John Logie Baird and the Secret in the Box: The Undiscovered Story Behind the World's First Public Demonstration of Television

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I. INTRODUCTION

On January 26, 1926 (see Fig. 1), John Logie Baird gave a demonstration at his laboratory in 22 Frith Street, London, of the live transmission of moving images, obtained in reflected light with tonal graduation, to members of the Royal Institution. This event is generally accepted as the first public demonstration of true television [1], [2, pp. 88–107], [3, pp. 65–84]. Ten months earlier, on March 25, 1925, Baird had demonstrated the televising of moving silhouette images, at Selfridge's department store, on Oxford Street in London [2, p. 57], [3, p. 75]. What had changed in those ten months to enable Baird to televise a sufficient tonal range of moving human faces? This article describes the set of events which led up to Baird's accomplishment and answers the question concerning the technology employed.

This month's history article traces the steps that led to John Logie Baird's first demonstration of the life transmission of moving images, and answers the question concerning the technology that led to this accomplishment.

Baird had, since his youth, possessed a strong interest in images and the potential for employing electrical engineering advances to be able to transmit them [4, p. 19]. When he decided, in 1923, to devote his full energy to the creation of a television system [4, p. 44], [5, pp. 40–41], he faced the challenge of limited funding. His work had to follow a path dependent on the reuse and adaptation of known technologies. His achievement stands as testimony to the ethos of engineers, who are sometimes described as transforming scientific learning into practical solutions. This article focuses on Baird's first engineering achievement and success in applying the ethos of engineering, to reach that major milestone in the development of television. (The IEEE recognized Baird's accomplishment by erecting a Milestone plaque at the Frith Street premises [32].)

In keeping with his constrained circumstances, Baird developed an electromechanical system, using a large, rotating Nipkow-type disk, modified to contain an array of glass lenses, to scan the object to be televised. This system swept a series of displaced images of the scene over a sensor that detected changes

Digital Object Identifier 10.1109/JPROC.2020.2996793

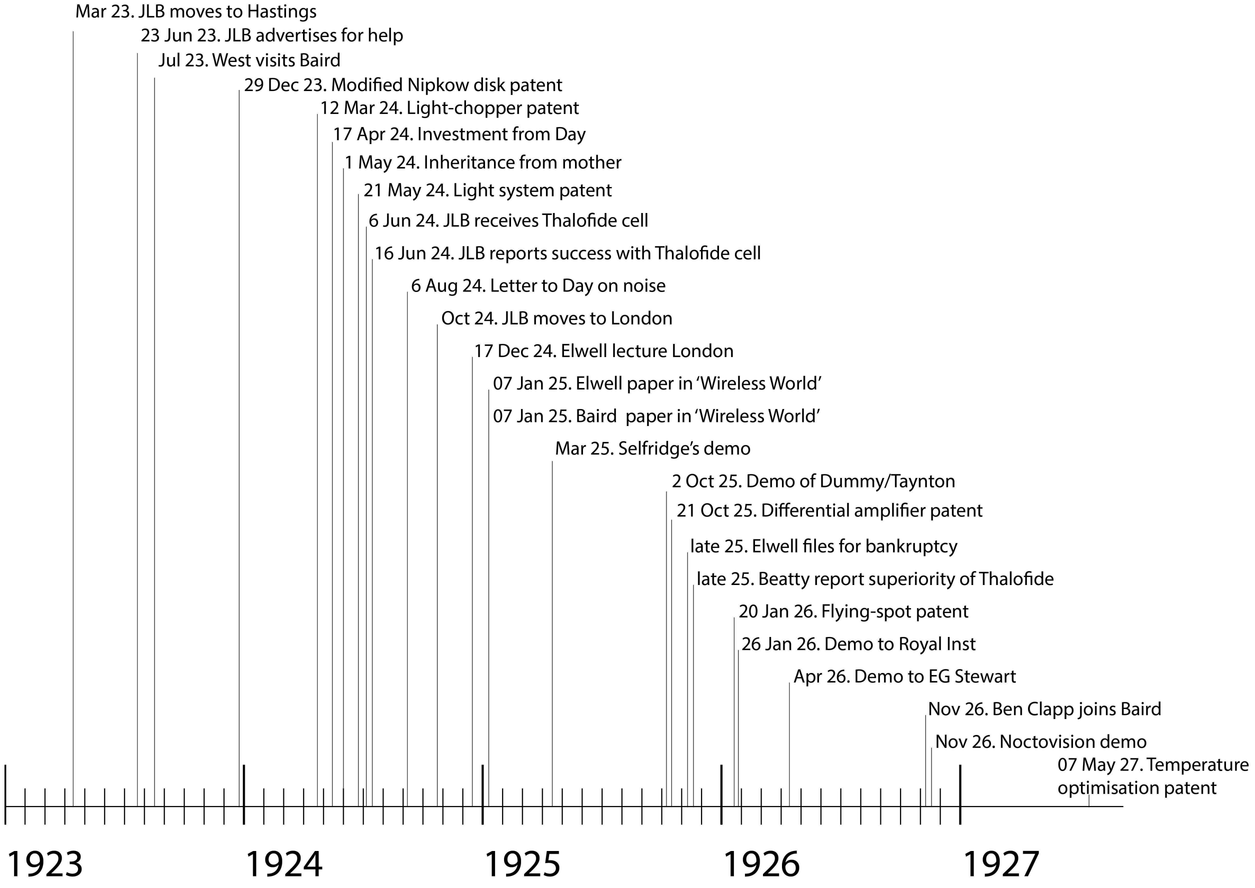

Fig. 1. ***Timeline of events relating to Baird's demonstration of television and subsequent developments. The entries for patents use the date when the application was filed.***

of the incident, reflected light, in effect creating a line-scan during the rotational passage of each lens. The response rate of the photocell had to be rapid enough to permit the system to "draw" a sufficiently resolved image, while also drawing enough of those images each second to take advantage of the "persistence of vision" of the viewer.

In Baird's system design, the photocell detected the brightness of the incident light and converted those light variations along each scan-line into changes in electrical current. The resulting signal was then amplified and transmitted to a receiver. There, a neon gas-discharge lamp was placed behind a second perforated disk, synchronized with the transmitter disk, where the converse process took place. A ground-glass screen diffused the lamp's glowing electrode [6, pp. 196–199], [10, p. 46], which was modulated by the received signal. The resulting "image" (composed of an array of discrete points of light, of varying intensities) was viewed on the surface of the spinning disk.

The technical challenge was to deliver enough images each second to enable the human visual system to perceive continuous motion. Specifically, the solution was limited by low-frequency signals and needed sufficient signal-to-noise characteristics. The bandwidth limitation relates to Baird's initial intended application, which was to provide a moving image of a live radio presenter, to enrich the listener's experience of the radio broadcast. Thus, the television signal needed to operate within the current audio bandwidth of the public transmitting equipment, which was nominally 10 kHz.

Baird solved these issues, as far as the technology and his constraints allowed, in a very short space of time, from the middle of 1923 to the beginning of 1926 (see Fig. 1). He did this by recognizing the applicability of components developed by others and incorporating useful advice, then adapting these or developing new approaches to serve his task. Here, we present our analysis of the critical steps of Baird's success, and we derive an interpretation of the events and Baird's choices that have puzzled historians of technology [2, p. 105–106], [3, p. 49], [8, p. 140–141], [9, p. 29], [12], [13 p. 35], [22, pp. 120–121], [30, p. 26] until now.

II. TRANSMITTER SYSTEM

The key factor in Baird's achievement of television was his imaging and signal-acquisition/amplification system, which we call hereafter the transmitter. We emphasize the term "system," because Baird successfully invented

Fig. 2. ***Baird with his transmitter believed to be used for the first demonstration of television in 1926 [14]. One of the 30 lenses can be seen to the left of the dummy's head mounted in a plywood, 1.5-m diameter scanning disk [4, p. 55].***

new solutions, or improved prior approaches, in each of the system's three major components: 1) the scanning device, whose purpose was to deliver light, reflected from small patches of the scene, as an ordered light "signal" onto; 2) a photo-responsive cell, which converted the incident light to real-time electrical current variations, which were and 3) amplified while maintaining the signal-to-noise ratio and retaining the signal's high- and low-frequency components.

A separate system, the receiver, took the signals and generated a display that was visible to the eye. We do not emphasize the receiver herein and only describe that system to the level needed to appreciate its relationship to the transmitter. In his first experiments, Baird connected the transmitter to the receiver by wires, but the intention was that the two parts of the system could be connected by a radio signal or "wireless" in British terminology.

A. Scanning Subsystem

We believe that the equipment (see Fig. 2) used in the demonstration to the Royal Institution, which was later described by Baird employee, Ben Clapp, involved a Nipkow-inspired scanning disk, with a single spiral of 30 lenses [7]. However, there is uncertainty over this matter, with some authors stating that a different scanning approach was used [8], [9]. Our evidence shows that Baird was experimenting with multiple scanning approaches and that he used different devices in the demonstrations he made from 1924 to 1926. Several photographs of Baird's different scanning arrangements, some of which seem posed for publicity purposes, with components arranged in an impossible configuration, contribute to the uncertainty.

We argue that the 30-lens scanning system used in the January 1926 demonstration was a Nipkow-based disk, but with lenses instead of apertures [8, pp. 134–135], [13, p. 45]. The original Nipkow design involved a disk with apertures, arranged in a spiral. The apertures of the Nipkow disk allowed light, reflected from the scene, to fall onto successive small regions on the surface of a fixed lens, with standard optical effects projecting each light-spot onto a sensing device. Baird's novel design was developed from the scanning device which he originally used for shadowgraph transmissions [10, p. 45], [11, pp. 533–535], known as the double-eight transmitter. This had 16 lenses arranged in two spiral arrays of eight, which formed part of an interlacing system with which Baird was also experimenting, in an attempt to reduce image flicker. That scanning apparatus has been extensively analyzed and documented by McLean [12]. The double-eight disk continued to be used for experimentation and development and allowed Baird to refine other aspects of the scanning technology, ultimately leading to the updated scanning design.

Nipkow's original design of the scanning device, with apertures arranged on a spinning disk, caused the reflected light from a scene to be "sampled" as each aperture passed in front of a fixed lens. That lens was placed so that it focused the part of the reflected light that passed through the individual and successive apertures onto a photocell, to generate current variations that were linked to the light intensity that was incident onto the disk. As Baird sought to derive scans of moving images, the scan rate had to be increased (faster than needed in Nipkow's work) so as to generate multiple scans per second. His reimagination of the Nipkow configuration altered the sequence of partitioning, sampling, and concentrating the light, with Baird's design involving a rotating disk of lenses that repeatedly focused selected samples of the reflected light onto the fixed photocell. In this article, we will refer to Baird's disk as a "Nipkow disk," even though his design was a novel adaptation.

Baird's brief was to create a commercial and marketable television system. Therefore, he quite deliberately chose to confine his equipment's specification to the characteristics of the British Broadcasting Corporation's (BBC's) medium-wave broadcast transmitter network. However, this presented limitations, as Baird stated:

> The picture was made up of 30 [vertical] strips. I found this to be the minimum necessary to transmit a clearly recognizable image of the human face. To decide the shape of the picture most suitable to take in the face without wasted space, I made endless measurements and ultimately decided on a long narrow picture in ratio 7 high by 3 wide [4, pp. 63–64]

Each vertical strip that was sampled by Baird's design contained both horizontal (across the width) and vertical (along the strip) light-intensity variations, as these reached the photocell. By treating the light as varying only vertically along the strip, each strip was represented in the receiver as having effectively a uniform intensity across its width. The strips presented in the final display have centerlines closer together than the width of the varying light spot acquired through the lens, to emphasize the sampling (linked to the response rate of the photocell) in the near centerline of the spot. The eye–brain combination is then able, when seeing the receiver image, to merge the strips' information and construct a more continuous, horizontal tonal interpretation than was actually generated. In practice, this design allowed the maximum number of tonal variations to be discretized along each strip, as could be achieved within the bandwidth and depending on the response rate of the photocell. Modern image displays rely on the same brain "tricks" and present images as lines and rows of discrete pixels that humans "see" by mental reconstruction as a continuous and smooth image. Baird's experiments with image-depiction options and his selected resolution are, if not the first example, then certainly among the earliest studies of the interface between imaging technology (choice of strips and effective in-line sampling) and human vision.

Baird was aware that his low-definition system had to be confined to a maximum bandwidth of approximately 10 kHz, as then specified by the General Post Office (the British regulatory agency for communications):

> The amount of detail which could be sent at that time was limited by the wireless transmitter. This also limited the number of pictures per second which could be sent out. It was a compromise between flicker and detail. More flicker-more detail; less flicker-less detail. So I decided on a picture with a fair amount of flicker and a fair amount of detail. The picture I got through was surprisingly good considering the small number of lines [4, p. 64]

As a rough estimate, we can derive the apparent resolution within each vertical strip, as follows, ignoring synchronization considerations in the data stream and treating the ~10-kHz bandwidth as representing 10 000 samples/values of light-strip information per second (each waveform amplitude denotes one gray-scale intensity value). A simple expression of the necessary bandwidth is

$$f = a \times b \times c$$

where f is the bandwidth (i.e., 10 kHz), a is the number of images per second, b is the number of vertical scanlines (30), and c is the number of samples along that line. At five images per second and with 30 vertical lines, the naïve calculation permits 66 samples in each of the image strips. Baird's stated [4, p. 64] image ratio of 7:3 requires 10 500 values of data to be transmitted per second, slightly above the nominal limit, but Baird may have concluded that broadcast improvements would enable his choices to be practical, an expectation validated by subsequent broadcasts at 12.5 frames per second [13, pp. 39–42]. Since Baird used wires to transfer his data, he could slightly "cheat" the bandwidth to demonstrate his proof of concept. To achieve the maximum rate, the amplitude of every demodulated cycle after broadcasting in amplitude modulation mode would have to be resolvable. In practice, the achieved apparent resolution must have benefitted from the smoothing associated with the analog signal, where errors would not have the same detrimental effects as they would in today's discrete (digital) communications formats.

The point to emphasize here is that Baird's work in developing this, or any other scanning systems that he was experimenting with, had to consider optics, mechanics, photo-reactive electronics, signal transmission, and other factors, along with human perception. Baird's contribution was that of a systems engineer who comprehended a wide spectrum of issues, whose combined improvements, and consideration of their interactions, were necessary to achieve a notable advance.

We argue that the modified Nipkow-type lens/disk scanning system, with 30 lenses, initially developed by

Baird in a reduced form (the smaller double-eight disk) in the preceding year and a half was utilized for the demonstration on January 26, 1926. Photographic images (see Fig. 2), published subsequently [14], show the large lenses in use. Our argument for Baird's use of this scanning system is as follows. The demonstration of January 1926 was achieved, we reason, because Baird had made improvements in each of the system components, just sufficient to be able to make the demonstration. Baird was likely pressed into making the demonstration by his investors, and we infer that he would have preferred to make further technical advances before exposing his work. We interpret that Baird was progressing multiple approaches to each system component [33], and his subsequent demonstrations represented incremental advances in and substitutions of the system components that had been under development all along.

Baird's January 20, 1926, patent [15], for flying-spot scanning reveals that he was developing multiple scanning approaches, seeking to identify solutions. Since he applied for this patent only a few days before the Royal Institution demonstration, a reasonable inference could be drawn [9, p. 29] that Baird used the flying-spot apparatus in that event. However, that method requires that the subject be located in a dark room. Contemporary reports make no mention of a darkened setting for the demonstration [1]. Furthermore, since Baird's goal was to attach television images to radio broadcasts, of, for example, newsreaders, it seems unlikely that he would wish to demonstrate television in a situation where the newsreader would have to read in the dark.

Certainly Baird's first human subject, William Taynton, televised on October 2, 1925, was not a willing participant, due to the bright lighting needed by Baird, who recalled:

> I went to the receiver only to find the screen a blank. William did not like the lights and the whirring disks and had withdrawn out of range. I gave him 2/6 [Note added: 2 shillings 6 pence, approximately equal to £7.50/$10 today] and pushed his head into position. This time he came through and on the screen I saw the flickering, but clearly recognisable, image of William's face [4, p. 58]

Baird's approach illuminated his subject with large banks of 40-W incandescent lamps (see Fig. 2), which converted the majority of the electrical energy into heat. Therefore, his subjects were not only subjected to bright light, but also a tremendous amount of heat, which was most uncomfortable.

B. Photosensitive Cell

A key element in Baird's transmitter was the photocell, which responded to incident light variations. Previously published analyses have concluded that Baird used one of a number of possible types of cells. The most plausible and most widely cited assessment, due to its depth of analysis and detailed documentation, is that by Burns [2, pp. 104–107], who concluded that Baird was using a colloidal selenium cell. This inference is quite reasonable, as Baird had been testing and trying to improve, like others, a selenium cell, and had even experimented with selenium in his childhood [4, p. 19]. Baird's efforts to design an improved photocell were sufficiently advanced that he filed a patent to protect his ideas [16]. That patent described a cell with an eye-like reflective chamber designed to capture more of the photons reaching the cell and thus deliver a larger signal. Burns reasonably deduced that Baird was describing an improvement to the selenium cell. But the patent does not state the exact composition or construction of the photosensitive device, rather stating "Improvements in or relating to light-sensitive electric devices." Burns also refers to a demonstration, given by Baird to engineer E. G. Stewart, in April 1926. Stewart's report of that demonstration refers to Baird keeping the photoelectric cell:

> A closely guarded secret of the inventor and he told me only sufficient of its construction to demonstrate that it was entirely different from existing cells on the market [2]

This statement appears to confirm that the cell used for the January 1926 demonstration was not like the existing selenium cells, but it gives no indication as to whether it was Baird's colloidal selenium cell, or a different type of cell altogether. Since the demonstration of television seemed to demand a new photocell, Burns' inference, linking the colloidal design patent with the demonstration, was entirely plausible. But we believe that a different interpretation is appropriate.

Baird was confronted by the problems of the insensitivity and slow response rate of the selenium photocells that were recognized as the available technological standard. In fact, he used such a photocell for the Selfridge's demonstration of the transmission of a slow-moving image, so he knew that cell's limitations. McLean notes that [13, p. 34], "it could only respond to changes in light slowly, creating blurred, smeared images lacking detail." This was not a problem for the transmission of still images, where the slow responsiveness in the selenium cell was allowed for by simply increasing the time to scan the image. However, the selenium cell was not a practical proposition for moving-image television, where the scanning time for an entire image had to be much less than a second in order to take advantage of the viewer's "persistence of vision."

The solution to this problem had to lie in improving the performance of the photocell component. We argue that Baird switched his attention to the thallium sulfide ("Thalofide") cell. This cell had been developed during 1916 and 1917, at the Case Research Laboratory in the United States, where Theodore Case discovered that partially oxidized thallium sulfide is very sensitive to infra-red radiation [17, pp. 20 and 152], [29, p. 232]. The practical use of this type of cell relates to the decoding of

Fig. 3. ***Thalofide cell packaging with cell (10 cm in height approx.) on the right. Courtesy of the Cayuga Museum and Case Research Lab.***

audio signals placed onto cinema films, which requires response rates sufficient to deliver multi-kHz signals. The characteristics of the thallium sulfide cell (see Fig. 3) are given by Coblentz [18]. He notes that the cell has its maximum sensitivity at a wavelength of 1 μm (near infrared), "where occurs the maximum emission of the tungsten lamp," whereas:

> Selenium is quite insensitive to these radiations, but has its maximum sensitivity at 0.7 μm, where the tungsten lamp is weak in radiation [18]

Coblentz also notes that the sensitivity of the Thalofide cell was greatly increased at a cooler temperature of 0 °C (see Fig. 4). This temperature produced approximately a two-fold increase in sensitivity compared with a temperature of 16 °C. The recognition of the effect of temperature on the Thalofide cell performance is very significant to Baird's achievement. An interesting unknown is how Baird may have discovered Coblentz's article, with its critical evidence of the role of cooling. The journal would not likely have been available in the Hastings Library, but Baird is known to have been in liaison with his financial backer Wilfred Day (1873–1936, cinema historian, owner of a cine and radio shop located in Lisle Street in the Soho district of London). He was also in communication with the United Kingdom's Admiralty Research Laboratory physicists, Rankine and Beatty [2, p. 107], [3, p. 74], [8, p. 217], [25, pp. 121 and 153], who may well have provided him with sight of this relevant report. To date, we have not located documents that tell us how Baird learned of this information.

We argue that Baird would never have been able to create true television with the selenium cells he had been

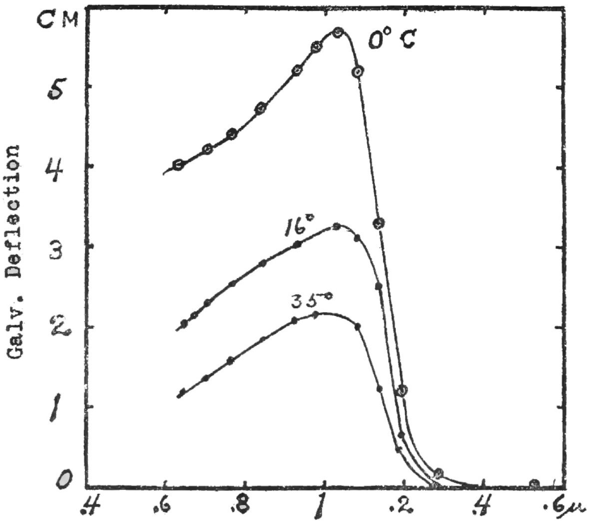

Fig. 4. ***Effect of temperature upon the spectro-photoelectrical sensitivity of Thalofide cell no. 717 (clear glass bulb) [18].***

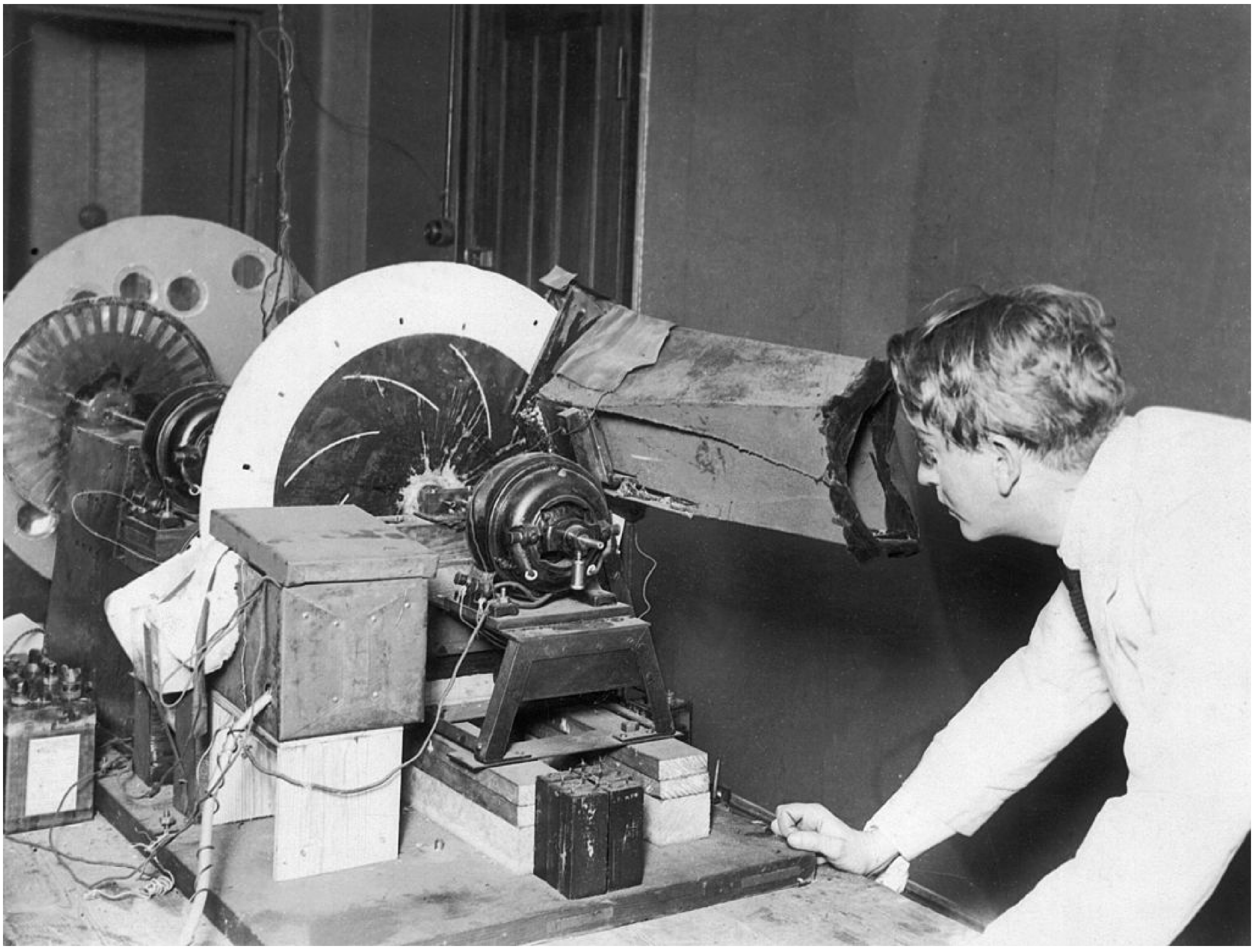

Fig. 5. ***Double eight transmitter, with the large metal box (circled) containing what is believed to be the Thalofide cell and amplifier. Fabric is used to eliminate background light and insulate the ice. Note the inferred use of a tube, on the left, for water drainage. Similarly, contrasting images [2, p. 74], [11, p. 534] show a variety of permutations of this apparatus during various stages of Baird's research and development, Image dated January 2, 1926 and copyright, Gettyimages (used with permission).***

using. They produced only a very weak response to the tungsten lamps used to illuminate his subjects, in addition to their slow response rate. Thus, the demonstration must have used either a colloidal selenium cell, for which no details are given, or the Thalofide cell, for which there is very strong circumstantial evidence, along with subsequent records.

Fig. 5 shows the double-eight equipment to which Baird refers in January 1925:

> At present the apparatus is one constructed purely for experimental purposes, and is capable of transmitting only simple objects. The letter "H," for example, can be clearly transmitted, but the hand, moved in front of the transmitter, is reproduced only as a blurred outline. A face is exceptionally difficult to send with the experimental apparatus, but, with careful focussing, a white oval, with dark patches for the eyes and mouth, appears at the receiving end, and the mouth can be clearly seen opening and closing [11, pp. 533–535]

In Fig. 5, a smaller serrated disk can be seen placed behind the scanning lens disk. Baird refers to this as his "light chopper," and its role is explained in Baird's patent GB235,619, filed in March 1924:

> This invention relates to a method of overcoming the time lag in a selenium or light sensitive cell used in a television system [19]

This evidence suggests that Baird had partially overcome the slow response of the selenium cell by this means. However, when Baird recalls this in his memoir, he states:

> I decided to try selenium cells and see what could be done—if anything—to overcome the time lag. The first thing I tried was to use interrupted light, by passing the light rays through a serrated disk, which acted as a light chopper. The time lag did not enter into the matter. The cell had to distinguish only between interruptions and no interruptions. With this I could use selenium but the light chopper split the picture into crude bars, so nothing could be sent but coarse outlines. I discarded the chopper and concentrated on the problem of overcoming time lag [4, p. 56]

No written records tell us of the full line of Baird's reasoning. He was notoriously reticent; moreover, any lab records he kept were presumably destroyed in the Crystal Palace fire in 1936. In the rather convoluted account that Baird gave to Wilson, published in 1937 [25], we learn that Baird realized that the physical characteristics of the selenium cells precluded their use for his purpose. On that basis, we believe that he sought out alternative technologies. This search led him to the Thalofide cell as a candidate device. Both Case [20] and Coblentz [18] reported on the Thalofide cell in 1920, but these publications may not have been widely known, beyond physics researchers. Thus, we must ask how the Thalofide cell specifically came to Baird's attention.

According to Baird's wife Margaret, while in Hastings:

> He spent the spring of 1923 sitting in the pale sunshine of the seafront or browsing in the public library [5, p. 41]

We believe that, in the Hastings Library, Baird may have come across an article published a short time earlier (October 1921) in the journal *Nature* by British physicist A. O. Rankine, who states:

> Selenium is not the only substance suitable for this purpose. Other photoelectric cells have been constructed during recent years, notably the "Thalofide cell" of T. W. Case [21, pp. 289–292]

According to Baird's memoirs, he decided in the middle of 1923, while still based in Hastings, to focus on the development of television as a commercially viable enterprise. Given Baird's character, it seems likely that his interest in television derived from the widespread publicity and speculation about this as a possible successor to radio. But it also matches up to his presumed discovery of a technical advance that might serve to overcome the lack of success by others seeking to create television. Rankine's article with its comment on the "Thalofide cell" may have provided that insight into a potential solution. Social discussions (in London) that involved the many interested parties could also have brought the key information to Baird's attention.

At any rate, Baird began his research in earnest, in Hastings, and developed the light chopper as an attempt to overcome the time lag of selenium cells [19]. Baird published an advertisement in *The Times* in June 1923, asking for technical advice. Captain A. G. D. West, from the BBC, visited Baird a few weeks later and was very supportive of Baird's investigations [31, pp. 64–66]. West assisted Baird in obtaining components, and this supports our assertion that Baird was part of a significant network of interested experts.

From these discussions and the published works that he likely became aware of through them, Baird must have come to appreciate the significance of the Thalofide cell, relative to addressing the light-sensitivity and response-rate problems of the selenium cells. However, the cost of a Thalofide cell was prohibitive at £50 [17, p. 57], [22, pp. 69 and 74], [29, p. 254], or £3000 in today's money, for a struggling developer and researcher. After Baird received an inheritance from his mother, who had died in May 1924, and with the resources now available to him from investor Day, Baird purchased a Thalofide cell from Elwell, who was what we now call a reseller, supplying components related to the speaking films technology. Baird received that Thalofide cell on June 6, 1924:

> The photoelectric cell arrived today—Elwell had one in stock which he sent me[.] I also received the selenium cell from Dr. Ray [2, p. 54], [24]

Only ten days later, on 16 June, Baird wrote again to Day:

> I have just got the cell sufficiently sensitive to work by reflected light—that is actual objects not transparencies [2, pp. 59–60], [24]

In the ten days following his receipt of the initial Thalofide cell, Baird had cooled the cell to take advantage of the improvement in sensitivity, as reported by Coblentz. Baird thus demonstrated (to himself and backers) that the Thalofide cell was capable of distinguishing sufficient tonal variations to serve his goal. But this by itself did not result in a working television transmitter, which required improvements of other subsystems. Given only the ten days between his acquisition of the cell and Baird's statement of success [2, pp. 59–60], [24], it is certain that he had not acquired the Thalofide cell by mere chance and that his acquisition of the cell had a well-reasoned basis. The significance of the Thalofide cell was such that Baird subsequently filed patent GB300,183 [13] (US1697451):

> This invention is for improvements in or relating to light-sensitive electric devices of the type in which light-sensitive materials such as selenium, thallium sulphide, carbon and so forth are used ... means for controlling its temperature whereby it may be operated in circumstances in which the temperature effect is additive to the optical effect when radiation falls on the cell: the sensitiveness is thereby considerably increased [16]

Why was this patent filed so much later? In other topics, Baird filed patents quickly. We believe that Baird understood that he alone had appreciated how the Thalofide cell's characteristics could provide a means of achieving television in the near future. He must have felt more secure in keeping this knowledge as a trade secret, as opposed to revealing his approach in patent documents that would be visible to all. Another possible reason for Baird's reticence may relate to concerns that his use of this technology could, if known, lead to complications arising in America in relation to this device:

> Elwell does not seem to have considered the need to seek Case's prior approval before agreeing to the sale [22, pp. 120–121]

The degree to which Baird kept this commercial and technical information within a tight circle of trusted colleagues and partners was so extreme that Baird's significant discovery has remained a secret until now.

On December 14, 1924, after Baird had moved back to London, Elwell gave a talk there in which he described the Thalofide cell. Elwell was the Managing Director of the British de Forest Phonofilms Company Ltd., a company using the Thalofide cell to play back sound recorded on film [17, pp. 60, 81, 84, 85], [22, p. 105], [29, p. 276]. It is possible that Baird attended the lecture. If so, this would have provided Baird with the information which was also included in the summary of Elwell's lecture, published in early 1925 [23, pp. 466–469], concerning the capabilities of the Thalofide cell. Perhaps more importantly, the increasing publicity about the Thalofide cell created a wider interest, with additional individuals exploring what the cell could do. Those experiments led to an understanding about the need to keep the applied potential difference below 30 V [6, p. 185], the cell's fragility, and ultimately, the value of using this device with flashed ruby glass enclosure [6, p. 185], [18]. The use of an evacuated glass envelope filled with helium was known to prolong the life of the cell, while at the same time to increase its light sensitivity fivefold [6, p. 185]. Baird's acquisition of a second Thalofide cell [22, p. 121] may well relate to the loss of the first one by exceeding its little-known limits during experimentation. The fragility of the Thalofide cell may well have increased Baird's motivation to develop a substitute (e.g., the designs for the colloidal "eyeball" cell) [6, p. 185], [16].

Examination of one of a number of similar, but differently detailed photographs of the double-eight transmitter, taken near the time of the Selfridge's demonstrations (see Fig. 5), supports our suggestion that Baird was experimenting with a Thalofide cell at that time. The image indicates that the photocell is mounted inside a plain metal box. This correlates with the description by Coblentz of how he mounted the Thalofide cell to give maximum results:

> In order not to injure the cell by exposure to strong daylight, it was placed in a suitable light-tight, tubular mounting (with a shutter), which could be slipped into the permanent ways which support the thermopile before the spectrometer slit. Subsequently, for testing the effect of temperature, this mounting was modified by surrounding it with a small tin box, which could be filled with ice or water . . . Moreover, since the cells were mounted directly at the exit slit, and 2 to 3 cm back of it, a wide portion of the photosensitive material was exposed to the radiation stimulus [18]

The presence, in this photograph, of the large metal box, presumably filled with ice, and with what appears to be a tube to drain the melted water, suggests the presence of the cooled Thalofide cell inside, arranged similarly as described by Coblentz:

> I have had a large steel case made to enclose the photo electric cell and the amplifier. This greatly reduces the interference and by further screening I hope to entirely eliminate it [2, p. 54]

The evidence strongly indicates that, by mid-June 1924, Baird had acquired a Thalofide cell, and by the use of cooling, was able to achieve a significantly improved sensitivity and had addressed the matter of noise. It then becomes a question as to why Baird did not exhibit this in the Selfridge's demonstrations some nine months later. We argue that there was a remaining challenge: to achieve signal amplification (see Section II-C) in a way that also overcame the lag of the cell. If the intent was to avoid exposing too much of the new technology at that point in time, then the decision to perform the Selfridge's demonstration with the by-then-superseded selenium technology also makes sense. Thus, it seems very likely that Baird's testing of the Thalofide cell occurred in parallel with continued development and demonstrations where he used the less-sensitive and slower selenium cell (the Selfridge's event).

C. Amplifier

We believe that the television system in January 1926 was based on the Thalofide cell. However, although he had succeeded in cooling the cell to increase its sensitivity (in June 1924) and had arranged shielding, these steps alone seem not to have been enough to achieve true television. The magnitude of the signal obtained from the cell was very weak and difficult to separate from the noise, reducing the clarity of the image produced and making any demonstration of the technology ineffective. Thus, Baird needed to find ways to boost the signal and to separate the signal from the noise.

Thalofide cells were high-impedance devices, typically having a resistance of 500 mΩ. They were designed to "read" a projection of the sound waveform as a variable-density image photographed onto the left-hand edge of the celluloid film strip. The moving image of the soundtrack, which was recorded onto the film separately by an alkaline earth oxide (AEO) lamp, resulted in a ladder-type pattern of variations of light intensity being focused and projected onto the cell [17, p. 40], [29, pp. 206–207]. Case had developed transformer-based amplifiers for amplifying the audio signals generated from the Thalofide cell that "read" the audio data. This amplified electric current was then suitable to drive a moving-coil loudspeaker for cinema audiences [17, pp. 39–54], [29, pp. 231–234].

However, the evidence presented in a report by Richard T. Beatty, of the Admiralty Research Laboratory, in December 1925 [2, pp. 96–97], suggested that low-definition television would benefit from a different approach when utilizing a Thalofide cell. During 1925, Beatty noted that his Thalofide cells would respond up to 20 kHz if used with resistance-capacitance amplifiers. Beatty visited Baird's laboratory before February 10, 1926 [2, p. 107], [8, p. 217] and was given a demonstration of the apparatus. We posit that Beatty's knowledge on the interaction of the cell with the amplification system was shared with Baird prior to the publications via the London network mentioned above, but there are no records of this.

With this information, Baird would have realized that, to achieve the Thalofide's full potential, he needed a suitable amplifier. Baird's bespoke differential amplifier was developed for the needs of his low-definition television system. His employee J. C. Wilson, effectively transcribing Baird's reflections [25], discarded the transformer-based amplifier commonly used for audio signals. These would have increased the gain of the signal, but that method of signal amplification would have been ineffective at the very low and very high frequencies that would occur with constant-brightness regions of the image or with rapid tonal changes. A transformer-based amplification approach would also not have improved the signal-to-noise situation. Concluding his analysis, Wilson states:

> For practical purposes, however, the best form of coupling is afforded by resistance-capacity, in which the anode load comprises a pure resistance and is effectively shunted by a grid condenser in series with the leak of the following stage, together with its grid input impedance [25, p. 158]

Wilson also discusses the four chief sources of background noise in valve amplifiers and notes the importance of cooling. It can be inferred that, if the signal-to-noise level was poor in the Thalofide cell, then cooling alone would provide sensitivity, but little or no net advantage would accrue if there remained a bad noise situation. Baird reported to Day, his financial backer, that he was also having trouble with noise, which he had resolved by:

> Keeping the valves well separated and enclosing the first three valves and the cell in steel cases connected to earth [3, p. 51]

We believe Baird was not only cooling the Thalofide cell, but also the resistive and valve elements of his amplifier that were connected to the photocell, in order to reduce or eliminate the noise generated by these electronic components and externally. Baird protected his discoveries, filing patent GB300,183 (US1697451), which states:

> This invention also comprises the combination with the light-sensitive cell, its circuits, and amplifying devices, of means for controlling the temperature of some or all of the parts in order that parasitic currents in the conductors may be minimised by cooling or freezing [16]

As an electrical engineer, Baird would have been aware that his purpose required a bespoke electronic amplifier. He needed to maximize the frequency response of the signal, while also suppressing noise, which included "noise" in the light falling on the cell from extraneous parts of the scene being imaged, along with electrical noise. Baird developed his own version of a differential, resistance-capacitance amplifier to boost the signals from the Thalofide cell [26]. Given the character of the signals arising from the photocell in use, and of the light signals incident onto it, Baird designed a gain control circuit that was based on the time-derivative of the incoming signal. The effect of this approach was to adjust the gain via a square wave that is "ON" for real signal and "OFF" for noise. Baird also arranged a bias potential to elevate the signal from the earth (ground) reference:

> In practice the lag of the cell can be treated as though the cell were equally responsive to variations in intensity of any rapidity and were shunted by a capacitance, so that it is possible to compensate for the frequency-attenuation characteristic of the cell by means of an electric network, the simplest form of which is obtained by placing an inductance in shunt across its output. In addition to this method of attenuation equalization, an artificial method of introducing the equivalent of the value of the first differential of the rising or falling voltage on the grid of the initial stage of the amplifier, in additive phase for a rising and anti-phase for a falling voltage, can be used with advantage [25, pp. 361–362]

Using this amplifier design, as well as protection within an earthed enclosure that contained the Thalofide cell, Baird was able to successfully televise a quasi-static image. This was achieved privately on October 2, 1925, and involved the transmission of an image of a dummy's head, and then an image of the office boy, William Taynton [4, p. 58]. This breakthrough in signal amplification was recognized by Baird [26] as being sufficiently important to warrant an immediate patent application, which he filed 19 days later. This approach to signal amplification allowed for the maximum image definition within the available bandwidth, producing the best-perceived image.

The evidence indicates that the *RC* dual-circuit amplifier, combined with the cooled Thalofide cell with its bias resistor, are the two key innovations that Baird combined and demonstrated privately on October 2, 1925, prior to his public demonstration on January 26, 1926. They allowed Baird to demonstrate true television, of moving images obtained in reflected light, in real time. Importantly, Baird was only able to demonstrate the Thalofide's performance, for the first time on October 2, not only after discovering how to increase its sensitivity, but, presumably, also after its integration with his improved *RC* amplifier, both located inside the cooled metal box, approximately 22 cm (9 in) in size, as scaled from the photographs.

In several senses, the first demonstration of moving, tonal television did not really represent a single invention, but instead was a milestone along a path that involved multiple inventions and improvements. Baird achieved his success by partitioning the whole task into a system of conceptual and then physical components. He improved the Nipkow-type disk, replaced the selenium cell with the Thalofide cell, and designed new electronic apparatus, that is, his resistance-capacitance amplifier circuitry, and used cooling. Each of the many demonstrations involved at least one major advance. The celebrated episode in January 1926 is certainly a deserved milestone [32].

III. SUMMARY AND CONCLUSION

This analysis of the world's first public demonstration of television reveals a purposeful approach that compartmentalized the task into a set of subsystem components that each required to be significantly improved or replaced, in order to achieve the outcome. The account paints a picture of an extremely talented individual who applied his skills and energy to achieve a significant goal in a remarkably short period of time. Baird's accomplishment did not emerge from a corporate laboratory; instead, he obtained funding from investors (now known as venture capitalists). The crude characteristics of his workshop attest to a highly motivated engineer who achieved his aim in spite of limited resources. Baird transformed information about the capabilities of the Thalofide cell into a solution for achieving television. To reach that goal, he had to improve the function of each subsystem element so that the Thalofide's capabilities could be maximized. The system was sufficiently functional and adaptable that it permitted Baird to demonstrate night-vision television (Noctovision) later that year, in November [3, p. 81].

The documentary evidence and technical analysis presented here point to Baird using a thallium sulfide or Thalofide photocell that was intended for a different application. This cell is one of the first photo semiconductor devices, according to the historical survey of such devices by Morris:

> One significant development was that of the Case "thalofide" cell invented during the war. . . . Arnquist notes that this work was significant in being the first real attempt to enhance the natural photoconductivity of a material by the addition of small amounts of another substance [27, p. 14]

Baird's work thus may be an early demonstration of the practical benefits of temperature optimization of semiconductor devices and their associated circuitry.

The aspects of commercial "intrigue" that emerge from this historical analysis exemplify the frequent conflicts between invention and commerce. Baird is readily identified with the "lone inventor" who overcomes obstacles due to his insights and hard work. He literally hid his secret inside a box to avoid the risks of being scooped by others seeking the same end. The British nickname for a television set, "the box," leads to the satisfying conclusion: the secret of "the box" was in the box. Furthermore, Baird's insight in applying existing technology toward another use, television, is the mark of someone thinking outside the box—now celebrated as an essential part of creativity. There is an element of (dry, British) humor in the out-of-the-box thinking, with the need to hide the results inside the box, in order to develop "the box." ■

Acknowledgment

The authors would like to thank Professor Emeritus Malcolm Baird, Department of Chemical Engineering, McMaster University, Hamilton, ON, Canada, for his invaluable advice and assistance with archival materials, along with comments on the contents of this article. Extensive, careful, and thoughtful reviewer comments have helped them to make significant improvements in the text. Ian Brown, Historical Radar Archive, is acknowledged for his considerable contribution toward the development of the first draft of this article. Professor Emeritus Mike Adams, Department of Radio, Television and Film, San Jose State University; Dr. Ian L. Sanders, Castle Ridge Press; and Dr. Douglas Brown, M.Phil., Ph.D., are thanked for their cooperation and assistance. They would also like to thank Jeremy Jago, the Chairman and the Newsletter Editor of the Narrow Bandwidth Television Association (NBTVA), for his helpful comments and suggestions. This article is dedicated to the memory of Peter E. Smith, C.Eng., G4JNU, who provided early inspiration to Brandon D. Inglis, and who was consistently generous in sharing his knowledge as a member of the NBTVA.

REFERENCES

[1] *The Times*, The 'Televisor' Successful Test of New Apparatus, Jan. 1926, no. 44181.

[2] R. W. Burns, *John Logie Baird, Television Pioneer*. London, U.K.: The Institution of Electrical Engineers, 2000.

[3] A. Kamm and M. Baird, *John Logie Baird: A Life Edinburgh*. Scotland, U.K.: National Museums of Scotland Publishing Limited, 2002.

[4] M. Baird, Ed., *Television and Me: The Memoirs of John Logie Baird*. Edinburgh, U.K.: Mercat Press Ltd., 2004.

[5] M. Baird, *Television Baird, the Story of the Man Who Invented Television*. Cape Town, South Africa: Haum, 1973.

[6] E. T. Larner, *Practical Television*, 2nd ed. London, U.K.: Ernest Benn Limited, 1929.

[7] BBC, *The Birth of Television*. Documentary First Broadcast, Nov. 1976.

[8] T. McArthur and P. Waddell, *Vision Warrior, The Hidden Achievement of John Logie Baird*. Kirkwall, U.K.: The Orkney Press, 1990.

[9] D. Brown, *The Three Dimensions of John Logie Baird*. Bedford, U.K.: Radio Society of Great Britain, 2012.

[10] A. Dinsdale, *Television, Seeing by Wireless*. London, U.K.: Sir Issac Pitman & Sons, LTD., 1926.

[11] J. L. Baird, "Television: A description of the Baird system by its inventor," in *The Wireless World and Radio Review*. London, U.K.: The Radio Society of Great Britain, Jan. 1925.

[12] D. F. McLean, "The achievement of television: The quality and features of John Logie Baird's system in 1926," *Int. J. History Eng. Tech*, vol. 84, no. 2, pp. 227–247, 2014.

[13] D. F. McLean, "Restoring Baird's image," *IEEE History of Technology Series*, London, U.K., 2000.

[14] Personalities of the Week, *Illustrated London News*, vol. 169, Feb. 1928.

[15] J. L. Baird, GB Patent 269 658, Apr. 20, 1927.

[16] J. L. Baird, "Improvements in or relating to light-sensitive electric devices," GB Patent 300 183, Nov. 7, 1928.

[17] S. Przybylek, M. Eckhardt, and J. Richerson, *Breaking the Silence on Film: The History of the Case Research Lab*. Auburn, NY, USA: The Cayuga Museum, 1999.

[18] W. W. Coblentz, "The spectrophotoelectric sensitivity of Thalofide," in *Bureau of Standards*

Scientific Papers. Washington, DC, USA: Bureau of Standards, 1920.

[19] J. L. Baird, "A system of overcoming the time lag in a selenium or other light-sensitive cell used in a television or like system," GB Patent 235 619, Jun. 12, 1925.

[20] T. W. Case, "Thalofide cell: A new photo-electric substance," *Phys. Rev.*, vol. 15, no. 4, pp. 289–292, 1920.

[21] A. O. Rankine, "Speaking films," *Nature*, vol. 108, no. 2713, Oct. 1921.

[22] I. L. Sanders and G. Bartram, *Cyril Frank Elwell*, 2nd ed. Morgan Hill, CA, USA: Castle Ridge Press, 2018.

[23] C. F. Elwell, "Speaking films," in *The Wireless World and Radio Review*. London, U.K.: The Radio Society of Great Britain, 1925.

[24] J. L. Baird, *Archival Collection Held by Hastings Museum & Art Gallery*, London, U.K., Jun. 1924.

[25] J. C. Wilson, *Television Engineering*. London, U.K.: Sir Issac Pitman & Sons, LTD., 1937.

[26] J. L. Baird, "Improvements in or relating to television systems and apparatus," GB Patent 270 222, Apr. 21, 1927.

[27] P. R. Morris, *A History of the World Semiconductor Industry*. London, U.K.: The Institution of Electrical Engineers, 1990.

[28] J. L. Baird, "Television," *J. Sci. Instrum.*, vol. 4, no. 5, p. 138, Feb. 1927.

[29] M. Adams, *Lee de Forest, King of Radio, Television, and Film*. San José, CA, USA: Springer, 2012.

[30] M. Exwood, *John Logie Baird, 50 Years of Television*. London, U.K.: The Institution of Electronic and Radio Engineers, 1976.

[31] S. Moseley, *John Baird, The Romance and Tragedy of the Pioneer of Television*. London, U.K.: Odhams Press Limited, 1952.

[32] *IEEE Milestone Celebration—The Evolution of Television from Baird to the Digital Age*. Accessed: Feb. 16, 2020. [Online]. Available: https://www.ieee-ukandireland.org/ieee-milestone-celebration-the-evolution-of-television-from-baird-to-the-digital-age/

[33] J. L. Baird and W. Day, "A system of transmitting views by means of telegraphy or wireless telegraphy," GB Patent 230 576, Mar. 19, 1925.

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Brandon D. Inglis received the Higher National Diploma (HND) in electronic and electrical engineering from Edinburgh Napier University, Edinburgh, U.K., in 1996, and the B.Ed. degree (Honors) in technological education from The University of Edinburgh, Edinburgh, in 2001.

During his childhood visit to the Edinburgh Wax Museum, Edinburgh, in 1984, the wax figure of John Logie Baird (JLB) and his double-eight transmitter (now located at The Carmichael Visitor Centre, Scotland, U.K.) left an indelible impression, and after seeing the poster, The Television Set, by Tim Hunkin, in 1988, he decided to embark on a private study of the life and work of JLB. Initial attempts to reconstruct JLB's equipment led to an acquaintance with Dr. Peter Waddell (retired, Department of Mechanical Engineering, University of Strathclyde, Glasgow, U.K.), and after a lecture by late Ralph Barrett, Fellow of IET, he was introduced to late Peter Smith, Chartered Engineer, G4JNU, a member of the Narrow-Bandwidth Television Association, and encouraged to join in 1992. In the following years, the then-chairman of NBTVA Doug Pitt promoted him to a Club Archivist. This led him to become involved in many projects ranging from accurate reproduction 30-line television equipment to eventually a full academic study, with some of that work forming the basis of this article. He has written and assisted with the preparation of articles for the *NBTVA Newsletter* and the biography *John Logie Baird: A Life*, NMS, in 2002. He mentored a distinction-awarded M.Sc. group project involving the design and construction of replica equipment at the University of Strathclyde in 2018.

Mr. Inglis has built replica television equipment for National Museums Scotland. He has been interviewed by British Broadcasting Corporation (BBC) Radio Scotland, Ninian Reid (Re: NMS, Baird video disk) and was involved with the production of the BBC/Easthaven JLB Film Ltd., documentary "JLB: The Man Who Saw the Future," in 2002, by supplying authentic 30-line re-enacted video materials.

Gary D. Couples received the B.S. degree in geology from Texas A&M University, College Station, TX, USA, in 1974, the M.A. degree in geology from Rice University, Houston, TX, USA, in 1977, and the Ph.D. degree in tectonophysics from Texas A&M University in 1986.

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