all of which are important components in radar and wireless communication systems. The value of ferrites as materials for ultrahigh frequency applications was not realized until 1940, when Snoek (1948) systematically studied ferrites for applications in devices that send, receive and manipulate electromagnetic signals at radio-frequency (RF), microwave and millimetre-wave frequencies, enabling non-reciprocal devices to be made.

Peter continued his work on microwave ferrites after he graduated and took a position as an engineer at the Applied Electronics Laboratories of The General Electric Company Ltd, in
Stanmore, between 1953 and 1959. Here he co-published a paper with Dr A. F. Harvey* at the Radar Research Establishment, Malvern (1)†. They conducted an experimental investigation of the propagation behaviour of circular waveguides containing longitudinally magnetized ferrite rods. Measurements were made from 9 to 250 GHz/s using nickel-zinc ferrite.

During his PhD studies, Peter developed a perturbation method (2) that enabled calculation of the propagation coefficient of such a circular waveguide loaded with microwave ferrites, where the field throughout the whole of the ferrite is circularly polarized. Theoretical and experimental results for the negative circularly polarized dominant mode compared favourably in the case of a Ferroxcube B2 ferrite. He later studied the dependence of propagation behaviour on ferrite rod diameter in detail using polystyrene foam and polystyrene as supporting media (4), and extended his perturbation method for determining the gain of

* Arthur Frank Harvey was born on 21 March 1910. He was admitted to the degree of D Phil in April 1940 at Jesus College, University of Oxford. During this time, he studied in the Engineering Laboratory, Oxford, where he began work on high-frequency thermionic tubes, later moving to the Cavendish Laboratory, Trinity College, Cambridge, He continued in the research and development of radar and microwave applications during and after the Second World War. This included work on the magnetron, which was of considerable importance during the Second World War. He died on 26 March 2006 aged 96. The IET AF Harvey Research Prize was established from his charitable trust.

† Numbers in this form refer to the bibliography at the end of the text.
travelling-wave ferromagnetic amplifiers (3). Using this method, the gain was determined for an amplifier employing a circular waveguide and an axial ferrite rod of small cross-section. He showed that the efficiency of such an amplifier was low, and a practical version would demand the use of larger rod cross-section and/or a slow-wave structure. He studied other possible waveguide configurations for amplifiers, together with all practical aspects of construction.

In the 1960s, while Peter continued studying microwave ferrites, he found both theoretically and experimentally that a waveguide of circular cross-section containing a concentric rod of dielectric or ferrite material had peculiar behaviour of the phase constant. He found that, as he predicted with suitable choices of geometry and properties of the rod, such a waveguide can support slow waves or backward waves, which was in stark contrast with the wave propagation in conventional waveguides (10). He later studied a necessary and sufficient condition for backward-wave propagation in the dielectric structure (11) and showed that, for the dominant mode to exhibit a backward-wave branch, the relative permittivity of the rod must exceed 91. The largest backward-wave region occurs when the permittivity has a complex value. At this permittivity, the cut-off conditions of the lowest-order H and E modes coincided. Peter showed this degeneracy in cut-off conditions to be intimately related to the appearance of backward waves, which was related to the ratio of rod radius to waveguide radius and the actual waveguide dimensions.

Peter was one of pioneers who initiated the study of wave propagation in waveguides filled with naturally occurring and artificial materials (7, 11–14). His important works have inspired studies on artificial dielectrics and, more recently, metamaterials (artificial materials
possessing extraordinary electromagnetic properties that cannot be found in nature). The latter area of research has become ever more popular since the 1990s and remains an active subject of study by physicists and engineers worldwide.

Peter published his first book, and arguably the first book of its kind, on *Microwave ferrites* for the publisher Wiley in 1961 (5). In this book, he predicted that microwave ferrites would be advantageous in many practical applications, as their microwave properties can be varied electrically. For example, the variation might be in the strength of an electric current flowing in a solenoid that produces a magnetic field within the medium. This type of variation could alter the microwave properties of ferromagnetic materials and ionized gases contained within the waveguide or coaxial line. Over the past 60 years, the book has been continuously cited by fellow researchers, including microwave and antenna pioneers such as the late Professor Jim R. James and Professor Joseph Helszajn. Although ferrites have been well studied since the 1950s, the usual perception is that this is a mature technology, with the implication being that anticipated advances will be incremental. This is, in fact, far from reality. Advances in materials processing and devices that have taken place over the last 10 years have been dramatic and significant. The breakthroughs could prove to offer a disruptive advance in the field of monolithic microwave integrated circuits technology. Low-loss, high-$Q$ ferrites are needed, and a better understanding of the response of nanoscale ferrites with changes in temperature is crucial, not only for basic science (the development of an atomistic and microscopic theory of the mechanochemical processes), but also because of the technological high-temperature applications in catalysis, ferrofluids and information storage. In addition to materials advances, new devices have enhanced performance, reduced size and, in some instances, added functionality. The ability to process thick film ferrites having perpendicular magnetic anisotropy and self-bias properties allows for the redesign of conventional microwave passive devices as light-weight planar constructs. New devices, based upon spin wave parametric pumping and nonlinear spin waves in feedback rings, employ ferrite films for high-frequency signal processing. All of these developments have benefited from Peter’s early research works (6, 8, 9, 15).

**Optical waveguides**

In the 1960s, Professor Charles Kao (FRS 1997) worked at Standard Telecommunication Laboratories, the research centre of Standard Telephones and Cables in Harlow, and it was here in 1966 that he laid the groundwork for fibre optics in communication with his seminal work ‘Dielectric-fibre surface waveguides for optical frequencies’ (Kao & Hockham 1966). Kao went on to win the 2009 Nobel Prize in Physics for ‘groundbreaking achievements concerning the transmission of light in fibers for optical communication’. Peter was quick to apply his knowledge of fundamental electromagnetics and waveguide theory to optical waveguides, and started his research on this topic in 1970. He discovered important similarities in the electromagnetic behaviour of optical waveguides, comprising concentric dielectric cylinders of slightly different refractive index, and corrugated circular waveguide feeds for microwave antennas (20) (figure 4). He had shown that, subject to approximations, which were justified in many applications, the eigenvalue equations for the two structures had the same form. In the same year, he published a paper that determined the excitation and propagation characteristics of the lowest-order modes of a glass-fibre waveguide, without recourse to approximations concerning the core or cladding radii. He also studied how a lossy coating to the exterior surface of the fibre can be used to suppress higher modes while having negligible influence...
on the attenuation of the dominant mode (21). These findings would turn out to be important contributions in understanding the propagation of light in commercial optical fibres.

In 1975, with the explosion in literature associated with the development of optical fibre waveguides evident from the appearance of many hundreds of references on the subject within a few years, he subsequently edited a book for the Institution of Electrical Engineers (27) on *Optical fibre waveguides*, and later wrote a review (28) in which he stated ‘the use of optical fibers for telecommunication purposes has grown from a position of speculative research into one of commercial reality. This growth has been largely due to the efforts of those engaged both in fiber manufacture and in the development of light sources. In a fast-moving field, the task is especially difficult as a subtle change in technology can rapidly shift the emphasis that should be given to a specific topic’. Peter’s research on optical fibre waveguides continued until 1980, by which time he had published two more monographs: *Transmission characteristics of graded-index fibers* (31) and *Progress in optical communication* (32).

**Microwave antennas**

One of Peter’s greatest achievements was in his renowned antenna research. His first antenna paper was published in 1967, around the time he moved from Leeds to Queen Mary College. In his paper on leaky wave antennas (16), which built upon the momentum of his waveguide research, Peter conducted a modal analysis in leaky waveguide. The radiation pattern of such antennas contains one main lobe for each mode of propagation, and he studied the design of a double-beam antenna in some detail. First, he gave consideration to a slotted double-ridge waveguide. It was shown both theoretically and experimentally that the structure can be designed so that pairs of higher-order modes cause radiation of nearly independent beams at angles that are closely spaced. When $H_{02}$ and $H_{03}$ modes are used for this purpose, the structure has the disadvantage of also supporting the $H_{01}$ mode and a slot mode at the operating frequency. Peter predicted that these undesired modes could be eliminated if an inductive, rather than capacitive, form of coupling is used between the constituent waveguides and if the radiating waveguide wall also has an inductive reactance. He realized the necessary inductive reactance by means of circular-cross-section coupling holes spaced periodically along the waveguide.

This work laid down the foundation for his future research on corrugated horns (figure 5), where purposely designed corrugations could be made to suppress high-order modes and avoid the spill-over in horn antenna radiation. Peter gained fame for his study of corrugated horns, in which subject he remained regularly active up to his retirement in 2004. In his seminal paper, ‘Theoretical analysis of cylindrical hybrid modes in a corrugated horn’ (17), he and co-worker Kumar Saha studied the propagation behaviour of a corrugated cylinder as hybrid-mode feeds for large reflector antennas. In the same year, Peter developed an approximate analysis of fields in a corrugated horn using spherical hybrid modes. He also developed a modal-expansion technique and applied the Kirchhoff–Huygen method, which can be used to determine the radiation pattern of a wide-flare-angle scalar horn. He proved that both approaches led to similar results, which agreed well with experimental results. His paper on corrugated antenna feeds has received many citations and still remains very popular among antenna researchers (22).

Peter also worked on the lens antenna, studying the ‘radiation pattern of a lens-corrected conical scalar horn’ (18). In this work, he derived an expression for the radiation pattern of a
Figure 4. Two figures from Peter demonstrating the similarities between optical waveguide and corrugated feed. (From (20), with permission from the Institution of Engineering and Technology.)
lens-corrected conical scalar horn; computed radiation patterns were presented for scalar-horn feeds containing planoconvex and meniscus lenses in their apertures. This work, together with that on corrugated horn antennas, has regained popularity recently, when researchers have applied various metamaterials and transformation optics (the concept pioneered by Professor Sir John Pendry (FRS 1984) for the ‘invisibility cloak’) to miniaturize original designs in looking for low-cost, lightweight antenna solutions. The lens-corrected horn configuration has continued to be widely used in radio astronomy receivers at short wavelengths, for example by Claude et al. (2005).
Peter’s second major contribution to antenna engineering was his pioneering work on reflector antennas, started in 1969. He and his group developed a technique for raising the efficiency of spherical-reflector antennas embodying the Gregorian method of phase correction (19). The method was based on the Galindo–Williams modified Cassegrain antenna. An additional sub-reflector was introduced between the Gregorian corrector and the spherical reflector in order to achieve uniformly distributed electric and magnetic fields over the main reflector aperture, with a theoretical efficiency of 93% predicted in the design. In 1974, Peter was invited to give a review on microwave reflector antennas at the European Microwave Conference. In 1977, he co-authored a paper with Dr Geoff Poulton (formerly of the Commonwealth Scientific and Industrial Research Organisation) for the Proceedings of the IEEE journal on ‘High-efficiency microwave reflector antennas’ (29).

Despite being wideband and highly efficient, the reflector antenna is limited by a lack of dynamic beam shaping and steering. In 1984, Peter and his group published two methods for the design of reflector antennas to generate shaped beams. In the first method, the aperture field was first reconstructed from the desired far-field and then synthesized using geometric optics. In the second method, the far-field was synthesized directly using a physical optics prediction program operating within an optimization search routine.

The use of shaping to get improved aperture efficiency in reflector antennas was developed widely and found many applications in demanding satellite, defence and space communications, and recently in the Square Kilometre Array (SKA), an international project addressing a wide range of questions on general relativity, dark matter and dark energy, the epoch of re-ionization, cosmic magnetism and search for extraterrestrial life. Many of Peter’s works on reflector antennas and corrugated horns, including at millimetre wavelength as early as in 1972, have direct relevance to radio-telescopes, and some of his techniques contributed to the development of the Arecibo Telescope, located in Puerto Rico.

After his early work in the 1970s, synthesizing antenna patterns for reflector antennas became the focus of Peter’s research, and his work on reflector antennas continued until the 1990s. Exemplar studies included ‘Optimum shaping of reflector antennas for specified radiation patterns’ (35) and ‘The performance of a prototype reconfigurable mesh reflector for spacecraft antenna applications’ (36). The latter paper won Peter and his co-workers the European Microwave Prize (figure 6). They came up with an ingenious idea where the reflector antenna pattern can be reconfigured under motor control. In a spacecraft application it would be possible to prescribe coverage, synthesize the corresponding rigid reflector surface, determine the control string lengths to ensure the best fit, facilitate drive through telemetry, and control motors to achieve the desired pattern. However, considerable work remained to be done before a flight model could be built, and many fundamental problems of both an electrical and mechanical nature had to be solved. Nevertheless, the idea was later adopted by the European Space Agency using elastomer dielectrics and shape-memory polymers, which are polymeric smart materials for shaping reflector surfaces. Such techniques have since been widely used by manufacturers for CubeSat applications. His innovative work (38–40) had laid down significant foundations for this antenna technology.

Computer modelling and electromagnetic simulation
Computer modelling and simulation became increasingly important to the study of electromagnetics during the 1960s. There were several reasons for this growing importance: first, mathematical modelling has been shown to be an effective tool for the investigation of
complex electromagnetic phenomena; second, the hardware configuration advances, such as memory, disk capacity and central processing unit (CPU) speed, in computer technology had made it feasible to apply the computational modelling paradigm to complex electromagnetic systems. Peter was one of the pioneers in the UK who developed several novel approaches in computational electromagnetics and applied them to solve problems in waveguide, antennas and wave propagation in complex media. As early as 1959 he had developed a perturbation method for the analysis of circular waveguides containing ferrites (2). He applied the modal matching technique to the analysis of a discontinuity in a planar surface waveguide in 1972 (24).

In the early days of research it was difficult to predict the radiation pattern from an antenna or scatterer when it was several wavelengths in size. Geometrical optics were insufficient, and Maxwell’s equations were difficult to solve because their solution may occupy a large region in phase space. In a numerical analysis, Peter and his co-workers developed a finite set of basis functions that defined a limited region in phase space and developed an optimization analysis that could accommodate a wide variety of bases. They attempted to match solution effort to a given accuracy in the scattered pattern of electrically large antennas (37).
The Finite-Difference Time-Domain (FDTD) method used by Peter is a direct solution to Maxwell’s time-dependent curl equations proposed by Yee (1966). It uses a simple central-difference approximation to evaluate the space and time derivatives. The FDTD scheme is a time stepping procedure with inputs that are time-sampled analogue signals. The region being modelled is represented by two interleaved grids of discrete points. One grid contains the points at which the magnetic field is evaluated, which can be called $H$ nodes, and the second grid contains the points at which the electric field is evaluated (or $E$ nodes). By alternately calculating the electric and magnetic fields at each time step, the propagation of the fields throughout the grid is simulated, and this time stepping continues until a steady-state solution or desired response is obtained. At each time step, the equations used to update the field components are fully explicit; there is no requirement for a system of linear equations to be solved. In 1998, under a project supported by the European Space Agency, Peter and his co-workers applied the method to the analysis of an annular slot antenna with all the auxiliary elements (feed/bias lines, air bridges) attached, the intermediate frequency filter and the model of a sub-millimetre-W-band (75–110 GHz) Schottky diode, which had opened up applications of FDTD to model active microwave circuits and antennas (42).

Despite his major contributions to fundamental studies of wave physics and radiation problems, Peter’s work was always very practical and demonstrated long-lasting impact to industry and society. For example, in 1971 he developed an approximate theory accounting for the scattering of focused electromagnetic waves by a turbulent rocket-exhaust jet (23). The predicted noise spectrum was found to be in good agreement with experimental results obtained at 9 and 14 GHz, and he recognized that the transverse-beam configuration was rather insensitive to variations in certain jet parameters, such as the turbulence scale.
General contributions

Peter served as the chief advisor to the Defence Scientific Advisory Council (DSAC). Much of his work had been applied to the UK defence industry; for example, in 1977 his team developed a system for the detection of non-metallic buried objects by microwave means (30). It utilized a frequency-modulated continuous-wave radar operating in the range 2–4 GHz and incorporated a forward-looking focused beam antenna. In the 1980s, he applied a multimode corrugated waveguide feed for monopulse radars and contributed to the study of novel radome design. A substantial amount of his work was related to satellite and space communications; for example, he had a long-term collaboration with the European Space Agency in the development of satellites and spacecraft for scientific Earth observation and communications missions.

Peter’s contributions to scientific and engineering studies was very broad. As well as the contributions discussed in the previous section, he was also active in developing antenna measurement techniques. The antenna laboratory at Queen Mary College is regarded as one of the best measurement facilities worldwide. Over the years, he and his colleagues developed several novel antenna measurement techniques (25, 33). He also contributed to the study of millimetre-waves, a frequency band proposed for 5G mobile communications (26). Despite his retirement in 1998, after he had completed his last Engineering and Physical Sciences Research Council-funded research project, he remained very active in the community.
Professor David Rhodes FRS CBE, another Leeds microwave graduate, invited Peter to consult for Filtronic plc, which he had founded and currently chaired. Peter initially served as a board member, contributing his advice to the development of microwave devices and systems for wireless communications, and subsequently chaired the company’s Technology Advisory Board. This was a role he greatly enjoyed, working with engineers from around the world and considering new concepts and technologies.

In 2015 he was awarded the Sir Frank Whittle Gold Medal, one of the Royal Academy of Engineering’s highest accolades, for his influential achievements spanning more than half a century (figure 7).

Peter was very productive in his academic publications. In addition to his impressive record of journal paper publications, he also contributed to book reviews for Nature. He published many books, including Corrugated horns for microwave antennas in 1984 (34) and Microwave horns and feeds in 1994 (41); the latter has been cited for more than 800 times. He was an author of the article ‘High performance compact corrugated horn’ published in 2004, when he was aged 72 (43), and ‘Forty years of European microwaves: what about the future?’ published in 2010 (44).

Peter founded the internationally acclaimed journal Electronics Letters and served as editor-in-chief for more than 40 years, together with Sir Eric Ash (FRS 1977) (figure 8). He initiated the International Conference on Antennas and Propagation, which is now the European Conference on Antennas and Propagation, the flagship conference for European and international antenna researchers.

Aside from being an exceptional scientist and engineer, he was a great mentor to many of his students and particularly understood the importance of diversity and the advancement of women in sciences. His life-long contribution to initiating and spreading microwave research in the UK and beyond cannot be overestimated. He is remembered affectionately by those he worked with, and often mentored, from the global microwave community. He had a special spark, enthusiasm and vitality that will be missed by all who knew him.

AWARDS AND COMMITTEE SERVICE

Awards

| Year | Award Name                                      |
|------|------------------------------------------------|
| 1960, 1961, 1962 | Electronic Division Premiums (IEE) |
| 1964 | Coopers Hill Memorial Prize (IEE) |
| 1974 | Marconi Premium (IEE) |
| 1989 | J. J. Thompson Medal (IEE) |
| 1989 | Measurement Prize (IEE) |
| 1989 | European Microwave Prize |
| 1992 | Oliver Lodge Premium (IEE) |
| 2000 | Millennium Medal (IEEE) |
| 2002 | Distinguished Achievement Award (IEEE) |
| 2015 | Sir Frank Whittle Gold Medal (RAEng) |

Fellowships

| Year | Fellow Name |
|------|-------------|
| 1964 | Fellow, IoP |
| 1968 | Fellow, IEE |
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1968 Fellow, IEEE
1969 Fellow, CGI
1983 Fellow, RAEng
1990 Fellow, Royal Society of London
1992 Honorary Fellow, IEE
1998 Honorary Life Fellow, IEEE
1999 Honorary Fellow, Queen Mary University of London

Committee memberships outside his main employment

Institution of Electrical Engineers: chair of IEE Electronics Division 1978–1979; vice-president 1979; chair of Conferences International Conference on Ferromagnetics and Plasmas 1964; chair of International Conference on Antennas and Propagation 1978; chair of European Microwave Conference 1979; chair of Military Microwaves 1988; chair of Microwaves & RF 1994; chair of Microwaves Vacation School 1964, 1966, 1968.

International Union of Radio Science (URSI): treasurer 1993–1999.

Royal Society: member of Finance & General Purposes Committee 1995–1998.

Ministry of Defence: Propagation Aerials and Waveguides Committee of ERC 1977–1980; DSAC Sensors Technology Board 1993–1996; Defence Scientific Advisory Council 1996–2000.

Filtronic plc: chair of Technology Advisory Board 1997–2005.

UK government committees: Electronics Research Council 1977–1980; Systems Technology Board and committees 1981–1993; DTI Communications Committee of Foresight (Phase I); Space Technology Advisory Board of BNSC 1996–2000; Central Technical Advisory Council of European Space Agency 1994–2003.

Editorial positions

1964–2010 Electronics Letters
1974 IEE Electromagnetic Wave Series
1995 Journal of Defence Science

Consultancies

1964–1974 Marconi Instruments
1964–1974 Microwave Associates
1971–1992 Andrew Antennas
1974–1998 ERA Technology
1974–1998 European Space Agency
1995–2005 Filtronic plc

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The frontispiece photograph was taken in 1990 by A. C. Cooper and is © the Royal Society. All other photographs are from the Clarricoats family’s collection, unless otherwise credited.


**Author Profiles**

**Sir Christopher Snowden FRS FREng**

Professor Sir Christopher Snowden is an engineer with wide experience of the international microwave and semiconductor industry. He was president and vice-chancellor of the University of Southampton (2015–2019) and previously the University of Surrey (2005–2015). He was knighted by the Queen in 2012 for services to engineering and higher education. He obtained his PhD from the University of Leeds, working in the microwave research group originally established by Professor Claricoats. Prior to his appointment at Surrey in 2005, Sir Christopher was joint chief executive officer of Filtronic plc, where Professor Claricoats chaired the Technology Advisory Board. He is currently chair of the ERA Foundation and was chair of the international judging panel for the Queen Elizabeth Prize for Engineering from 2016 to 2021 and a member of the UK Prime Minister’s Advisory Council for Science and Technology from 2011 to 2016.

![Sir Christopher Snowden](image)

**Yang Hao FREng**

Professor Yang Hao received his PhD from the Centre for Communications Research at the University of Bristol, UK, in 1998. From 1998 to 2000, he was a postdoctoral research fellow at the School of Electrical and Electronic Engineering, University of Birmingham, UK. In May 2000, he joined the Antenna and Electromagnetics Group, Queen Mary University of London, initially as a lecturer and was promoted to reader in 2005 and to professor in 2007. Here he worked with Professor Claricoats on antenna research. He is now dean for research at the Faculty of Science and Engineering, Queen Mary University of London. Over the years, he has developed several fully-integrated antenna solutions based on novel artificial materials to reduce mutual RF interference, weight, cost and system complexity for security, aerospace and healthcare.

![Yang Hao](image)

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(2) 1959 A perturbation method for circular waveguides containing ferrites. *Proc. IEE B Electron. Comm. Eng.* 106, 335–340. (doi:10.1049/pi-b-2.1959.0267)

(3) The gain of travelling-wave ferromagnetic amplifiers. *Proc. IEE C Monogr.* 106, 165–173. (doi:10.1049/pi-c.1959.0030)

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(6) 1963 (With W. E. Courtney) Absorption phenomena in parallel-pump experiments. *J. Appl. Phys.* 34, 1279–1280. (doi:10.1063/1.1729471)

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(14) 1965 (With W. E. Willshaw) Microwave behaviour of ferromagnetics and plasmas. *Electron. Power* 11, 428–429. (doi:10.1049/ep.1965.0329)

(15) 1966 (With J. McStay) Microwave power measurement using the parallel-pump instability in yttrium–iron garnet. *Electron. Lett.* 2, 56–57. (doi:10.1049/el:19660043)

(16) 1967 (With P. E. Green) Waveguide structures for double-beam leaky-wave antennas. *Proc. IEE* 114, 604–610. (doi:10.1049/piee.1967.0122)

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