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Arthur Melville Thompson 1917–2009

Barry D. Inglis

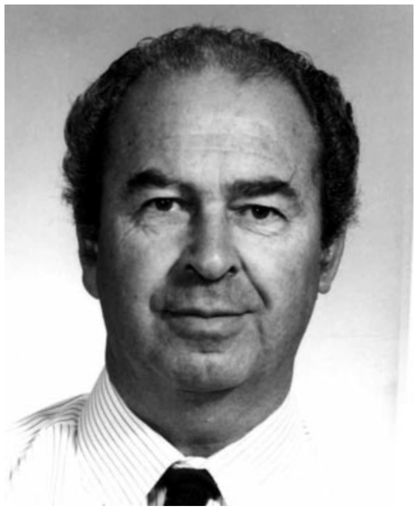
National Measurement Institute, PO Box 218, Lindfield, NSW 2070, Australia.
Email: barry.inglis@measurement.gov.au

Arthur Melville ('Mel') Thompson graduated from the University of Adelaide in 1938 with First Class Honours in Physics. After graduation he joined Australia's Council for Scientific and Industrial Research as one of the 'founding fathers' of the National Standards Laboratory and embarked on a life-time career in metrology. His work in precision electrical measurement, ratio-arms transformer bridges and techniques for defining and measuring small capacitances is internationally renowned. He conceived the design of a calculable-capacitor, the Thompson-Lampard capacitor, which led to a new theorem in electrostatics and provided the basis for an absolute determination of the unit of resistance with an increase in accuracy of an order of magnitude. Beyond the calculable capacitor his work had a major impact in electrical impedance measurement in general and on other fields of metrology such as dilatometry and thermometry. Mel Thompson was an inspirational leader and his work facilitated the development of many scientific careers.

Arthur Melville ('Mel') Thompson was born in Adelaide on 4 January 1917, the third of five children, to William Harold Thompson, a draper, and his wife Alice, née Reedman. Mel died in Sydney on 8 August 2009.

Mel received his primary school education at a State school in North Adelaide and his secondary school education at Adelaide High School. In 1934 he received a Government Bursary to attend the University of Adelaide. It was during these early years that Mel met Joan Worthley, the sister of a school and university colleague, later to become his wife. Mel was always a very practical person, skilled in the use of hand tools and a very keen student. He was also a keen sportsman in his early years, playing representative baseball for the University.

At the University of Adelaide Mel studied Science, majoring in mathematics and physics. He graduated with a BSc in 1936, achieving a top credit in each of his majors, and went on to complete an Honours degree, graduating with First Class Honours in Physics in 1938. Following graduation he worked for a year as a Demonstrator in the Physics Department at the University on a grant from the Council for Scientific and Industrial Research (CSIR, later CSIRO). During this time he was also involved in the installation of an experimental X-ray tube, X-ray diffraction equipment and a Finch X-ray diffraction camera.



In 1938 the Australian Government decided to create a National Standards Laboratory within the CSIR to be responsible for the establishment and maintenance of national standards of measurement and associated research in support of testing and uniform measurement in Australian secondary industry. The Laboratory was to comprise three Sections (Metrology, Physics and Electrotechnology) and N. A. Esserman, G. H. Briggs and D. M. Myers were appointed their respective Officers-in-Charge. The three Officers-in-Charge were sent almost immediately to the National Physical Laboratory (NPL)

at Teddington in the UK to gain experience in standards and precision measurement. Following the initial appointments, three new graduates, P. M. Gilet, A. F. A. Harper and W. K. Clothier, were appointed on CSIR studentships and sent to NPL for eighteen months and then to the National Bureau of Standards (NBS) in Washington, USA for six months for training. This was followed by the offer of a further three CSIR studentships for new graduates to receive similar training. Whilst still at the University of Adelaide, Thompson was awarded one of these studentships and in 1940 was sent to the NPL and to the NBS for training, particularly in electrical measurements. During his time at NPL and NBS he also had the opportunity to visit several industrial laboratories. Mel returned to Australia in 1941 and was appointed an Assistant Research Officer in the Electrotechnology Section of the new National Standards Laboratory (NSL) located in the grounds of the University of Sydney at Chippendale. In this role he was one of nine 'founding research fathers' charged with establishing the National Standards Laboratory in Australia.

Mel arrived back in Sydney per the SS *Mariposa* on 22 April 1941 and commenced duties at NSL on the same day. He then took a period of one week's leave from 24 April 1941, during which time he returned to Adelaide and on 1 May 1941 at Glenelg he married Joan Worthley, his wife and partner of 68 years.

The War Years

There was much for Mel to do after arriving at NSL, not only to help establish the Laboratory as a working concern by installing and commissioning new equipment, but also to support the war effort. This meant working with industry and the armed forces to satisfy their measurement and calibration needs and to support investigations on behalf of the armed forces. Within Electrotechnology, responsibilities for leadership in these functions were distributed between three key research staff, one to support investigations on behalf of the Army, one to support investigations on behalf of the Navy and the third to support normal Standards work and miscellaneous investigations. Mel Thompson was assigned responsibility for investigations on behalf of the Navy, the work involved relating mainly to matters associated with magnetic mines and the magnetic treatment ('degaussing') of ships. His performance was highly regarded and in June 1944 he was promoted to Research Officer.

Standards Research

In the late 1940s and the 1950s the range of services offered by NSL expanded rapidly to support the demands of Australia's growing manufacturing industry. In recognition of the importance of testing and the need for accurate measurement the National Association of Testing Authorities, the first comprehensive laboratory accreditation service in the world, was established with the support and encouragement of CSIR and particularly NSL. A greater range and accuracy of national measurement standards was required, and new young and talented research staff were recruited and given a great deal of freedom and responsibility to improve existing measurement standards and to develop new ones.

Mel Thompson was charged with leading a group responsible for basic electrical standards, for electrical impedance at audio frequencies and for time and frequency measurement. However, there was a great spirit of co-operation and enthusiasm within NSL and nominal responsibilities were no barrier to this.

A major metrological challenge in the area of electrical measurement at that time was the absolute determination of units and, in particular, the absolute determination of the unit of resistance—the ohm. Traditionally, at the major national laboratories such as NPL and NBS, the absolute realisation of the 'ohm' had been achieved through the use of a calculable inductor and a known frequency to determine reactance and then using bridge techniques to transfer this to resistance. However, accurate calculation of inductance is extremely difficult, requiring the accurate determination of the geometry of a coil of wire, with corrections for finite wire diameter and wire spacing. The highest accuracy that had been achieved was in the order of 2×10^{-6}. People had considered using capacitance instead of inductance but the construction of a calculable capacitor with sufficient accuracy and the development of the necessary bridges and bridge techniques to transfer to resistance had always

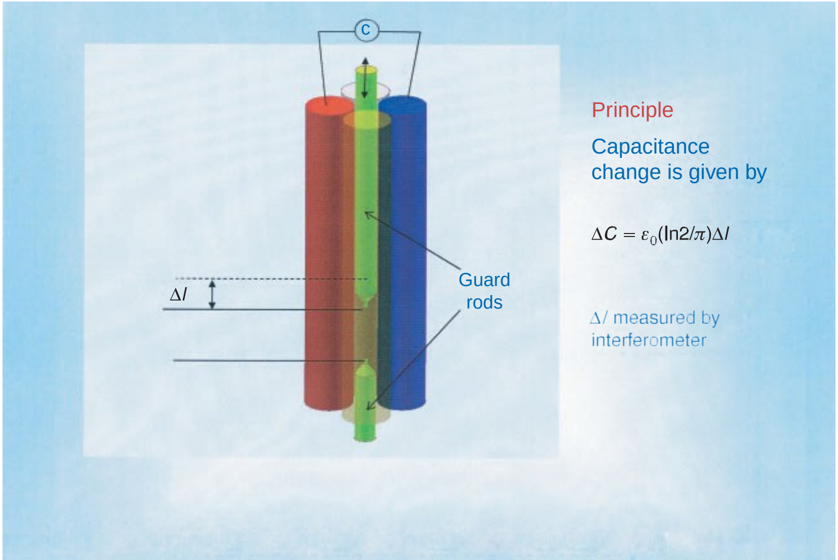


Figure 1. Schematic of Calculable Capacitor, one electrode removed.

been seen as more difficult than the inductance route.

Mel Thompson in collaboration with Keith Clothier, his senior colleague responsible for alternating-current measurement at power frequencies and a brilliant experimentalist, determined to re-visit the possibility of an absolute determination based on capacitance. An absolute 'ohm' determination became a major project for the Electrotechnology Section of NSL. Clothier with a small team set about constructing parallel-plate capacitors with very accurately defined electrode geometry using thin-film evaporation techniques, while Thompson and his team focused primarily on the development of new bridge techniques for the accurate definition and measurement of very small capacitance. There was much interaction and collaboration between Thompson and Clothier and Thompson was well aware of the difficulties confronting Clothier and the inherent limitations of a parallel-plate design. He considered other possible capacitor designs that might inherently have the potential for greater accuracy and this led him to a capacitor design involving four parallel cylinders symmetrically spaced around a common axis. He investigated this design experimentally and concluded that the capacitance between diagonally opposite pairs of cylinders, the cross-capacitance, was independent of the diameter of the cylinders and further, that the sum of the cross-capacitances was constant and independent of spacing between the diagonal pairs as long as symmetry was maintained. This was a remarkable discovery and had the potential to reduce the calculation of capacitance to the accurate measurement of a single dimension, the separation between the ends of two guard rods inserted along the main axis of symmetry between the cylinders (see Fig. 1), instead of the accurate measurement of three dimensions required with a parallel-plate capacitor.

Having established the concept experimentally (10) the next challenge was to calculate the capacitance and to put the concept on a sound theoretical basis. Here Thompson called on the expertise of another colleague, Doug Lampard (Redman 1996), to investigate the concept further. Lampard was an outstanding mathematician and after carrying out a preliminary analysis he concluded that the concept extended far beyond circular cylinders and indeed was the basis of a general mathematical theorem (6). Lampard went on to generalize the theorem formally with full mathematical rigour (Lampard 1957).

Following Thompson's discovery, Clothier ceased work on his parallel-plate designs and concentrated fully on the design and construction of a cross-capacitor. Apart from the challenges of producing a design that would achieve the necessary inherent stability with fabrication tolerances better than anything previously achieved, Clothier, in consultation with C. F. Bruce, the leader of the Optics Group at NSL at that time, also designed and fabricated the optical interferometric measuring system incorporated into the capacitor design to measure the displacement of the guard electrode. Clothier's expertise in mechanical design and fabrication, together with the machining and fabrication skills of his assistant H. Bairnsfather, were critical to the success of the project. The NSL Cross-Capacitor (Clothier 1965) was commissioned in 1964 and advanced the accuracy of capacitance measurement by nearly two orders of magnitude, achieving an accuracy of better than 1×10^{-7}. The NSL capacitor continues as the longest continuous-running calculable capacitor in the world.

One difficulty with the cross-capacitor is its inherently very low value of capacitance. The NSL capacitor had a maximum useable value of ~ 0.25 pF and to achieve an accuracy of 1×10^{-7} required the measurement of capacitance to an accuracy in the order of 1×10^{-8} pF. This demanded the development of very special bridges and bridge techniques, together with the design of sophisticated and stable ancillary capacitors to enable capacitance build-up and ultimately the transfer to resistance. Thompson's work in developing the necessary bridges and bridge techniques for the measurement of small capacitances (9, 14) was an outstanding contribution to measurement science and indeed provided the basis for the absolute realisation of the 'ohm'. Based on the NSL Calculable Capacitor, the ohm was realized (15) in 1966 with an estimated uncertainty of 2×10^{-7}. The accuracy of the determination at that time was limited to 7×10^{-7} because of the uncertainty in the speed of light, this being necessarily invoked to relate electrostatic units to the electromagnetic units in terms of which the ohm is defined. However, in 1983, following a redefinition of the metre in terms of the speed of light, this limitation was eliminated.

There was considerable interest by national standards laboratories around the world in the announcement of Thompson's discovery and its potential. Thompson visited the NBS in the USA in late 1956 and reported on the work at NSL. In the following year Dr Forest K. Harris, who was in charge of the Electricity Section at NBS and a leading expert in electrical metrology, visited NSL and in the same year the Director of NBS (Dr Allen V. Astin) also visited to participate in a review of NSL. A key member of Thompson's group was invited to work at NBS to assist in the construction of the NBS calculable capacitor and associated ancillary equipment in 1957 and this was followed by the visit of a key NBS researcher (Robert D. Cutkosky) to work at NSL in 1960.

Thompson and Lampard were honoured as joint recipients of the Instrument Society of America's Albert F. Sperry Medal in 1965 'in recognition of their contributions to the improvement of fundamental international standards of capacitance and resistance resulting from their development of a new theorem in electrostatics, and its application to the design of a calculable standard of capacitance'. In 1967 Thompson was awarded an honorary degree of Doktor-Ingenieur by the Technical University of Hanover 'in recognition of his contributions to the field of electrical measurements'. He also received the 1977 Morris E. Leeds Award of the Institute of Electrical and Electronic Engineers (IEEE) for 'outstanding advances in absolute electrical measurements, particularly capacitance and resistance'.

Recognition for the invention of the calculable capacitor is justifiably shared by Thompson and Lampard. However, the concept and initial experimental verification of the hypothesis were due to Thompson and it is fitting that the capacitor is known as the Thompson–Lampard capacitor. This is how it appeared in the first publication on the work (6), with the full support of F. J. Lehany, the Chief of what was by then a separate Division of Electrotechnology. The generalization and mathematical development of the theorem was clearly due to Lampard.

In many ways the work of Mel Thompson on precise capacitance measurement and the Calculable Capacitor put Australian metrology and, in particular, the NSL on the international map. J. F. H. Wright in his book *Measurement in Australia 1938–1988* (Wright 1988) in this regard quotes from a talk given by Mr Walter Williams, US Under-Secretary of Commerce, in December 1957 (Press Release 1957). Speaking in Boston soon after the launching of the

Soviet Sputnik, Mr Williams said: 'There are those who have been disturbed by the recent Russian successes in the satellite field. Certainly no thoughtful person would pooh-pooh these accomplishments. By no means. Yet, it stands to reason, doesn't it that a nation that concentrates its efforts and resources in a specific field is most likely to be the first in that field. Only recently I was advised that Australia – little Australia with only 7 or 8 million population – leads all other nations of the world in one specific branch of scientific research. This relates to precise and absolute measure of electrical capacitance'. As Wright points out: 'Of course, Australia had not concentrated all of its resources in this one field, but in it the Laboratory had certainly achieved world leadership'.

The achievements of Mel Thompson associated with the determination of the ohm were major contributions to international metrology. However, more than this, the reputation that NSL earned as a result of his work was invaluable in later years as a basis for Statements of Equivalence agreements with other national laboratories. Statements of Equivalence signed with NPL and NBS during the 1980s, in particular, were used to advantage by Australian industry in winning defence 'off-sets' contracts against international competition, having the servicing of internationally registered aircraft in Australia accepted by the Federal Aviation Authority in the USA, and having testing in Australia recognized internationally.

Beyond the Calculable Capacitor

The number of publications authored by Thompson during his career rather belies his contribution to metrology more generally. He was never one to write three or four papers when one would suffice. In consequence many of his papers are quite dense and some of the appendices in his papers are worthy of a publication in their own right. The impact of his work is far-reaching and the following are a few examples of areas where his contribution had a major effect.

AC Bridges and Ratio Transformers

The transformer bridges and techniques developed by Thompson were a major advance in the measurement of capacitance and were rapidly adopted by leading National Measurement Institutes around the world (McGregor *et al.* 1958). They were also taken up by leading instrument manufacturers and led to the development of the highly successful and highly accurate commercial General Radio Precision Capacitance bridges GenRad Models1615-A and 1616. His work also had an impact on the development of commercial high-accuracy inductive voltage dividers.

Dilatometry

Dilatometers are used to determine thermal expansion properties of solids and in the early 1960s G. K. White (White 1961) described a high-sensitivity capacitance dilatometer based on a three-terminal capacitance construction and using ratio-arms bridge techniques developed by Thompson. The dilatometer had a sensitivity of a few parts in 10^8. This was a major innovation that revolutionized dilatometry and was adopted by many other workers in the field, as described by Cwenson (Cwenson 1998) and Ruffino (Ruffino 1998). These dilatometers led to the generation of a large quantity of accurate data that provided the basis for understanding basic properties of materials and advanced the understanding of solid-state physics.

Thermometry

During the 1970s, significant advances were made in the accuracy of temperature measurements through the use of resistance thermometry and in particular platinum resistance thermometry. This required the accurate definition and measurement of a temperature sensitive resistive element. Special bridge techniques to accurately measure changes in resistance were required, and again the transformer bridge and ratio-transformer techniques developed by Thompson and his co-workers in the impedance measurement work provided the basis (16).

Mentor and Leader

Mel Thompson was not a person to seek recognition but he played a major role within the NSL and its later guises as the CSIRO National Measurement Laboratory and CSIRO Division of Applied Physics. He was never Chief of Division but he was Acting Chief on many occasions, a role that he fulfilled with distinction in spite of his low tolerance for excessive bureaucratic and administrative matters. Indeed, his views on such matters were clearly in evidence in his advice to young scientists at his retirement function to 'keep your feet out of the bureaucratic bog!'.

As a scientist he collaborated with many fellow scientists in other disciplines and was always willing to provide advice and guidance. As a leader, he was responsible for overseeing the development of frequency standards, the development of a hydrogen maser and the early adoption and development of quantum standards. In these areas, as well as in many others, he facilitated the development of successful careers and the generation of large numbers of publications.

For a young scientist, a technical discussion with Mel Thompson could be rather daunting. He was not one to bear fools lightly and yet for someone willing to learn, with commitment, he was extraordinarily generous with his time and helpful in the extreme. NSL guarded the quality of its publications jealously and for a young scientist, in the electrical area, the biggest challenge in submitting a paper for publication was to have it passed by Mel Thompson. After that, journal referees were incidental.

Mel Thompson rose through the research scientist ranks of CSIRO to be appointed Chief Research Officer in 1962 and Chief Research Scientist 2 in 1971. After retiring in 1982 he continued his research for a further year as an Honorary Senior Research Fellow. He was a great mentor and an inspirational leader.

Epilogue

It is interesting to note recent renewed interest in the Calculable Capacitor, some fifty years after its discovery. In the interest of pursuing increased accuracy for the fundamental Planck Constant through the ratio of electronic charge to Planck Constant, the International Bureau for Weights and Measures (BIPM) entered into a co-operative agreement with Australia's National Measurement Institute (NMI)* to undertake a joint project to produce a calculable capacitor with an accuracy better than 1×10^{-8} and indeed possibly approaching 1×10^{-9}. Under the agree- ment the aim is to produce two capacitors, one to be maintained at BIPM and the other at NMI. NMI is responsible for the design of the capacitor and the fabrication of the precision cylindrical electrode bars. The bars are required to be round and uniform to within 50 nm over their length of 450 mm. BIPM is responsible for the fabrication of other critical components to NMI design. All ancillary electrical bridges, build-up capacitors and resistors are the responsibility of the individual institutes. The capacitors are now nearing completion. Since entering into the agreement with BIPM, NMI has also agreed to make design details available to the national institutes in China and Canada and to fabricate their bars. NMI is undertaking this work through the services of two post-retirement Fellows and former colleagues of Mel Thompson and Keith Clothier, Greig Small and John Fiander. This renewed interest in the calculable capacitor is further testimony to the significance of the Calculable Capacitor and of Thompson's work.

Mel had few hobbies outside his work but always enjoyed the use of his practical skills in home maintenance and continued to maintain an interest in baseball. He is survived by his wife Joan and his children Marcus and Haydn.

Honours and Awards

Mel Thompson was a foundation member of the Australian Institute of Physics in 1962, he was elected a Fellow of the Australian Institute of Physics in 1968 and a Fellow of the Australian Academy of Science in 1972. Other awards included:

1965 Instrument Society of America's Albert F Sperry Medal (with D. G. Lampard)
1968 Honorary degree of Doktor-Ingenieur conferred by the Technical University of Hanover
1977 IEEE Morris E Leeds Award
2003 Centenary of Federation Medal.

Acknowledgements

I should like to express my thanks and appreciation to Dr W. R. Blevin FAA and Mr G. W. Small for their helpful comments and suggestions in the preparation of this memoir and also to Haydn and Marcus Thompson for sharing with me a family perspective.

* The National Measurement Laboratory, the successor to NSL, separated from CSIRO in 2004 to join with the former Australian Government Analytical Laboratory and the former National Standards Commission to form a new National Measurement Institute with responsibility for all aspects of physical, chemical, and legal metrology and for all relevant standards.

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