FRANCIS RONALDS (1788–1873): THE FIRST ELECTRICAL ENGINEER?

This month's article takes a look at the many contributions of Francis Ronalds, a prolific inventor of electrical, mechanical, and meteorological devices.

HISTORY has remembered relatively little about Sir Francis Ronalds FRS (Fig. 1) beyond his early electrostatic telegraph. He was in fact a prolific inventor of electrical, mechanical, and meteorological devices. He also documented important theoretical insights in electrical science, generated valuable data sets, and helped to create a world-leading observatory and a large engineering institution. Little has been written either in the modern era about how these contributions were viewed by his peers and successors. At the bicentenary of his most noticed innovation, it is timely to dip into his life and portfolio of work and explore why he might be called the first electrical engineer.

Ronalds was born on February 21, 1788 at the family's cheesemonger business in the heart of the City of London, the second of 12 children and eldest son. He was apprenticed when he turned 14 and, at his father's death four years later, was running the business. It was a substantial enterprise with an annual turnover exceeding £150 000 and part ownership of at least a dozen ships that brought cheese and other commodities from the north of England and farther afield for sale in the capital [1].

But Ronalds preferred science to business. His specific hope was to apply science to create things of use—to be an engineer. Electrical science was of particular interest to him because he could see its potential to be of enormous value to mankind.

I. EARLY ELECTRICAL SCIENCE AND ENGINEERING (1810–1817)

When he came of age in 1809, Ronalds began using his inheritance to buy scientific equipment. The time was a decade after Alessandro Volta had invented his battery. Static electricity had been observed in nature for much longer, and also created using electrostatic generators to explore the effects it produced. There was not yet any consistent terminology to help explain the observations however, nor a clear understanding of how static electricity and the "galvanism" from Volta's battery might be related. Electricity was still very much a scientific curiosity [2], [3].

A. Electrical Insulation and Atmospheric Electricity Observation

Ronalds' earliest work to be found in the literature dates from this period; it was documented by his scientific mentor George Singer who gave lectures on electrical science in London. Singer announced an improved form of electrical insulation in early 1811 [4], although Ronalds referred to the invention as "*called* Singer's (originally mine)" [5]. It entailed enclosing an electrified wire in a narrow glass tube coated inside and out with sealing wax to minimize circulation of moist air. Both Singer [2] and Ronalds [6] used the approach in their straw and gold-leaf electrometers to isolate the charged element through the top of the case (Fig. 2) and the design continued to be used well into the 20th century [7].

The 18th century work of Giovanni Beccaria inspired Ronalds to study atmospheric electricity. Singer described Ronalds' experimental setup, which used a long exploring wire insulated in "his" way, in his 1814 text *Elements of Electricity and Electro-Chemistry* [2]. Before long, Ronalds created a better form of insulation for this purpose, which he published the year Singer died—1817 [8]. To prevent condensation he now used a small lamp to heat the interior of a partially hollow glass pillar that supported the end of a conducting rod (Fig. 3) [9].

Ronalds developed several means of registering the atmospheric electricity observations in his absence. Singer mentioned in *Elements of Electricity and Electro-Chemistry* that Ronalds

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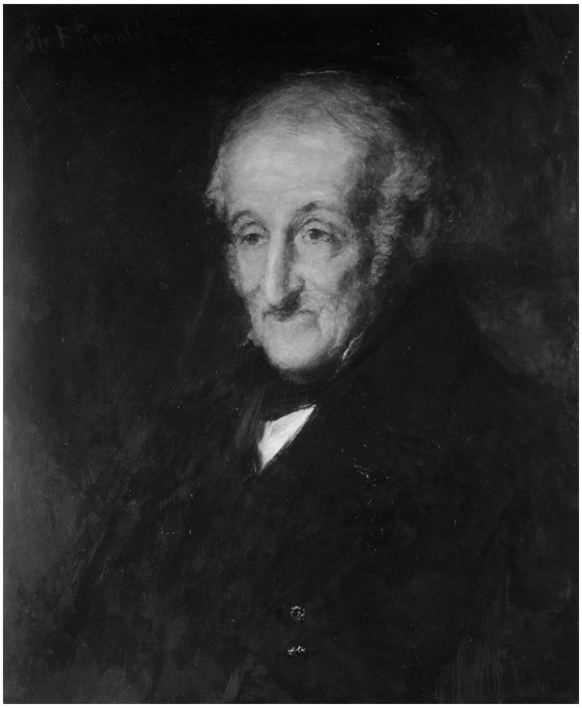

Fig. 1. ***Portrait of Ronalds at age 79, painted by his nephew Hugh Carter and held by the Institution of Engineering and Technology (IET).***

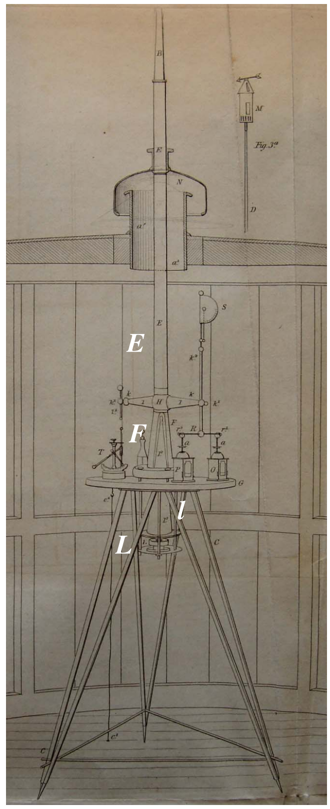

Fig. 3. ***Second form of insulated atmospheric electricity collector (from [9]). The long metal conductor E protruding through the roof is insulated by a trumpet-shaped glass support F, which is heated constantly inside by a small lamp L via a copper chimney I. Horizontal bars just above the insulation hold various electrometers. This 1850 model rests on one of Ronalds' tripod stands (mentioned below) and is retained intact at the Science Museum.***

deployed a series of electrometers, one of which was linked to the conductor at each chosen time through a clockwork mechanism [2]. He designed electrometers that retained their readings so that the variation through the night could be seen at one observation [1, pp. 132, 393–394].

He also built what he called an electrograph [10], [11], which comprised a circular plate driven by a timepiece (Fig. 4). A track formed in the resin coating of the plate that varied with the properties of the electricity it received from the atmospheric electricity conductor. Singer credited himself in his book with communicating the original idea to him. The machine was later adopted at the Royal Observatory in Greenwich [1, p. 434]. It is also cited in histories of today's xerography photocopier [12], and was described in detail in Tal Shaffner's

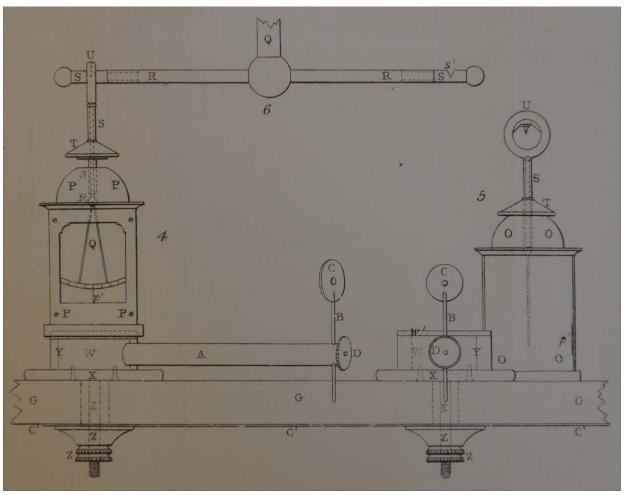

Fig. 2. ***Ronalds' 1844 version of Volta's straw electrometer (from [6]). Electricity passes to the straws Q within a glass tube coated with sealing wax, generally called "Singer's insulation." A brass lantern-shaped case with a glass plate front and rear avoids the visual distortion of the arced scale caused by the usual glass bottle and acts as a Faraday Cage (which Ronalds referred to as a "Franklin's Can"). Readings are made at a distance using a magnifying eye piece C to help reduce influences of the human body on the electricity. Examples survive in the Science Museum in London.***

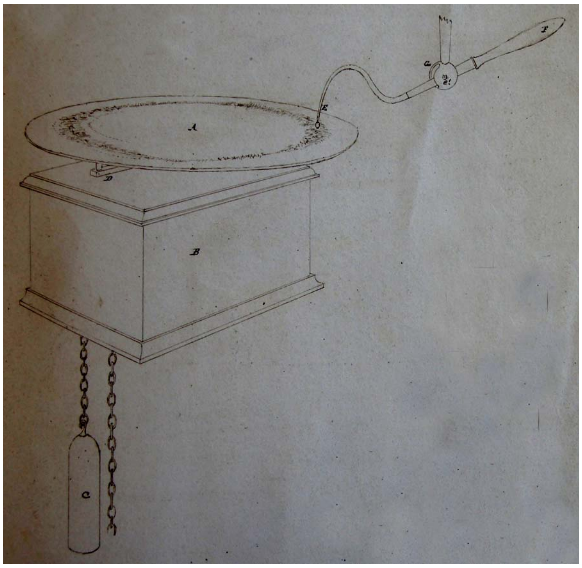

Fig. 4. ***Ronalds' electrograph (from [11]). A disk coated with resin revolves at the desired speed on a clockwork mechanism. Electricity from the conductor heats and softens the resin according to its sign and intensity. The track is highlighted by dusting with powder and an impression of the pattern may be made using moist paper.***

1859 *Telegraph Manual* because it was considered by some to be a step in the development of electric telegraphy [13]. Ronalds himself recorded that he conceived the idea of using electricity to transmit messages while working with the long exploring wire [5].

B. The Dry Pile and Delineation of Electromotive Force and Current

It was by now the period 1814–1816, and this was when much of Ronalds' electrical science and engineering was conducted. He had just been able to hand the family business over to his next oldest brother, and he also had a new mentor, Jean-André de Luc, who was Reader to Queen Charlotte in George III's court. A more supportive relationship developed with de Luc than Ronalds managed with Singer, and Ronalds later reminisced how much he enjoyed "the society and instructive correspondence of so warm hearted, justly celebrated, and truly amiable a man" [10].

De Luc, among others, had recently developed the dry pile (also called the electric column), which became a new focus for Ronalds. It differed from the Voltaic pile in that the disks of cardboard or paper separating the pairs of dissimilar metals were not soaked in brine [14].

Ronalds investigated the properties of the dry pile in two papers in the 1814 *Philosophical Magazine*. The first was republished nearly 30 years later in the *Annals of Electricity, Magnetism, and Chemistry* [15]. In the second, he used a gold-leaf electrometer to delineate two separate electrical effects he saw. The degree of divergence of the leaves was the "intensity." He also noted the inverse of the time taken to diverge, or the frequency of the divergence/collapse cycle as the leaves struck the earthing strips on the sides of the bottle, which he called "a measure of the quantity of electricity arriving at a certain intensity" [16]. By these definitions, "intensity" and "quantity" are akin to today's electromotive force and current. He found that quantity and intensity both increased with temperature. The corresponding relationship under changing humidity was more complex and thus the overall relationship between the two defined parameters was often nonlinear for a dry pile.

He had first made such observations on intensity and quantity with atmospheric electricity, and in so doing was monitoring both the potential gradient and air-earth currents in the global atmospheric electricity circuit [1, pp. 411–413], [8]. With atmospheric electricity, like the dry pile, the current is usually extremely small and the relationship between it and the potential difference depends on weather conditions.

Nearly 50 years later he wrote of his efforts: "I think that those exper^{ts} were the first in which the distinction between "*quantity*" & "*intensity*" was observed. (These terms have been ever since much employed)" [5]. The words certainly became standard in later decades and, prior to Ronalds' work, had already been used by several scientists in qualitative descriptions of electricity. His contribution was to enhance the understanding of the terms by separating the two phenomena, specifying their individual measurement using a common electrometer, and describing the relationship between them. Doing so also gave a tangible link between the familiar static electricity and the new galvanism.

Another new means of measuring current—the galvanometer—became available after Hans Ørsted's discovery in 1820 of a link between electricity and magnetism. Ronalds was then able to underline the previous point: "it is only when frequency is great that *galvanometers* manifest a current" [17]. Thirteen years after Ronalds published his original paper, Georg Ohm used a galvanometer to find his proportional relationship for a circuit [3]. It was not until the later decades of the 19th century that the parameters were formally teased apart, their physical bases defined, and standard units of measurement developed and adopted [18].

The observation of "quantity" helped Ronalds to develop an early (and accurate) appreciation of how the dry pile worked. He advised de Luc in 1815 of his belief that the electricity was associated with "decomposition"; "if certain conditions which allow of a change of state did not exist electricity could not be evolved" [19]. (The chemical reactions did not leave a visible trace because the current was so small.) De Luc disagreed, replying: "I still believe that no *change of State* is necessary... electromotion on the Electric-column... is only owing to the contact of Zinc and copper" [20]. Singer and Volta both held the same view as de Luc [2]. It was decades before the pile's mode of operation came to be accepted, with different groups favoring the so-named "chemical" or "contact" theories, respectively [14]. Ronalds did not participate actively in the debate.

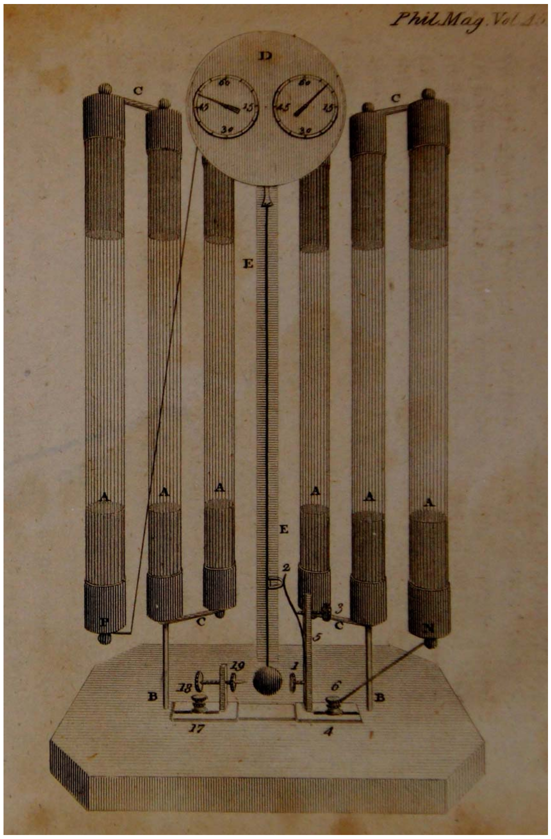

Fig. 5. ***First battery-operated clock (1815), from [21]. The opposite terminals of the vertical bank of dry piles A electrify the central pendulum E and discharge it each cycle through a small air gap at the bob. An increase in electricity is counteracted by larger amplitude of vibration and additional charge draw-off through the reduced air gap. The simple clock face D is at the top. Two of these dry piles are held at the Science Museum.***

C. Battery-Operated Clock

The major challenge in deploying dry piles in practice was the variability of their electrical properties with the weather. On the plus side, they have the remarkable feature of retaining their potential difference. At the Clarendon Laboratory at the University of Oxford, a bead suspended on a thread swings through attraction and repulsion between bells at the opposite terminals of two dry piles; made in 1840, the chime continues to work with the original power source [14].

In early 1815, Ronalds chose dry piles to maintain the steady periodicity of a pendulum connected with a ratchet and pawl, and a clock face, thereby creating and publishing the first electric clock (Fig. 5). He trialled various means of supplying the electricity: his triple aims were to regulate the exciting force delivered to the pendulum across a range of meteorological conditions, while minimizing mechanical effects that might jar the smooth oscillation, and enabling ready adjustment of the time keeping [21]–[23]. In later models, the piles were encased in cement to help shield them from the atmosphere. He recorded that these kept time "as *regularly at least* as any common clock" [10].

Dry pile clocks were also developed by Giuseppe Zamboni and his associates around this time in continental Europe, although they did not appear initially to incorporate meteorological or mechanical compensation [24], [25]. Several of the group's later models survive [26]. The first patent for an electric clock powered by current was awarded in 1840.

D. Electrostatic Generators

Electrostatic generators were another interest for Ronalds in this period. The friction machine was temperamental, particularly in humid conditions, but he found that its reliability could be enhanced by placing small spirit lamps under the metal collecting tubes (Fig. 6) [10]. His suggestion was published in numerous magazines and books and heat came to be applied routinely [1, p. 137].

Next, he built an influence machine that enabled a small charge to be amplified semiautomatically through induction (Fig. 7). It had three plates, two of which were fixed in position while the third swung between them [10]. Wires earthed the plates or provided electrical contact between them at just the right points in the cycle for charge to accumulate. The apparatus was described in the 1890 text *Electrical Influence Machines* as being "very convenient where a constant discharge of sparks for a considerable length of time was required" [27]. Ronalds had created it to power his telegraph.

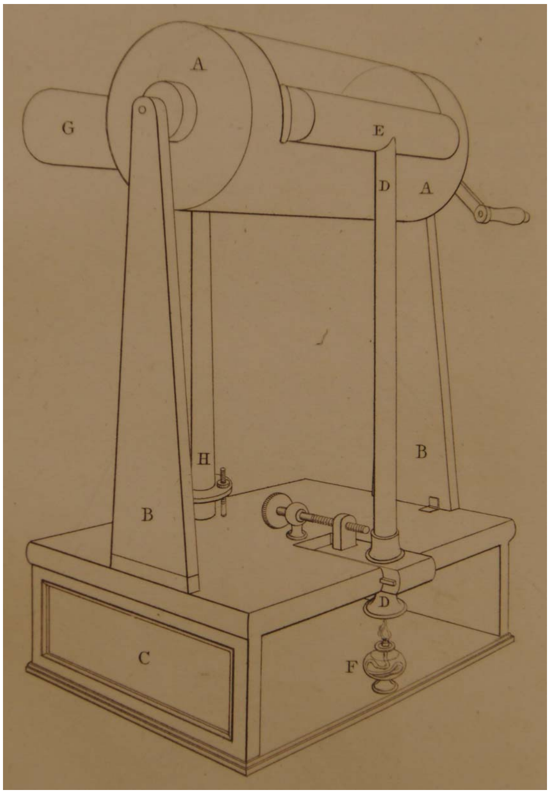

Fig. 6. ***Reliable friction electrostatic generator (c.1816) comprising a central glass cylinder and two metal tubes heated by lamps positioned below their supports (from [10]). A cushion rubs on the glass cylinder as it is rotated and electricity collects on the metal tubes.***

E. Telegraph

The telegraph came to fruition in summer 1816. By now Ronalds had a vision for a future electrical age and could see its first large-scale application:

> electricity, may actually be employed for a more practically useful purpose than the gratification of the philosopher's inquisitive research. . . it may be compelled to travel. . . many hundred miles beneath our feet. . . and. . . be productive of. . . much public and private benefit. . . why. . . add to the torments of absence those dilatory tormentors, pens, ink, paper, and posts? Let us have *electrical conversazione offices*, communicating with each other all over the kingdom. . . give me *materiel* enough, and I will electrify the world [10].

Accompanying his vision was a working system buried in a 160-m-long trench and connected to a suite of telegraphic equipment (Fig. 8). He used his first form of electrical insulation to protect the electrified wire, with sleeved expansion joints overlapping each pair of glass tubes [10], [28]. Messages were relayed using a revolving alphanumeric dial at each end. The scheme also incorporated a testing post where the wire rose out of the ground to help locate and repair subterranean line damage. The attention to practical detail prompted the later telegraph engineer Latimer Clark to say in 1875 that it "might almost serve for a description of a telegraphic system at the present day" [29].

Ronalds also considered what would be involved in creating a national telegraph network. He described cable protection, redundancy, and surveillance approaches to ensure durability and reliability and suggested suitable locations for testing posts [10]. The biggest potential problem for a buried telegraph in his view, and the one he addressed first in his risk management strategy, was signal retardation. He realized that the wire surrounded by moist soil with an intermediate insulator resembled a long Leyden jar that could generate induction and retain the charge [5], [10].

Notwithstanding his expansive vision, Ronalds was also very diffident, particularly in his younger years (which was perhaps the root of his difficulties with Singer). It was a big step for Ronalds to offer up his work for public scrutiny [30]. Given the potential importance of rapid communication he advised the Admiralty of his telegraph, where it was rejected on August 5, 1816 as being "wholly unnecessary" [31]. The previous year Singer had written in the *Philosophical Magazine* that his battery-operated clock was "an electrical toy" with "very little chance of becoming at all useful" (after suggesting that a friend of his had given Ronalds the idea) [32], [33]. With two inventions of which he was quite proud being dismissed, Ronalds decided "to bid a cordial adieu to Electricity" [10].

Commercialization of the telegraph began in the late 1830s, by William Cooke and Charles Wheatstone in Britain and in the United States by Samuel Morse. They were able to use current rather than static electricity because batteries had recently been developed that were much longer lasting and more reliable than the Voltaic pile [28]. They also capitalized on the numerous discoveries in electromagnetism that had been made in the intervening decades. In addition, they borrowed elements from Ronalds' work—Cooke's family, and Wheatstone himself, had both enjoyed operating his telegraph

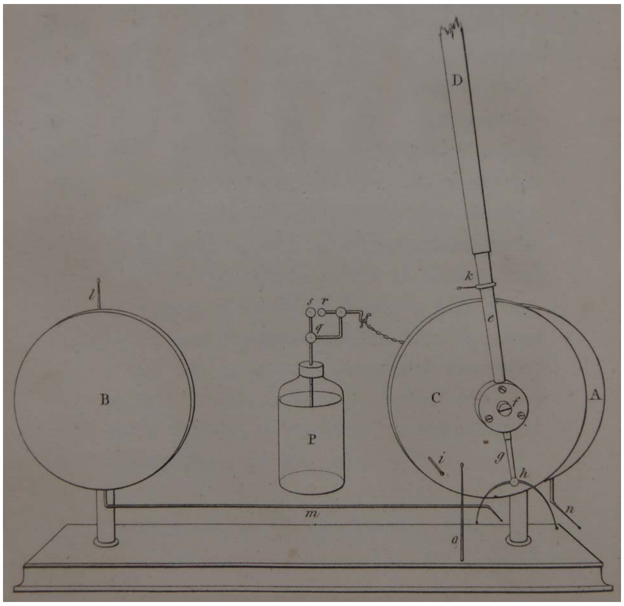

Fig. 7. *Influence electrostatic machine (1816) to generate electricity with minimal manual intervention (from [10]). Plates A and B are stationary and plate C oscillates back and forth between them, driven by clockwork or, at larger scale, a steam engine. Electrostatic induction across the plates causes the charge to almost double each cycle, enabled by earthing or electrical connection through various wires. The electricity is stored in a Leyden jar (or capacitor) P.*

in 1816 [1, pp. 147–148]. Before long, the challenge of signal retardation emerged in practice. It was studied experimentally by Clark and explained by Michael Faraday in 1854 with the aid of the same Leyden jar analogy, as part of what became known as Faraday's Law of Induction [34].

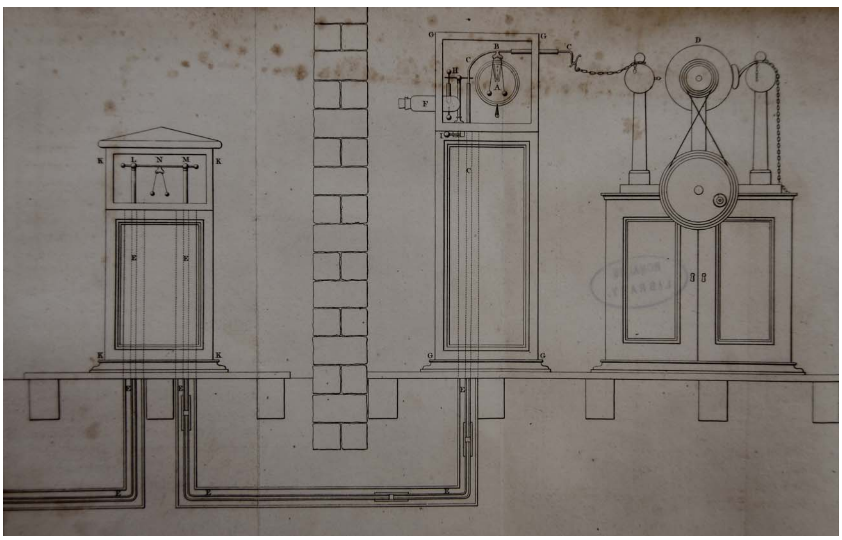

Fig. 8. *Subterranean electric telegraph system (1816), from [10]. The rotating alphanumeric dial delivering the messages is housed in the middle cabinet. On the right is an electrostatic generator and a testing post is shown to the left. Several sleeved expansion joints are seen along the insulated buried cable. Elements of the system are on display in the Science Museum.*

II. ALTERNATIVE INTERESTS (1818–1841)

Ronalds meanwhile had embarked on a Grand Tour in 1818, and explored parts of Turkey, the Holy Land and Egypt as well as mainland Europe. He delighted in visiting the laboratories and sites where esteemed electrical scientists had conducted their work; these included Luigi Brugnatelli, who had invented electroplating, as well as Volta, Beccaria, and Zamboni [1].

He documented just one set of electrical experiments conducted while abroad. Utilizing his second form of electrical insulation and his electrometers, he studied atmospheric electricity in mid-1819 in two novel situations. His investigations near the crater of Vesuvius would have been the first to be made at an erupting volcano—such monitoring is now performed using remote sensing techniques [35]. During a dry sirocco wind in Sicily he observed with considerable surprise an essentially single daily cycle in the potential gradient, also probably for the first time [1, pp. 135–136], [10]. The double cycle that had been seen to date in northern Europe (and continued to be for many years) is now understood to have been influenced by smoke pollution. In the 20th century it was ascertained through observations over the oceans that the characteristic diurnal variation in fine weather and clean air is single peaked [36].

On his return to England, Ronalds chose to move into mechanical design and engineering, which at this stage of the industrial revolution was already a larger and more anonymous world than that of traditional scientific enquiry with learned publication [1, Ch. 12].

He first patented two drawing instruments in 1825 [37]. One created a perspective view of an object directly from drawings of its plan and elevations. Its initial application was to help explain his inventions through detailed illustrations—he always preferred to hone and then communicate ideas through drawings and those included here are just a small sample of his work. The second instrument created an accurate perspective drawing by "tracing" a scene or object in life. In addition, he developed a stand to support his drawing board, with three pairs of legs that were hinged to a triangular metal head. An example is seen in Fig. 3 and it remains the standard form of portable stand today for theodolites and the like. He set up a production facility for his new inventions and hundreds were sold [1, pp. 230–235], [38].

The renowned London tool makers Holtzapffel marketed and sold a device Ronalds developed in 1829 as an accessory to their lathes. It was a slide rest that held a series of guides, enabling any desired shape to be replicated exactly by the cutting tool. Over 50 years after the invention, the Holtzapffel family's book *Turning and Mechanical Manipulation* advised that it "contains the germ of all the turning and carving machinery since so extensively employed for the mercantile production of numerous *fac-similes*" [39]. Mass production of furniture and such items using steam power had commenced around mid-century. By 1837 Ronalds was contemplating using "electromagnetism" to drive his own lathe [40].

Other inventions included a universal joint for horse-drawn carriages, steam-driven machinery, and equipment for printing, plumbing, fire mitigation, surveying, and astronomy. He published none of them in the scientific literature and so many were unattributed [1, Ch. 12]. His early work continued to be remembered however—the *Encyclopædia Britannica* described nine of his electrical science and engineering achievements in its 1842 and 1855 editions [41].

III. KEW OBSERVATORY (1842–1853)

A. Atmospheric Electricity and Geomagnetism

It was 25 years before Ronalds was enticed back to his favorite subject. A public subscription was raised in 1842 to begin comprehensive atmospheric electricity measurement in London to complement the extensive international study of geomagnetism being conducted at the time [1, p. 329]. A building called the Kew Observatory was taken on for the purpose under the auspices of the large and influential British Association for the Advancement of Science (now the British Science Association). Ronalds was well qualified to establish the observatory and its equipment and quickly volunteered his services [42].

At the heart of the new laboratory was his conductor rod with the second form of electrical insulation, his electrometers, resin plate electrograph, and clockwork-driven registering electrometers [6]. He continued to improve these instruments and also developed many new ones.

B. Photo-Recording Cameras

Ronalds' next electrograph, built in 1845, utilized the very recent innovation of photography and can be considered to be the first successful "movie camera." A timepiece moved a photosensitive surface slowly past the aperture of the camera box, capturing an image of the variations of an instrument to form a continuous record 24 h per day [43]. He trialled his two favorite electrometers for this purpose—the Volta straws and his modified Coulomb torsion balance. It is the former that is illustrated in Fig. 9. The latter may be

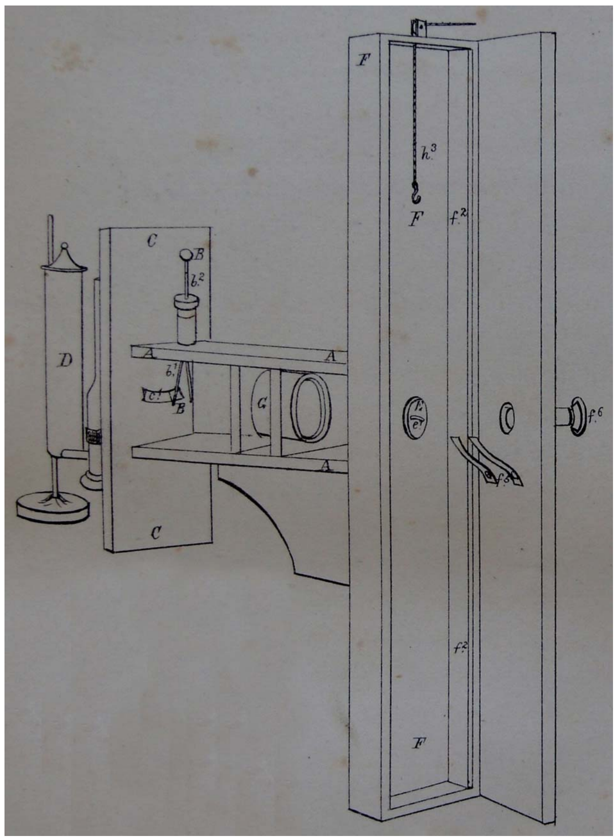

Fig. 9. ***Photo-electrograph (1845), from [43]. At the center is the horizontal camera box holding the lens tube and illuminated by a lamp or daylight on the left. Just the tips of the straws of the Volta electrometer are visible through the arced slit in the aperture diaphragm on the right. The photosensitive surface travels gradually along the vertical case, pulled by a line from a clock, and records the changing divergence of the straw tips over time as a pair of curved lines. Several of Ronalds' cameras survive in the Science Museum and their photographic traces are held in various archives.***

regarded as a forerunner to Kelvin's renowned quadrant electrometer developed in the 1860s [44]. Similarities between Ronalds' and Kelvin's instruments over the original Coulomb device include the use of a simple suspended metal needle and a fixed piece in the same plane, both charged via wire connections, and the employment of a Faraday cage, in addition to photo-registration [1, pp. 389–391].

Ronalds developed further cameras to record atmospheric pressure, temperature, humidity, and geomagnetic forces. His suite of equipment was used in creating a detailed electrical and meteorological data set of five years' duration, which was analyzed and published by his observatory associate [45]. Atmospheric electricity studies remained a speciality of the Kew Observatory until it was closed in 1980.

The electrical and photographic equipment was also supplied to numerous other observatories around the world and updated models saw use long into the 20th century [1, Ch. 15]. His vision was to delineate potential gradient, air-earth currents, and their relationships with other meteorological parameters on a global scale, and contrast their behavior with geomagnetism [46].

The phenomenon now known as geomagnetically induced current was seen on British telegraph lines in 1847–1848 during the first sunspot peak after the network began to take shape. Ronalds received galvanometer data from telegraph operators to compare with his observatory measurements and hoped "to elucidate *a little* the subjects of atmospheric electromagnetism & the Aurora" [5]. Lack of resources unfortunately prevented him from pursuing this work toward a conclusion. Further disturbances to the international network occurred during the next sunspot peak in 1859 and prompted other scientists and engineers to begin addressing the problem in detail [1, pp. 413–418].

Unlike the earlier decades of his career, Ronalds was at the hub of British science in his Kew years. The quality of his meteorological instruments and observations had quickly attracted esteem and numerous influential supporters across the British Association's membership at just the same time that the telegraph was becoming a reality.

IV. LAST YEARS AND LEGACY (1854–1873)

Retiring from his position as Honorary Director of the Kew Observatory in late 1853 at the age of 65, Ronalds returned to the Continent for nine years, probably in part to regain something of his previous anonymity.

A. Electric Lighting

One of his areas of interest documented in his retirement concerned the reliability of electric lighting. The carbon arc lamps then under development began strongly, but soon flickered and stopped due to rapid and uneven burning of the charcoal electrodes. For applications like lighthouses where regular pulses of light were required, Ronalds' simple suggestion was to disconnect the battery repeatedly and adjust the electrodes mechanically in these intervals [46].

The French literature reported his ideas in 1856 for enabling multiple lamps to run for extended periods on a single power source. His "electric candelabra" incorporated automatic means to close off any branch of the circuit that had been broken through a failed lamp [48], [49].

B. Recognition

Back in Britain, the successful completion in 1866 of the transatlantic telegraph cable led to public calls for Ronalds to be honored formally as one of the originators of the technology. It was now exactly 50 years since his demonstration. He was knighted in 1870 at the age of 82 [1, pp. 159–164].

The following year saw the creation of a professional body in the United Kingdom for the industry. The Society of Telegraph Engineers (STE) became the Institution of Electrical Engineers (IEE) in 1888 and is now the Institution of Engineering and Technology (IET). Ronalds was invited to join the new society and published a piece in the first volume of its journal. He outlined Volta's early proposal for an electrostatic telegraph—Ronalds had discovered it when organizing Volta's papers in Como in 1860–1861 at the request of his son [50].

Ronalds was regarded by the members as the first of their cohort. Acknowledging at the STE's first meeting the early developers of practical telegraphy, Ronalds was called "the pioneer of all" [51]. The inaugural President, William Siemens, commissioned a bust of him and presented it to the Society. The death of "the father of Electric Telegraphy" on August 8, 1873 was advised at the second Annual Meeting [52]. The society published a biography of Ronalds in 1880, recording that he "must always stand as the first of English Telegraph Engineers" [30]. His early work was again discussed seven years later:

> Mr. Ronalds wrote a paper on underground telegraphs that would do credit to any member of this Society if written in the year 1887. It is perfectly astonishing how that man's instinct saw the various troubles that were likely to be met with in the construction of long underground lines… it is a pamphlet that is well worth studying by everybody here. [53]

Finally, the author of the first official history of the IEE wrote of Ronalds in 1930: "Electricity had become a science, but not yet an engineering science. He bridged the gap that for so long separated tentative efforts from trials… designed to work efficiently and to endure" [54].

C. Ronalds Library

Additionally to his various electrical inventions and insights, and in particular his telegraph demonstration, Ronalds contributed to the profession itself. He had sought books on electricity almost all his life, with the long-term goal of creating a library that would "be of as much use as possible to... persons... engaged in the pursuit of Electrical Science" [55]. (He managed his growing collection using a card catalog, which has been described in an American Library Association paper as the first practical example of what became the standard library documentation system until the digital age [56].)

Ronalds' library was bequeathed to the STE on his death. Clark, the incoming President at the time, advised that it was "considered without exception the most perfect technical (as regards Electricity and Telegraphy) library in the whole world" [57]. Initial trustees included Kelvin and Siemens as well as Clark. Clark and Ronalds had collaborated in their collecting activities in the latter's last years and Clark's library was later purchased by Schuyler Wheeler and presented to the American Institute of Electrical Engineers [58].

The IEE President at the beginning of the 20th century called the Ronalds Library "the glory of electrical engineers" [59]. One young man who had utilized the resources was Arthur Kennelly, who went on to become an early Professor of Electrical Engineering at Harvard and MIT [60]. The card catalog had been published in book form and is referenced in *Origins of Cyberspace* (2002) as "the first bibliography pertaining to telecommunications, and probably the first published bibliography... on specialized subjects in physical science" [61]. It was reprinted in 2013 by Oxford University Press [62].

The Ronalds Library had proved to be a significant boon to the embryonic society. It was an imperative for survival and a foundation for success—it gave gravitas, instigated the creation of a legal entity, and provided a scholarly base for the electrical engineering discipline. Ronalds had played a role in creating the profession at both ends of his long life.

V. CONCLUDING REMARK

Ronalds was a very modest man. When it was announced in the *Times of London* that he had been knighted as "the original inventor of the electric telegraph," he wrote to the newspaper explaining that the descriptor was not valid [63]. He had always emphasized that he built on the work of earlier scientists and that "innumerable subsequent inventions and improvements" by those following him had "very greatly facilitated telegraphic operations" [64].

In just the same way, it is impossible to pinpoint definitively a first "electrical engineer." Countless people have contributed to the development of the many technical and professional competencies now embodied in that title, and applied them in novel ways to deliver value to society. The author nonetheless contends that Sir Francis Ronalds warrants greater credit than he has received in recent decades for his part in foretelling, demonstrating, and supporting the electrical age and launching its enabling profession. He was the first to articulate the benefits of a future electrical world, to describe its initial application in rapid communication, and to illustrate it with a working system. His vision brought a further valuable outcome for the emerging profession 60 years later in the form of his library. In between, he developed various other pioneering electrical devices, and he might have delivered many more if his early work had not been belittled by his first mentor and the government. ■

Acknowledgment

The author would like to thank staff at the IET Archives, Royal Society in London, U.K. National Meteorological Library and Archive in Exeter, Science Museum in London, Museum of the History of Science at Oxford, University College London (UCL) Library Services, Royal Greenwich Observatory (RGO) Archive at the University of Cambridge, and the British Science Association for their kind assistance in this research.

REFERENCES

[1] B. F. Ronalds, *Sir Francis Ronalds: Father of the Electric Telegraph*. London, U.K.: Imperial College Press, 2016.

[2] G. J. Singer, *Elements of Electricity and Electro-Chemistry*. London, U.K.: Longman, 1814.

[3] S. Reif-Acherman, "Georg Simon Ohm and the first comprehensive theory of electrical conductivity in metals," *Proc. IEEE*, vol. 104, no. 1, pp. 198–209, Jan. 2016.

[4] "Intelligence and miscellaneous articles," *Philos. Mag.*, vol. 37, pp. 79–80, 1811.

[5] "F. Ronalds to S. Carter," University College London Library Services, Special Collections GB 0103 MS ADD 206, Feb. 21, 1860.

[6] F. Ronalds, "Report concerning the observatory of the British Association at Kew, 1843–4," in *Report of the British Association for 1844*. London, U.K.: Murray, 1845, pp. 120–142.

[7] W. D. Hackmann, "Eighteenth century electrostatic measuring devices," *Annali dell'Istituto e Museo di Storia della Scienza di Firenze*, vol. 3, no. 2, pp. 3–58, 1978.

[8] F. Ronalds, "An account of an atmospheric electrometer," *Quart. J. Sci. Arts*, vol. 2, pp. 249–253, 1817.

[9] F. Ronalds, "Report concerning the observatory of the British Association at Kew, 1850–1," in *Report of the British Association for 1851*. London, U.K.: Murray, 1852, pp. 335–370.

[10] F. Ronalds, *Descriptions of an Electrical Telegraph and of Some Other Electrical Apparatus*. London, U.K.: Hunter, 1823.

[11] National Meteorological Library and Archive, "Journal of Meteorological Observations at Kew Observatory, 1843–4," Exeter, U.K. Y54.F-Y52.D.

[12] P. M. Borsenberger and D. S. Weiss, *Organic Photoreceptors for Xerography*. New York, NY, USA: Marcel Dekker, 1998.

[13] T. P. Shaffner, "Ronald's electric telegraph," in *Telegraph Manual: A Complete History and Description*. New York, NY, USA: Pudney & Russell, 1859, pp. 147–156.

[14] W. Hackmann, "The Enigma of Volta's 'Contact Tension' and the Development of the 'Dry Pile'," in *Nuova Voltiana: Studies on Volta and his Times*, F. Bevilacqua and L. Frenonese, Eds. Pavia & Milan, Italy: Hoepli, 2000, vol. 3, pp. 103–119.

[15] F. Ronalds, "Experiments on the variable action of the electric column," *Philos. Mag.*, vol. 43, pp. 414–419, 1814.

[16] F. Ronalds, "On electricity," *Philos. Mag.*, vol. 44, pp. 442–445, 1814.

[17] F. Ronalds, "Report concerning the observatory of the British Association at Kew, 1849–50," in *Report of the British Association for 1850*. London, U.K.: Murray, 1851, pp. 176–186.

[18] L. Clark, "On electrical quantity and intensity," *Proc. Roy. Inst. Great Britain*, vol. 3, pp. 337–341, 1862.

[19] "F. Ronalds to J. A. de Luc, draft," IET Archives, 1.6.56, May 9, 1815.

[20] "J. A. de Luc to F. Ronalds," IET Archives, 1.6.56, May 11, 1815.

[21] F. Ronalds, "On electro-galvanic agency employed as a moving power; with a description of a galvanic clock," *Philos. Mag.*, vol. 45, pp. 261–264, 1815.

[22] C. K. Aked, "The first electric clock," *Antiquarian Horology*, vol. 8, pp. 276–289, 1973.

[23] B. F. Ronalds, "Remembering the first battery-operated clock," *Antiquarian Horology*, vol. 36, pp. 244–248, 2015.

[24] L. W. Gilbert, "Vorläufige Nachricht von grossen zu Stuttgard ausgeführten trocknen Säulen, und von einer sogenannten electrischen Uhr," *Annalen der Physik*, no. 3, pp. 187–190, 1815.

[25] T. Thomson, "Account of the Improvements in physical science during the Year 1816," *Ann. Philos.*, vol. 9, pp. 1–89, 1817.

[26] M. Tinazzi, "Perpetual electromotive of Giuseppe Zamboni," presented at the *Atti del XVI Congresso Nazionale di Storia della Fisica e dell'Astronomia*, Como, 1996.

[27] J. Gray, "Ronalds' Pendulum Doubler," in *Electrical Influence Machines*. London, U.K.: Whittaker, 1890, pp. 84–85.

[28] B. F. Ronalds, "The bicentennial of Francis Ronalds's electric telegraph," *Phys. Today*, vol. 69, no. 2, pp. 26–31, Feb. 2016.

[29] L. Clark, "Inaugural address," *J. Soc. Telegraph Eng.*, vol. 4, pp. 1–23, 1875.

[30] A. J. Frost, "Biographical memoir of Sir Francis Ronalds, F.R.S.," in *Catalogue of Books and Papers Relating to Electricity, Magnetism, the Electric Telegraph, &c including The Ronalds Library*. London, U.K.: Spon, 1880, pp. vii–xxvii.

[31] "J. Barrow to F. Ronalds," IET Archives, 1.9.2, Aug. 5, 1816.

[32] G. J. Singer, "The electric column considered as a maintaining power, or first mover for mechanical purposes," *Philos. Mag.*, vol. 45, pp. 359–363, 1815.

[33] G. J. Singer, "Correction of some errors in Mr. Singer's paper on the mechanical applications of the electric column," *Philos. Mag.*, vol. 46, pp. 11–12, 1815.

[34] M. Faraday, "On electric induction—Associated cases of current and static effects," *Philos. Mag.*, vol. 7, pp. 197–208, 1854, ser. 4.

[35] F. Ronalds, "Observations on atmospheric electricity made on Vesuvius, in June and July, 1819," *Quart. J. Sci. Arts*, vol. 14, pp. 333–334, 1823.

[36] R. G. Harrison, "The global atmospheric electrical circuit and climate," *Surv. Geophys.*, vol. 25, pp. 441–484, 2004.

[37] F. Ronalds, "Apparatus for tracing from nature," Patent 5132, Mar. 23, 1825.

[38] "F. Ronalds to E. Sabine," Royal Society, Sabine Collection, Sa.1088, Nov. 10, 1848.

[39] J. J. Holtzapffel, "Curvilinear apparatus," in *Turning and Mechanical Manipulation*. London, U.K.: Holtzapffel, 1884, vol. 5, pp. 94–104.

[40] F. Ronalds, "Turner's Manual," c.1837, IET Archives, 1.2.1–2, 1.5.39–40, 1.6.74.

[41] "Electricity," in *Encyclopædia Britannica*, 7th ed. Edinburgh, UK: Black, 1842, vol. 8, pp. 565–663.

[42] R. H. Scott, "The history of the Kew Observatory," *Proc. Roy. Soc. Lond.*, vol. 39, pp. 37–86, 1885.

[43] F. Ronalds, "On photographic self-registering meteorological and magnetic instruments," *Philos. Trans. Roy. Soc. Lond.*, vol. 137, pp. 111–117, 1847.

[44] W. Thomson, "Report on electrometers and electrostatic measurements," in *Report of the British Association for 1867*. London, U.K.: Murray, 1868, pp. 489–512.

[45] W. R. Birt, "Report on the discussion of the electrical observations at Kew," in *Report of the British Association for 1849*. London, U.K.: Murray, 1850, pp. 113–199.

[46] F. Ronalds, "Notice of observations carried on at the Kew Observatory," in *Report of the British Association for 1847*. London, U.K.: Murray, 1848, pp. 30–31.

[47] "F. Ronalds to I. Tremblay, copy," IET Archives 1.9.1, Jul. 7, 1858.

[48] "Académie des sciences," *Cosmos Revue Encyclopédique Hebdomadaire*, vol. 8, pp. 371–379, 1856.

[49] T. du Moncel, "Lumière Electrique," in *Exposé des Applications de l'Electricité*, 2nd ed. Paris, France: De Lacroix-Comon, 1857, vol. 3, pp. 214–281.

[50] F. Ronalds, "Correspondence," *J. Soc. Telegraph Eng.*, vol. 1, pp. 243–244, 1872.

[51] "The Society of Telegraph Engineers," *J. Soc. Telegraph Eng.*, vol. 1, pp. 19–39, 1872.

[52] "Second annual meeting," *J. Soc. Telegraph Eng.*, vol. 2, pp. 411–423, 1873.

[53] "Remarks on underground telegraphs," *J. Soc. Telegraph Eng.*, vol. 16, pp. 421–437, 1887.

[54] R. Appleyard, "Francis Ronalds," in *Pioneers of Electrical Communication*. London, U.K.: Macmillan, 1930, pp. 301–331.

[55] "Trust Deed of the Ronalds Library," IET Archives, 1875.

[56] M. S. James, "The progress of the modern card catalog principle," *Public Libraries*, vol. 7, pp. 185–189, 1902.

[57] "Third annual meeting," *J. Soc. Telegraph Eng.*, vol. 3, pp. 444–458, 1874.

[58] W. D. Weaver, Ed., *Catalogue of the Wheeler Gift*. New York, NY, USA: AIEE, 1909.

[59] "Royal Meteorological Society jubilee celebration," *Quart. J. Roy. Meteorol. Soc.*, vol. 26, pp. 173–202, 1900.

[60] V. Bush, "Arthur Edwin Kennelly 1861–1939," *Nat. Acad. Sci. USA, Biograph. Memoirs*, vol. 22, pp. 83–119, 1940.

[61] D. H. Hook and J. M. Norman, *Origins of Cyberspace*. Novato, CA, USA: historyofscience.com, 2002.

[62] A. J. Frost, Ed., *Catalogue of Books and Papers Relating to Electricity, Magnetism, the Electric Telegraph, &c. including The Ronalds Library, compiled by Sir Francis Ronalds, F.R.S.* London, U.K.: Spon, 1880.

[63] Times of London, Apr. 7, 1870, p. 7f.

[64] F. Ronalds, *Description of an Electrical Telegraph*, 2nd ed. London, U.K.: Williams & Norgate, 1871.

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