PROFESSOR DAVID EDWARD HUGHES [1829/1830/1831(*) -1900]

Fons Vanden Berghen
Halle (B) in December 2018

Introduction

There is a lot to tell about David E. Hughes. People know him for his revolutionary printing telegraph and his carbon microphone, but he had a lot more to offer. This is described in great detail in the fantastic book "Before We Went Wireless" by Ivor Hughes (not related to David E. Hughes) & David E. Evans (see [1] in the Bibliography at the end of this article). That book, published in 2011, was the result of in-depth research that took ten years. It resulted in a very informative book of 386 pages about the life and work of professor David Hughes. As far as I am concerned, it deserves a PhD cum laude! I was contacted by Ivor in 2009 when he discovered that there were three different models of the historical 'piano keyboard telegraph' in my collection and asked for permission to include some of my photographs in his future book. Of course, honoured with his question, I gladly allowed that. I then had the pleasure to exchange a number of e-mails with him. So I learned that he had previously published a detailed summary of the life and work of Professor Hughes in the Journal of the American Wireless Association [3]. And now he has given me permission to use his article extensively to upholster my article below. I could not find a better source and almost everything here in Part 1 is based on his article! I have limited myself here to the field of telegraphy. This well-known microphone and to his discovery of wireless transmission; but Ivor's article also describes Hughes's further experiments in other fields.

(*) Regarding the three different years of his death, I have the following explanation from Ivor Hughes:
"His Obituary quotes 1831 and his grave May 16th, 1830. Our research, though (see page 7 of my book) puts it at 18th June, 1829. This is based on baptism records which state his birth date. We were never able to find an actual birth certificate. Hope this either helps or confuses."

PART 1:HISTORICAL INFORMATION

1.1. Prologue

Professor David Edward Hughes was a brilliant inventor and practical experimenter, as well as a gifted musician, ever inquisitive and a true lover of science. He was born when Michael Faraday and Joseph Henry were still uncovering the mysteries of "electricity", a time when they and others were wrestling with the observations that electricity could create magnetism, and magnetism could be used to create electricity. He lived through a period rich in famous names still familiar today, such as William Thomson (Lord Kelvin), Cyrus Field, Samuel Morse, Thomas Edison and Alexander Graham Bell.

Hughes was to leave his mark through his inventions and discoveries in the fields of telegraphy, telephony, wireless, metal detection, and audiology. He was an international scientist whose life was spent between America, Britain, and Continental Europe, and became one of the most decorated scientists, receiving high honors from no less than nine countries. Hughes was one of the few self-made scientists who were able to amass a substantial sum of money over his lifetime, which upon his death he generously donated to the London Hospitals. However, like many of the early scientific foot soldiers who laid down the foundations of our communications industry, his name has tended to sink below the history horizon.

1.2. His early years

His father, originally from Wales, and a boot maker by trade, was a gifted musician who moved to London, married and had four children. David Hughes and his two brothers and sister appeared to have inherited their father's gift and also turned out to be natural musicians. At only six years old, David is known to have played the harp and English concertina to a very high standard! This talent wasn't wasted, as an infant musical troupe was formed and toured the music halls of London and the provinces. They were billed as the "Child Prodigies" and went on to perform for the Royal Family and other notables. Buoyed by their success, the child prodigies musical show was taken on tour to America, which opened its arms to the child performers. Their popularity and novelty led to the honor of performing at the White House. After several years of show business they had acquired significant wealth and the family retired from the entertainment business to take up touring for pleasure. Their travels were extensive, covering North America from Nova Scotia to New Orleans. Any thoughts of returning to the old country appear to have slipped away, and in the 1840s the family settled down on a farm in Virginia.

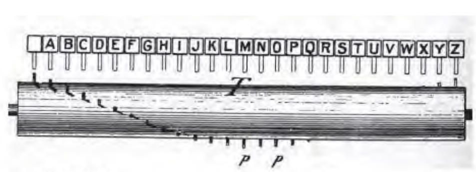
The "Child Prodigies"

During their travels, the children's education was not neglected and a private tutor traveled with them. David Hughes showed the same flare for the sciences as he had for music. He was both inquisitive and inventive and his father built a laboratory next to the farm for him. Here, Hughes spent his time carrying out chemistry experiments, taking mechanisms apart, building new ones, and making improvements to their mining equipment. Hughes was living in an interesting period and would see the birth of many new technologies throughout his lifetime. One of these was the transition of electricity from a poorly understood phenomenon into a technological powerhouse. This occurred when it was applied to the electric telegraph introduced during the 1840's by William Fothergill Cooke and Charles Wheatstone in England and Samuel F.B. Morse and Alfred Vail in America. Overnight, almost, it seems that communication time shrank from months, weeks or days to a matter of minutes.

1.3. The Telegraph Era

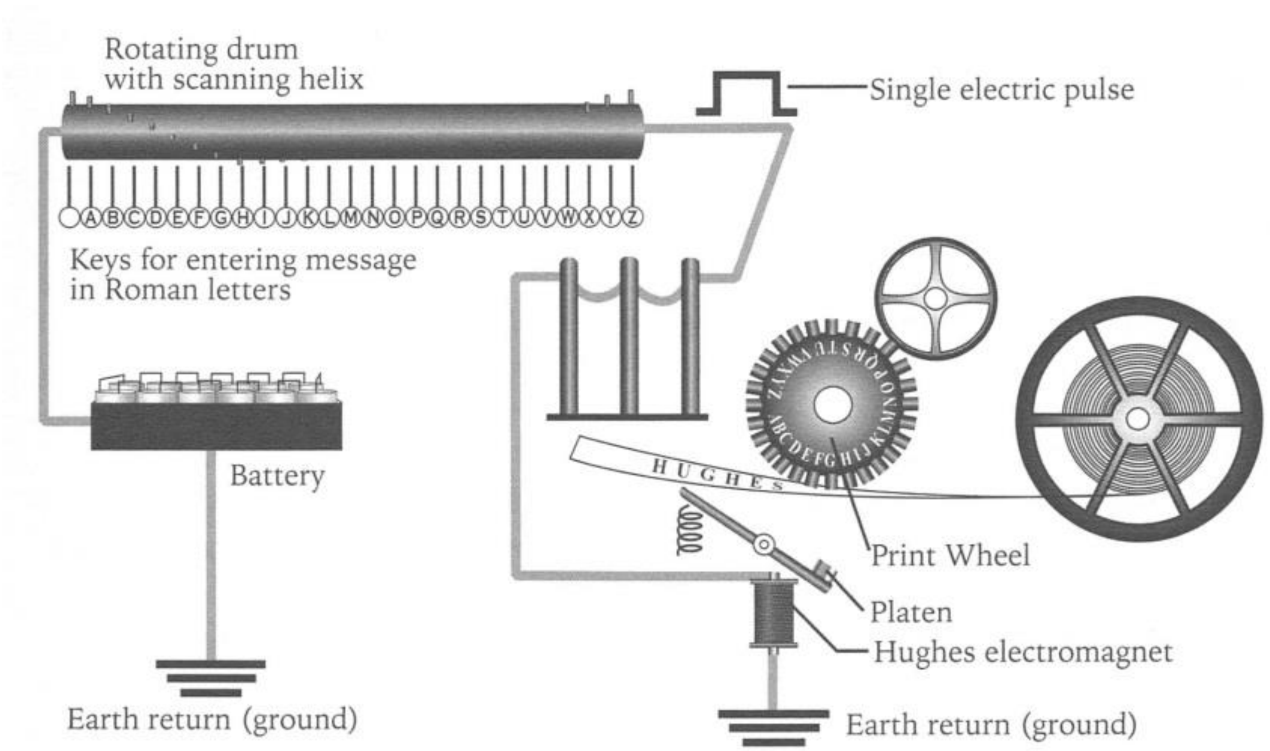
It was while Hughes was a teenager that he first saw a Morse telegraph system in operation. Always inquisitive when he saw new mechanisms, he questioned the operator as to how it worked. Whilst simple and practical in its operation, it must have set his innovative mind to pondering how such a system could be improved. Over the following few years, he was to bring his ideas to fruition by inventing his own telegraph instrument. As he came to the end of his teen years, he became restless, tired of the limited amenities of rural Virginian farm life. People were starting to look to the west for new opportunities and he decided to join the migration. He applied, and was accepted for a post as a professor of philosophy and music at St. Joseph's College in Bardstown, Kentucky. This was somewhat of an accomplishment at his young age, but Hughes was proud of becoming a professor, a title he maintained throughout his life. The move to Kentucky in 1850 turned out to be a tough period for him as he had limited money and had to juggle his time to accommodate teaching, taking on private music students and experimenting with his ideas for a new telegraph instrument.

Indeed, during this period Hughes started to formulate how he could implement the telegraph instrument he had in his mind. He decided that instead of using codes that required operator training, as well as requiring multiple pulses to be transmitted, it would be better if one could just type in the message directly as alphabetical characters and print them out at the receiving station. Hughes was not alone in attempting to invent a better telegraph instrument and a number of systems had or were appearing, using a variety of operating principles and vying for their place either in the European or the American market. These used signaling methods such as a multitude of short and long pulses as in the Morse system; a long stream of pulses as in the step by step systems; or signals of different polarity as in the needle or dial systems. In America at that time there were only two serious contenders to the Morse system: the Alexander Bain electrochemical telegraph and the Royal Earl House printing instrument patented in 1846 and in operation by 1847. Whilst these instruments were used by some of the telegraph companies, Morse was by far the dominant system, and he constantly fought to keep it that way by challenging any attempts by patentees of other systems. Hughes's idea of typing in letters and either displaying or printing them at the receiver was not new, and had been used by Paul Gustave Froment in France and Royal Earl House in America. However, his ideas and approach would result in an instrument that would both look and operate differently.
His concept was to provide a keyboard at the sending end so that the letters could be typed in directly, and at the receiving end print out the letters and words onto a paper tape. One of the most ingenious parts of his telegraph, though, was in its method of transmitting the information from transmitter to receiver. Up to that time, telegraph systems were based on transmitting voltage pulses and used only three parameters: amplitude, polarity and duration, in their method of signaling. Hughes, however, introduced a time element to his scheme. His notes indicate that he conceived of a one "wave" system (waves were often used to refer to pulses). He had figured out how to transmit all 26 letters of the alphabet using a single pulse. To accomplish this he constructed a keyboard not unlike a manual typewriter, except the keys were arranged in alphabetical order. Next, he constructed a mechanical scanning device that could scan the keyboard to determine when a key had been pressed. This was implemented by using a rotating cylinder that had a helical pattern of 26 protruding pins (not unlike a musical box cylinder), and driven by a clockwork mechanism.
When a letter key was pressed down, it pushed forward a contact that was struck by a pin of the helix on the rotating cylinder. By connecting a battery across the cylinder and keys, a voltage pulse would be generated whenever a contact was made. The cylinder was rotated at a constant speed and scanned all 26 letters once each revolution. For example, if the "A" key was pressed the first pin on the rotating cylinder would make contact and if "E" was pressed then the fifth pin was struck (but displaced in time by 5/26 of a revolution). Thus, he had set up a repetitive time base (equal to the rotation of the cylinder) that was in turn subdivided into 26 time slices. Each time slice could transmit a one or a zero, represented by a pulse or no pulse. (In actual practice, Hughes used 28 keys and the machine ran at 120 rpm). Depending at what position the pulse



Helix Scan

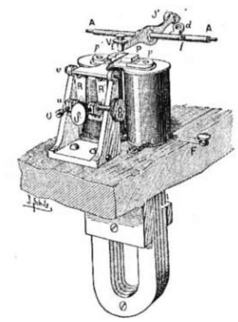
occurred within the time base indicated which letter had been transmitted. What he had conceived of was a *pulse position modulation* system that would find many future applications and would later evolve into *time division multiplexing*.



The Hughes telegraph system showing the keys and scanning rotating helix of the transmitter. Pressing any key resulted in the transmission of a single electrical pulse which activated a Hughes relay in the (synchronized) receiving instrument, causing the rapid release of the platen and the printing of the letter on a moving paper tape.

At the receiver, he arranged for a print wheel (with 26 letters plus the two extra positions - a period and a blank) to rotate at a constant speed and in phase with the scanning cylinder in the transmitter. Below the print wheel was a platen that could be rapidly raised against it, and a continuous paper strip was fed over the platen. When a pulse was received, it triggered the platen to be rapidly lifted and briefly contact the print wheel to print a letter on the paper tape. Other mechanisms advanced the paper and inked the print wheel.

What follows is for technical people…
Hughes's challenge was how to get two telegraph instruments to run in perfect synchronism and phase separated by tens or hundreds of miles. Here all his experimenting with clocks came into play, as they were at the time the highest precision mechanism available. He solved the problem by using a vibrating spring strip to provide the precision timing instead of a pendulum, which would have proved far too slow. The oscillating spring strip drove a typical clock mechanism with an anchor escapement. The power for the mechanisms was provided by a falling weight drive similar to that used in grandfather clocks. In return, the vibrating spring received a nudge from the escapement wheel each period to keep it oscillating. The vibrating spring was also fitted with a temperature compensating mechanism to keep the vibrating frequency constant.

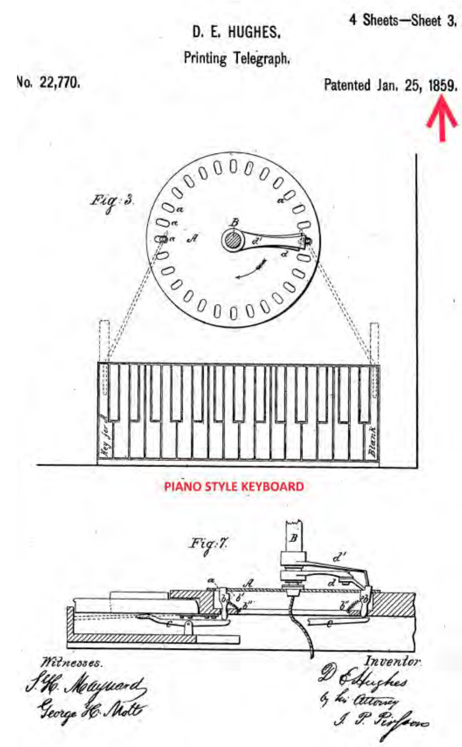


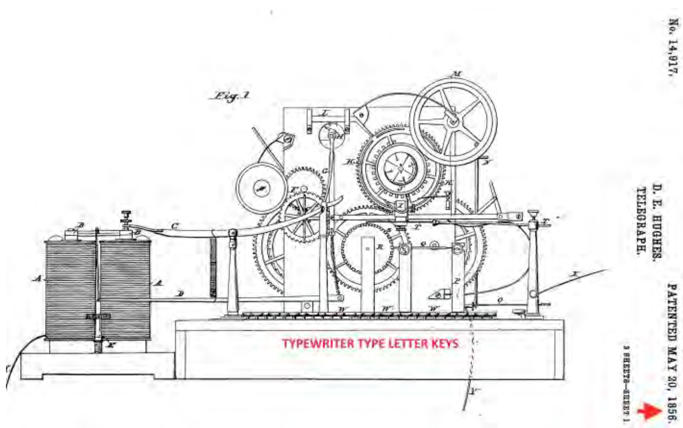
Hughes's approach was based on transmitting low voltage pulses and using a sensitive detector in the receiver (later called a polarized relay). The detector was a smart piece of design. Hughes used a permanent horseshoe magnet with soft iron pole pieces onto which were wound coils. He then arranged an armature to close across the gap, held by the magnetic force of the magnet. The armature had a spring attached that could be tensioned such that it was just about to pull the armature clear. When a pulse was received it was routed through the coils. The resulting magnetic field generated was in opposition to that of the permanent magnet, thus weakening it. This caused the armature to release and to fly off under the influence of the tensioned spring. Not only did this need a lot less electrical power to operate but also the response of the detector was very rapid. The release of the armature triggered the platen to rise against the print wheel. The actuation power for the receiver was also provided by a falling weight drive. As the printing was able to take place without stopping the print wheel, it contributed to its overall higher operating speed than other systems. Once the platen had operated, it also reset the armature of the detector.
End of this rather technical part

Hughes's design actually integrated a transmitter and receiver into one instrument, and it was designed from the start to operate in duplex mode (able to transmit and receive simultaneously). It was also possible to send more than one letter per revolution of the scanning cylinder, provided that they were spaced a number of letters apart equal to the time needed to recycle the receiving relay. For example, the word "fly" could all be transmitted within one revolution, again further contributing to the speed of transmission. The usual quoted average was three letters per revolution, and five was the maximum.
The instruments at the sending and receiving end had to by synchronized, and the following procedure was used to accomplish this. Instruments could initially be accurately set to run at close to the same frequency after manufacture. Then installed instruments, say in New York and Philadelphia, were set to start in phase. The transmitting instrument and receiver instrument were first latched in the "blank" position. In both instruments, the mechanisms were all running, except that the print wheel was declutched from its rotating shaft and held at the blank position in a waiting mode. The transmitting operator then pressed down the blank key on the keyboard. When the receiver detected the blank signal, it unlatched the print wheel setting both instruments to run in synchronism. This clever arrangement also took care of instrument time lags and transmission line lags by automatically offsetting the print wheel equal to the time difference. As these time lags would remain constant, the instruments would remain in synchronism. Time lags up to one revolution of the print wheel could be accommodated (0.5 sec for a rotation of 120 rpm).
Next, to ensure that both instruments were running at the same frequency the following procedure was used. The transmitting instrument sent out a string of the letter "A". If the receiver printed out a series of "A"s then they were running at the same frequency. However if the receiver printed out letters that were running away, say B, C, D, etc., then the receiver was running too fast or if it was printing Z, X, Y, etc., then it was running too slow. Thus, the frequency of the receiver was adjusted until a series of "A"s was printed.

Hughes finally managed to complete his prototype instruments and get them to successfully operate over telegraph lines in 1855, with an average speed of 44 words per minute. His next move was to patent the instruments and see if he could get the telegraph companies interested in buying the rights. At the time there were many competing telegraph companies, with a fragmented operation covering the Eastern part of America. One of their big customers was the newspapers, and, in particular, the Associated Press (AP), who had an ongoing battle to reduce the cost of sending their dispatches over the Morse-dominated telegraph lines. When Hughes had barely completed his prototypes, the AP got wind of his invention and summoned him to New York. If they could acquire Hughes's telegraph, they could put pressure on the Morse telegraph companies by threatening competition to force reduced rates and possibly bring about some cohesion in the industry. Hughes's new instrument provided the impetus for the New York businessmen to move forward with some bold plans and form the "American Telegraph Company" (ATC) with Peter Cooper as president and Cyrus Field, David Hughes and others as 'corporators'. The AP played a prominent role in bringing this about. Hughes was offered $100,000 for his telegraph system - a sum that must have been beyond his wildest dreams. This was to set a pattern for his life, as he always seemed to be just in the right place at the right time with the right product. He was, however, unaware that his invention was to be a pawn in the American Telegraph Company business dealings. The AP and ATC now had a competing telegraph system and some clout to use against the Morse companies to start forcing them to amalgamate with the ATC and reduce their costs.

Hughes' instrument was assessed as not being robust enough to survive the daily use by telegraph operators. To solve this, the ATC put their experienced technician, George Phelps, to work with Hughes in upgrading the instrument. This relationship was not always harmonious, as the young Hughes was protective of his invention, while the more senior Phelps - an experienced machinist and familiar with the telegraph instruments of the day - was probably full of ideas as to how to improve the mechanisms. The eventual outcome, however, was an instrument that was more robust, incorporating various changes and improvements. These were: replacing the typewriter keyboard with a piano style keyboard, changing the mechanical scanning mechanism to a rotating commutator, beefing up the clockwork mechanism, adding a corrector mechanism to keep the instruments in tight synchronism, and combining the transmitter and receiver weight drive mechanism. Manufacturing commenced and the instruments started to be put into service. Hughes patented his original telegraph in England in 1855 and in America in 1856.





By 1858 Cyrus Field was ready to make a second attempt to lay a cable across the Atlantic and invited Hughes to England to join him. Hughes couldn't refuse the challenge and was drawn into the project. His involvement briefly spanned the summer and fall of 1858. In that period he was to meet, and work with, the 'famous' William Thomson (later to become Lord Kelvin). But his contributions came to a sudden stop in the fall of 1858 as the cable that had operated for a short while went dead. After that failure, Hughes tried to break into the British market dominated by the established "Cooke and Wheatstone" telegraph system, with no success (*check my article on them*). He had decided that there wasn't much point in returning to America, since ATC owned the rights to his instrument and the telegraph industry was starting to become monopolized by them and, eventually, Western Union. His instrument was subsequently further modified by Phelps, who combined some of the features from the Hughes and House instruments with his own to construct what became known as the "*Combination Instrument*" and remained in service for many years.

Somewhat disillusioned in Britain, Hughes headed for France. It turned out that they were open to evaluating new systems. After a successful trial period, his telegraph system was adopted in 1861 - again he just happened to be in the right place at the right time. The French put his system into use on the heavily used telegraph lines: Paris-Lyon, Marseille-Lyon, Paris-Bordeaux, followed by Paris-Le Havre and Paris-Lille. They were happy enough with the system and Hughes's performance that Emperor Napoleon III presented him with the 'Imperial Order of the Legion of Honor' in 1864. Unlike in America, (and initially Britain), where the telegraph companies were private or publicly traded, the Continental telegraph companies were all state run. The Administration arranged to have Paul-Gustave Froment and his workshop in Paris manufacture Hughes's telegraph instruments. This turned out to be an excellent choice as Froment was able to make many improvements and upgrades. In the photo hereby we see a typical Froment model. Froment unfortunately died in 1866. But the workshop continued to operate under the name of Dumoulin-Froment.

Adoption of his system then spread to Italy, Russia (with a solution for Cyrillic alphabet!), Germany, Turkey (with a solution for the fact that writing was read from right to left!), Holland, Switzerland, Belgium, Spain, Servia, &c until it was in operation throughout Europe. The reader will certainly allow me to expand a bit on Belgium…
In 1868, during the conference in Vienna of the International Telegraphic Union, the Hughes telegraph was generally accepted and Belgium introduced it in 1869. In 1877, the important telegraph station in the railway station Brussels North had 21 of them in use, and these remained in service until 1947! A Hughes telegraph achieved a speed of 40 to 45 words per minute, compared to 25 for the Morse telegraph. However, the Hughes telegraph did not push the Morse telegraph out of the market because it was rather expensive; he did indeed only profit on the busiest lines. In 1925 Belgium owned 2,631 Morse telegraphs against 122 Hughes ones. The basic design of the model in 1947 was largely identical to that of 1856, and lasted for nearly 100 years! Belgium later awarded Hughes the title of 'Officer of the Royal Order of Leopold'.

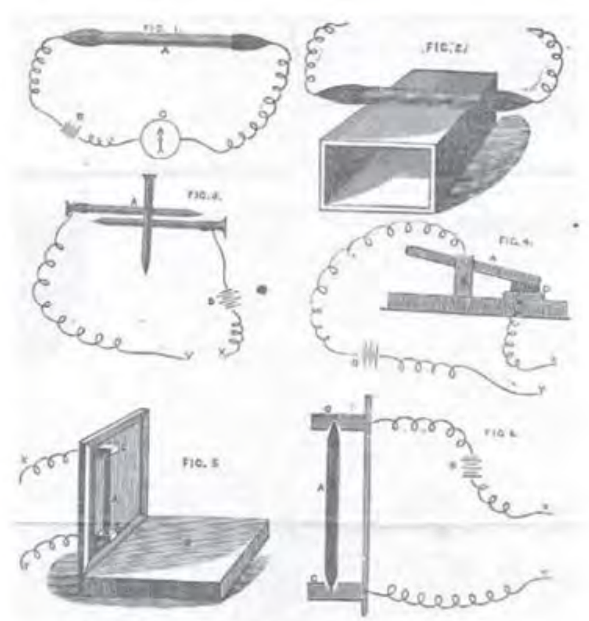
Whilst England initially had given Hughes the "not invented here" treatment when he had tried to introduce his telegraph previously, they eventually had to adopt his instruments to be compatible with the rest of Europe (although there was some rumour that they removed his name from the instrument to avoid embarrassment!). His instruments were put in to use by the United Kingdom Electric Telegraph Company, of which Hughes also became a director. Around 1870, his instruments were in routine service on many of the cross-Channel undersea cables. By the 1870s Hughes's telegraph, system was in widespread use throughout Europe as well as in South America.

Hughes spent most of the 1860s and early 1870s based in Paris, travelling widely on the continent in support of his telegraph systems, for which he had licensed a number of manufacturers. During this time he continued to make upgrades and improvements. These included adding numbers and symbols for a total of up to 56 characters, providing tactile feedback to the operator so as to know when a character had been transmitted, improvements to the timing mechanism, and changing over to electric motor drive.
By the end of the 1800s there were some 2,500 Hughes telegraphs in operation in Europe (where are they all gone?... ;o). The total number of telegraphs manufactured over the years was probably about 3,000. In the UK there was also a version that used a compressed air motor!

Hughes became known as one of the expert telegraph engineers of the day; he was not just in the business of selling instruments but was also promoting a communication system. He was also called on to investigate the growing problems of electrical interference and lightning strikes on telegraph installations. He was recognized for his service, as he became one of the most decorated scientists of the day, receiving honors from all the countries he had systems in. He also received the Gold Medal at the Paris Exhibition in 1867, along with Cyrus Field. In 1877, Hughes decided to move to London, then considered the scientific epicenter. His telegraph system had been so successful that he had become relatively wealthy, allowing him to become financially independent. He was now regarded as one of the pre-eminent telegraph men in Europe and was about to take his place in the scientific circle as an independent researcher.

1.4. The Telephone Era

Also in 1877, Alexander Graham Bell had just introduced his telephone, and it was the talk of the town. Whilst it was a wonderful invention, it had its limitations. Hughes, along with others, was quick to recognize this. Bell's telephone used the same electromagnetic component and diaphragm both as a receiver and transmitter. While it worked well for the former, it lacked power as a transmitter and therefore was limited in its signal output, and hence its range of transmission. Hughes decided it would make a good research project. While he recognized the components as functioning pieces of the telephone he saw them also as splendid pieces of test equipment. The telephone receiver, for him, was a device that enabled the amplitude and frequency range of signals to be easily measured for the first time over a wide dynamic range. He constructed a number of receivers for his own use as pieces of laboratory equipment. Next, he turned his attention to the transmitter. Hughes had actually used and demonstrated an earlier version of a telephone in 1865, when he borrowed a "Telephon" from the German scientist Prof. Philipp Reis. The Reis telephone had actually been the starting point for many of the early telephone experimenters such as Bell and Edison. Hughes made some experiments trying to improve on Reis's approach but they were unsuccessful. He next started his enquiry by pondering if there was a material or substance that could convert sound directly into electricity. This line of reasoning was based on the fact that it had been discovered that selenium altered its electrical characteristics when exposed to light. William Thomson had also shown that placing a wire under strain resulted in a change to its resistance. Hughes decided to pursue this approach. He set up a stretched wire to see if he could get it to vibrate when exposed to sound waves, believing that if it did then the strains experienced by the wire would change its resistance which in turn could be detected. His circuit consisted of a battery, the stretched wire and the telephone receiver, all connected in series. Fortunately, the experiment failed, but it was a failure that set him on a path of discovery. Hughes was a great experimentalist and seemed to be able to sniff out which way to proceed. In the failed experiment, which resulted in the wire being so extended that it broke, he noticed at the point of failure that he could hear in the telephone receiver a rushing sound and then a final crackle. Too many a broken wire or loose connection would be an annoyance but he was intrigued by the sounds he heard when the wire broke, it was something to be investigated. He tried holding the wires together and found that noises could be heard. He then laid the wires down on the table one on top of the other slightly weighted to hold them together and was surprised that he could hear sound. He embellished this experiment by laying three nails down to form a letter "H" and connected them into his circuit. Now he could hear even better – but not with much fidelity. He had discovered the loose contact effect as a means of detecting sound. His basic apparatus relied on being able to



Various Hughes microphones.

modulate a current by the loose or poor contact. It was a device whose resistance changed in accordance with the sound waves, just what he had been looking for. He went on to try many different arrangements and materials in a quest to improve the quality of the sounds he could hear. Some of these were glass tubes filled with metal filings, with charcoal pieces or charcoal powder as well as charcoal that had been impregnated with mercury**.** He tried many types of material contacts and found that metals that oxidized became unusable. Materials that didn't oxidize were platinum and carbon, and he chose the more economical of the two. As he refined his devices he found the most successful were based on a carbon pencil loosely supported between two carbon supports mounted on a piece of wood or sounding board. These he connected in series with a battery and the Bell receiver. He named it a "microphone", a magnifier of sound (in keeping with the microscope that magnified light). It was a true microphone in that it had many more applications other than just as a telephone transmitter.

He declined to patent the microphone, declaring that he was giving the technology away free to be used by anyone. His experiments were published by the technical societies and in many of the technical journals. The floodgates soon opened, and within a few months others were repeating his experiments and working on their own versions. Variations of the carbon pencil microphone were extensively used in conjunction with an electromagnetic receiver in Europe for many years by several companies. As an example I am showing here a Belgian model developed by a certain Mr. De Jongh (Dejongh?). A later variation, based on Hughes's demonstration of the use of particles in loose surface contact, resulted in the carbon granule microphone of Henry Hunnings. In America this technology was further developed by A. White into what became known as the solid-back transmitter, and in the UK as the Post Office insert number 13 microphone. The carbon granule transmitter was not superseded by any other technologies for use in telephones until the 1980s (and in some parts of the world they are still in use!). Hughes's theory as to how the microphone worked was that it was a surface effect due to the number of points in contact that "varied in sympathy with the sound waves".

Hughes was said to be always full of interesting experiences and of a light heartedness that made him excellent company. However at times he become a catalyst (or as some viewed it a lightning rod) for stimulating great debates within the scientific community, either on the theory of electrical phenomena or on his experimental results. One of these instances came about with his discovery of the carbon microphone when he crossed swords with Thomas Edison. Edison believed he had invented the carbon microphone first and suspected one of the English government officials (William Preece), whom he had confided in, of leaking his secrets to Hughes. Hughes's decision to give away his invention freely to the world only further infuriated Edison, who intended to capitalize on this invention. Unfortunately, the "Wizard of Menlo Park", as Edison was known, had misunderstood the circumstances, and before checking and discussing with Hughes, or others that he was accusing, immediately took the dispute public in the newspapers. Therefore, an affair that could have been settled amiably became a nasty war of words and accusations and counter accusations dragged out in the major technical journals and newspapers. The dispute drew in the who's who of the scientific world, who waded in with their opinions and in support of their respective champion. The dispute eventually became nationalistic pitting the much larger scientific community of Europe against the smaller one of America. In the end, it was concluded that each had carried out their research independently and there had been no leaks. Hughes, having discovered the microphone a device that had wide applications and Edison having concentrated specifically on the telephone transmitter. The chief scientist of the day in

Britain, Sir William Thomson (Lord Kelvin) scolded Edison in the press over the affair and requested an apology from him for his unfounded accusations - Edison never did reply.

Let me add here that the word ‘microphone’ was already coined by Charles Wheatstone in 1827 for a mechanical sound amplifier.

1.5. Wireless discovery in 1879

One of his discoveries was probably his most innovative, but was to be a bittersweet story. His experimentation, resulting in the discovery of wireless, became virtually hidden for many years and his discoveries only became known in the waning years of his life. His experiments took place a number of years before Hertz and Marconi. History finally credited him with the discovery but over time it has slipped off the pages of history.

It all came about when Hughes was experimenting with his “induction balance” in the fall of 1879. He had started with a primary circuit consisting of a set of coils being pulsed from a battery by clockwork driven contactor. A secondary circuit consisted of a second set of coils inductively coupled to the first that were connected to a telephone receiver. When he rearranged this configuration, it gave him some unexpected results - in that he could still hear the make and break signal even when he though he shouldn’t. He suspected it was either due to an effect called the “extra current” (the current induced in an inductor when its magnetic field rises or collapses) or the breakdown in the insulation of one of the coils. However, it turned out to be a loose connection between some wires. As the effect was puzzling, he pursued it, substituting one loose connection for another by inserting one of his loose connection microphonic joints from his microphone experiments. Still he was able to continue to hear the signal in his telephone receiver. The mystery grew as he separated the primary circuit from the secondary by some distance and only connected by a single wire. He was struggling as to how the signal could be heard with a circuit that was apparently incomplete - that is open circuit. He also experimented by removing the coils from the secondary part of the circuit and he could still hear the signal of the make and break in the telephone receiver. He then proceeded to the next inevitable step he cut the connecting wire and still could hear the signal. He was baffled and rationalized that the signal must be traveling between the two circuits by “conduction” through the building structure. Initially the gap between the two circuits was only six feet. He then moved the receiver (although Hughes didn’t use this term until much later) to the next room, and eventually some 60 feet of separation.

What was significant was that he was detecting the make and break with a receiver in which the secondary coils had been removed and consisted only of a telephone receiver in parallel with his microphonic joint. In these experiments, he had started to ground one side of the circuit to either a gas pipe or water pipe (not unusual for a telegraph engineer). He also took the receiver a couple of floors down in his house to his basement where he could still plainly hear. He grounded the receiver to one of the pipes and believed the signal grew louder and put this down to the fact that the different metals were creating a battery effect. This led him to add a small low voltage battery to the receiver circuit with the microphonic joint. To solve the mystery as to how signals were traveling between the transmitter and receiver he suspended the receiver by non-conducting cords from the ceiling and concluded that it could no longer be conduction through the house structure but the signal was coming through the ether (the air was considered to be more complex in the Victorian period). He concluded it was traveling by lines of force and the more of them he intercepted the louder he could hear the signal. It is surmised he came to this conclusion by comparing it to the invisible lines of force that surround a magnet or current carrying conductor.

Although he continued to call the device a microphonic joint it had become a detector and through extensive experimentation it had taken on a much different form and characteristics. His experiments revolved around trying to improve this device so that he could hear signals louder. He settled finally on two configurations for the detector: one of oxidized copper wires looped together, and the other a steel

needle resting on a piece of coke. He encapsulated these detectors into small bottles for protection. In arriving at these he had also tried many other forms of his microphone components with mixed results such as a glass tube filled with metal filings and iron wires dipping into mercury.

Hughes next took his receiver mobile and walked out into the street and continued walking, and was still able to hear the signal until by 500 yards it had faded away. This was an embryonic “wireless” experiment but the phenomenon of creating the invisible electromagnetic waves and being able to detect their presence was unknown at the time. It is interesting to note that his previous inventions of the microphone and induction balance and his use of the telephone receiver were all necessary prerequisites and essential ingredients leading up to this discovery.

Hughes was a scientist of the school that was called “the practical men” whereby discoveries were made by experimenting. Any supporting theory or formula was a rarity and quite often regarded as suspect by these “practical men”. However there was a new breed of scientist surfacing, these were mathematicians and physicists who tackled problems first from a theoretical point of view. One such person was James Clerk Maxwell a brilliant Scottish mathematician and physicist working at Cambridge University. In the 1870’s he predicted mathematically the theory of electromagnetic radiation, (the basis of wireless signals), a theory he amazingly developed without any experimental evidence or indication of how electromagnetic waves might be produced or detected. Looking back, this was profound, and its impact wasn’t fully understood at the time. Meanwhile, just over 50 miles away in London, Hughes had experimentally demonstrated just what Maxwell had predicted in the 1870’s and had produced electromagnetic waves and detected them - which was the experimental validation of his theory and the missing link. Unfortunately, fate was to intervene, Maxwell died young in 1879, the year Hughes made his discoveries. And Hughes, who was not a mathematician, would not have been able to decipher Maxwell’s complex mathematical equations. Hughes, however, was so excited by what he had discovered that he repeated his experiments in 1880 to important members of the Royal Society, the premier scientific organization of the day that included Professor Gabriel Stokes. Stokes was also from Cambridge University and a mathematician who knew Maxwell and was aware of his work. Could he possibly make the connection between Maxwell’s theories and Hughes experiments? However, it all unraveled, and what could have been the start to a brilliant discovery possibly Hughes greatest and the verification of Maxwell’s work was stopped dead. Stokes observed the experiment and stated that it was not a new phenomenon and could be explained by already known facts of electromagnetic induction. He failed to make any connection with Maxwell’s theories or recognize it as a new phenomenon. It was just like pricking a balloon, dashing Hughes’s hopes and swaying the opinion of the other observers in the process. But his promising discovery, instead of being encouraged, was scuttled. Hughes was frustrated and angry after the meeting. For some reason, though, Hughes did not appear to have talked about his theory of the signals being transmitted by lines of force, but talked about conduction, probably confusing the issue.

1.6. His later life

Hughes was elected a ‘Fellow’ of the prestigious Royal Society in 1880, and continued his research and experimentation. See references [1] & [3] for the details. It was during this period in the 1880s that it seems Hughes finally managed to find time in 1882 to marry his longtime friend from Paris, Anna Chadbourne. She was an accomplished artist, a resident of Paris, and also an American citizen. In 1886 he was elected President of the ‘Society of Telegraph Engineers’ (later to become the ‘Institution of Electrical Engineers’ and now the ‘Institution of Engineering and Technology’, or IET). He continued to be recognized for his scientific contributions and in 1885 was awarded the ‘Royal Medal’ from the Royal Society. He was also active with the ‘Royal Institution’, becoming their Vice President in 1891. The Royal Institution had had such prestigious past president as Sir Humphry Davy and his protégé Michael Faraday.

Hughes realized as time went on that his breakthrough invention period was probably over. He still continued to receive money from the success of his telegraph systems and he had judiciously invested it, which provided him with a sound financial base. He and his wife, while enjoying a comfortable lifestyle, were not extravagant, and they elected to live in an apartment on Great Portland Street and later round the

corner in Langham Street. They enjoyed an extended tour of Europe each summer.
He started to use his energies in other directions, such as helping younger prospective engineers and scientists on their way. He was keen on seeing them get ahead with an education, especially if they showed initiative in helping themselves. To be in a better position to promote and influence them, he became associated with the London Polytechnic School of Engineering and became their President. He took the job seriously and often stayed up late at night writing letters of encouragement and advice to students, giving them hints and opinions on their inventions or experiments. He continued to be recognized for his work and was awarded the Albert Medal in 1897, a medal that Faraday, William Thomson (Lord Kelvin), Louis Pasteur and Sir Joseph Lister had previously received. As the century came to a close his health started to deteriorate and he barely saw the New Year in, as he died on January 22nd, 1900 and was laid to rest in Highgate cemetery.

Always generous in life he was also generous after his death. After providing for his wife and relatives he left a substantial amount of his wealth to the London hospitals in the form of "The David Edward Hughes Hospital Fund". To the professional organizations he left sums of money to establish medals to be awarded annually in recognition of original scientific research. The Hughes medal continues to be awarded annually at the Royal Society and has been presented to such notables as Stephen Hawking in 1976 and Alexander Graham Bell in 1913, as well as: Max Born, Robert Watson Watt (Radar), H. Geiger, Neils Bohr, Edward Appleton, Ambrose Fleming and Augusto Righi.

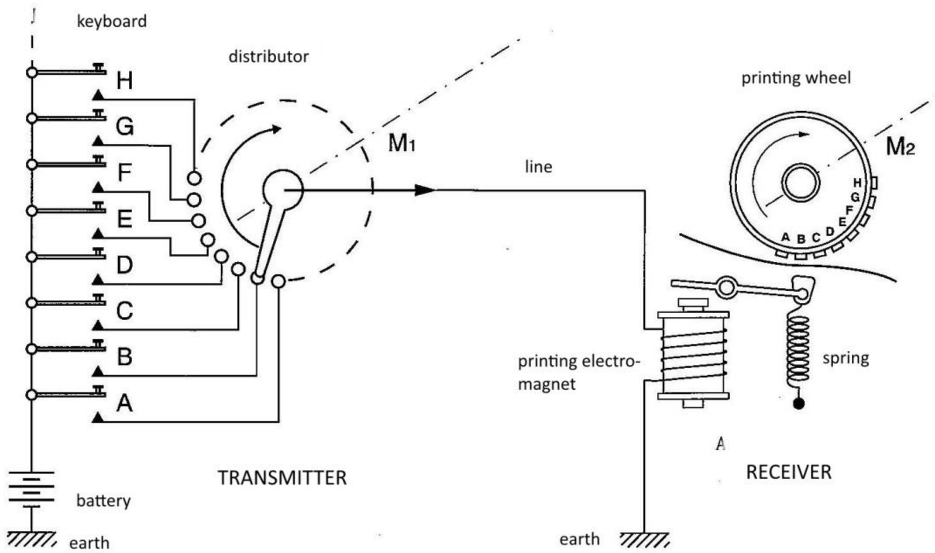
Epilogue

To me it is very remarkable that there are really many similarities between the life of professor David E. Hughes and that of Lars M. Ericsson (see my article on ERICSSON here in this chapter in my website).

PART 2: ABOUT HIS PRINTING TELEGRAPH

2.1.How does it work

Most old books on telegraphy have a chapter on the functioning of the Hughes telegraph. However, the explanation is not always clear. This is not surprising, if you know that in the book by Montoriol (see the Bibliography at the end of this article), he needed 287 pages to explain it...
I explain here, briefly, the principle of the 'modern' model.



In the transmitter all characters are connected to a corresponding contact point at the circumference of the distributor disk. A feeler arm is turning around. When a key (e.g. character B) is pressed on the keyboard, a voltage is applied to the corresponding contact point of that character. This voltage is picked up for a moment by the feeler arm which transfers it as a current pulse to the receiver. There a print wheel rotates, synchronously and in phase with the transmitter. All characters are embossed on the outside (circumference) of that print wheel. When the current is detected in the electromagnet the received current pulse will energize the electromagnet exactly at the moment that the print wheel has the letter B above the paper tape. The force of the electromagnet causes a hammer, normally retained by a spring, to push the paper tape to the letter B. On top of the print wheel (not shown in the figure) another wheel rotates with a felt band moistened with ink on the edge. As a result, the character is printed. The paper tape was then removed and pasted into appropriate pieces on a telegram form which was then handed over to the recipient as a telegram by the 'telegrams' boy.
For more technical details I gladly refer to Ivor Hughes's book, Appendix I, part 2 [see 1]

2.2. Different models

2.2.1. Ivor Hughes distinguishes four different models on his website [2]

Telegraph #1
The earliest models of Hughes printing telegraph are described in his British patent #2085 of 1855 and American patent #14917 of 1856 (see page 6). The patent model instrument is in the Smithsonian Museum, Washington. DC. (Photographs taken by the author). The instruments were powered by a weight driven clockwork mechanism. As described in Part 1 they had an alpha keyboard, a scanning helix mechanism, a vibrating spring strip (that provided the timing), the reduction gearing and clutches, a print wheel and the very sensitive Hughes polarized electromagnet relay.
In the photo here, a few elements are missing.

Telegraph #2

The function and method of data transmission stayed basically the same. What changed were the implementation and the hardware. This model was UK patent #938 of1858 and USA patents 22531 & 22770 of 1859 (see also page 6). A number of improvements were made: The helical scanning component was replaced by a rotating commutator, the horizontal vibrating timing spring was redesigned into a vertical vibrating rod, and the instrument was made more robust. The keys were switched to a piano format.
This model was also used in tests with Cyrus Field on the Atlantic Telegraph Cable while it was in storage. To increase the instrument sensitivity, Hughes added a sensitive galvanometer type relay and pulse polarity changer to his receiver. He also slowed the speed of transmission down and lengthened the transmitting pulse to make it compatible with the retardation experienced with undersea cables.
These additional features were covered in UK patent #1002 (1858).

Telegraph #3

This model was patented in the UK in 1863, patent #241. and was used extensively in Europe.
Again, the functionality of the instrument was the same but the implementation was evolving with additional requirements and robustness due to its heavy use. The vertical timing rod was replaced by a horizontal pendulous spring and bob weight, fixed at one end and caused to describe a circular motion at the other end.

Telegraph #4

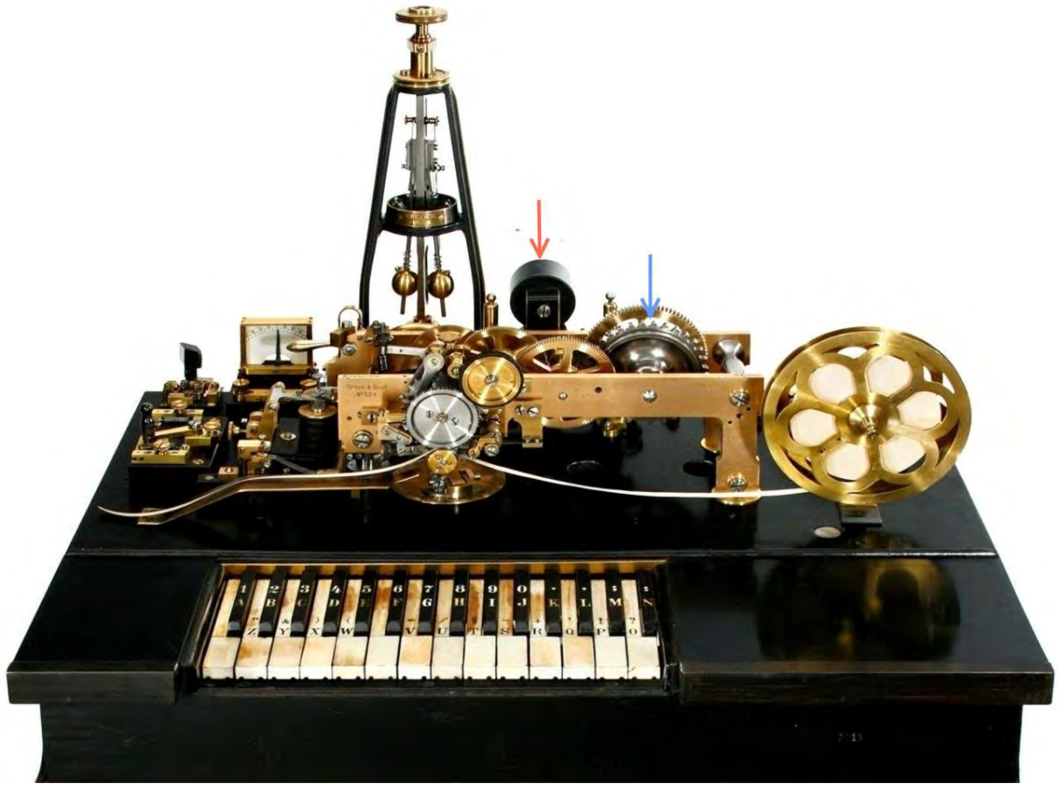
This final model used a vertical speed regulator with centrifugal drag brakes to maintain constant speed. The weight drive had now been replaced by an electric motor. This model stayed in operation until the 1930s, with some believed to be still in use during WWII.

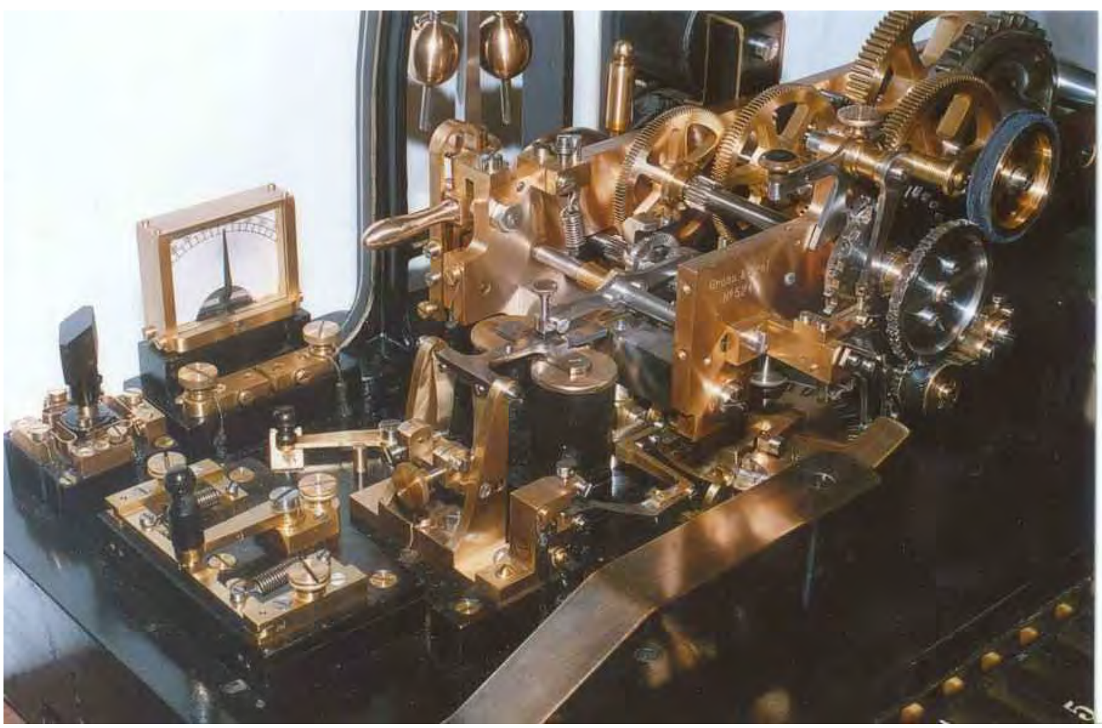
2.2.2. In my collection were 3 models, all with the vertical speed regulator but with different methods for driving the mechanism: by (1) weights, (2) by weights or an electric motor, (3) by an electric motor.

My 'model 1'
The photo shows the model that was powered by weights. The total weight of the lead discs was 50 to 60 kg! When they reached a critical depth they mechanically rang a bell to alert the telegraph operator, who could then 'pump' the weights upwards via a foot pedal (visible on the photo*)*.

My ‘model 2'

Later an electric motor was added to the model with weights (see the red arrow on the picture below). One could thus still switch to the weights in the event of a breakdown of the electric supply (then still in its initial phase)



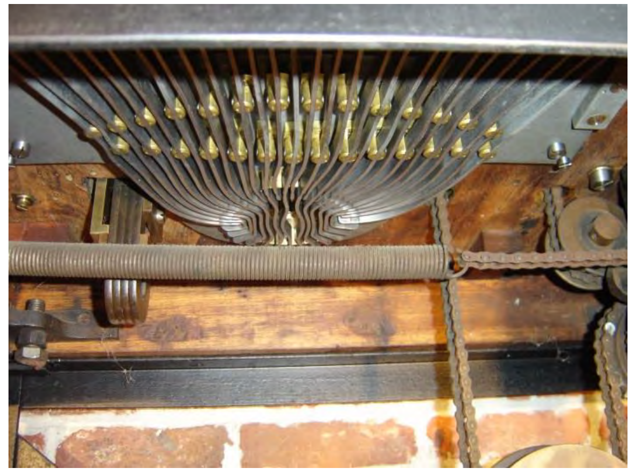


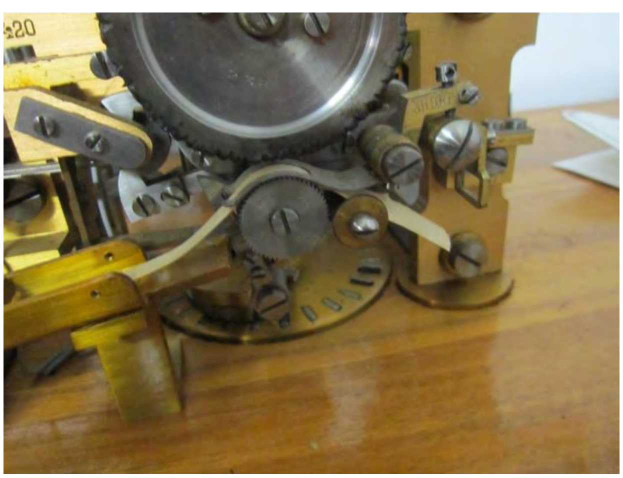
My ‘model 3'

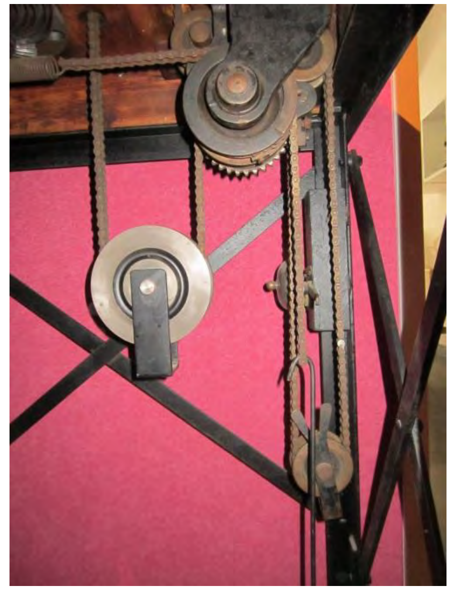
And finally there was the model equipped only with an electric motor and that was, therefore, mechanically much simpler. (It’s the one that can also be seen on page 1)

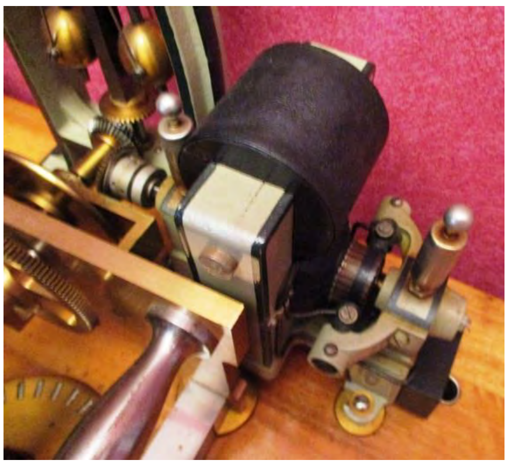
2.3.Then let's look at some parts

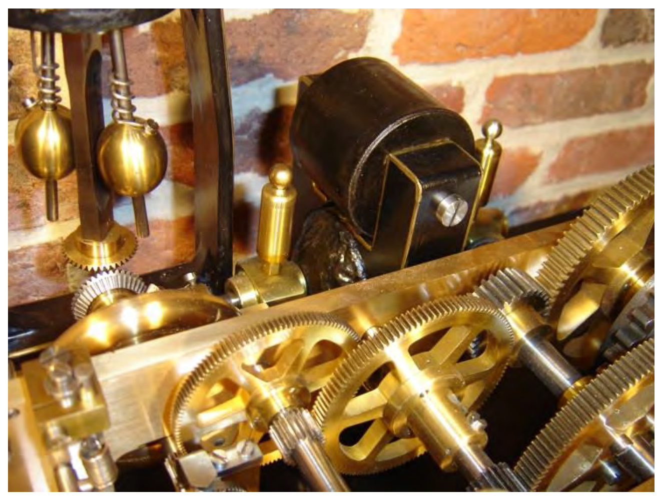
Collectors are fond of images of the instruments; well, here you are ;o)

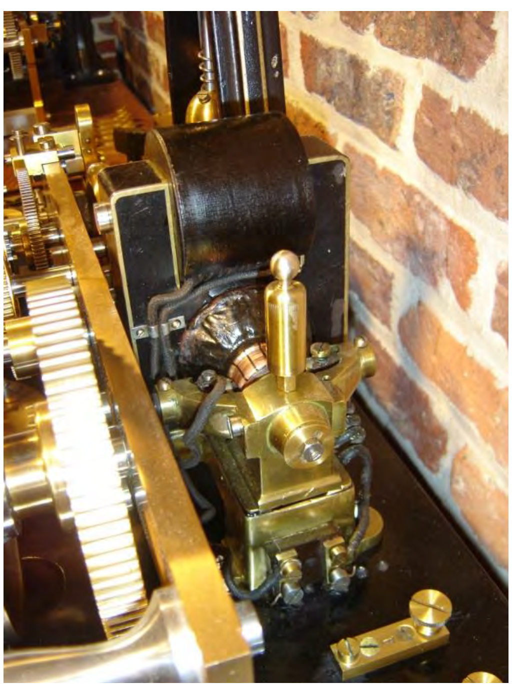


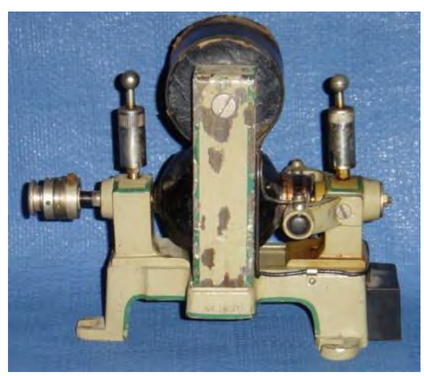


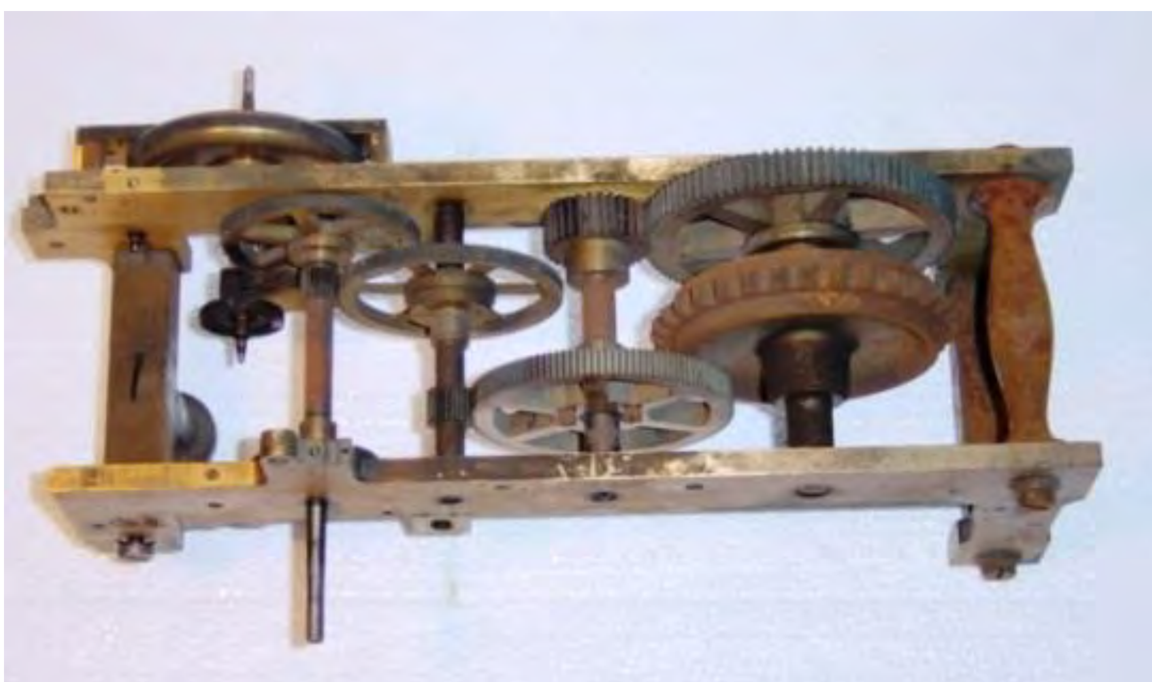










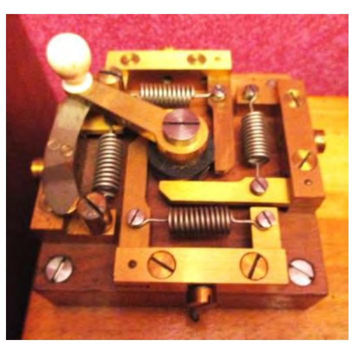



SIEMENS & HALSKE
PATENT

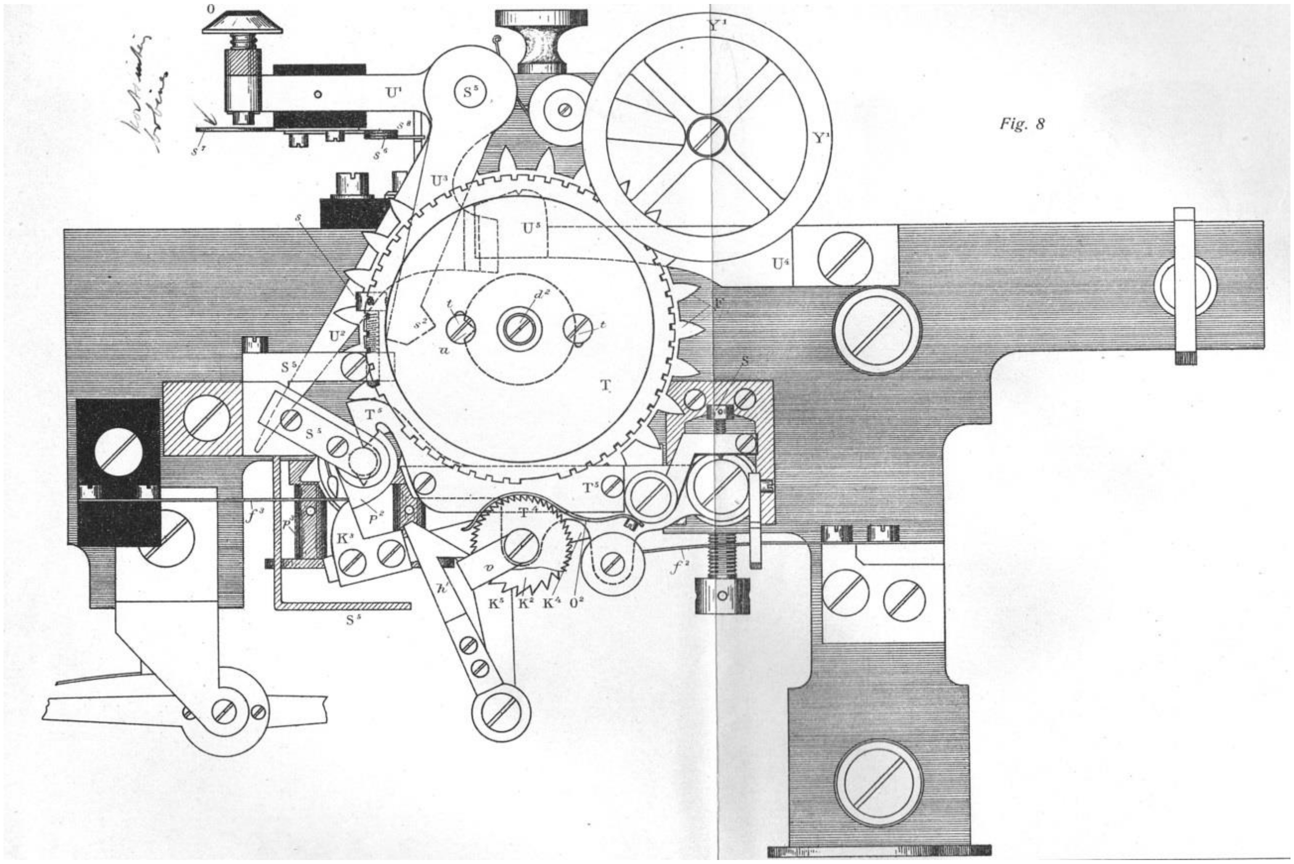

Siemens & Halske


Groos & Graf
Nº524


Siemens & Halske
Nº5420



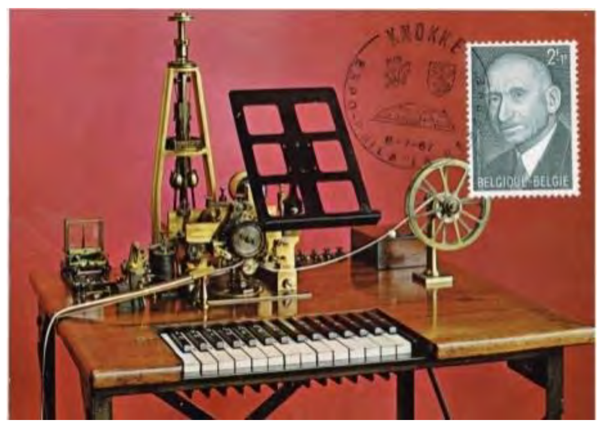
The following drawing gives a partial insight into the compexity of the mechanical parts (here the printing mechanism).

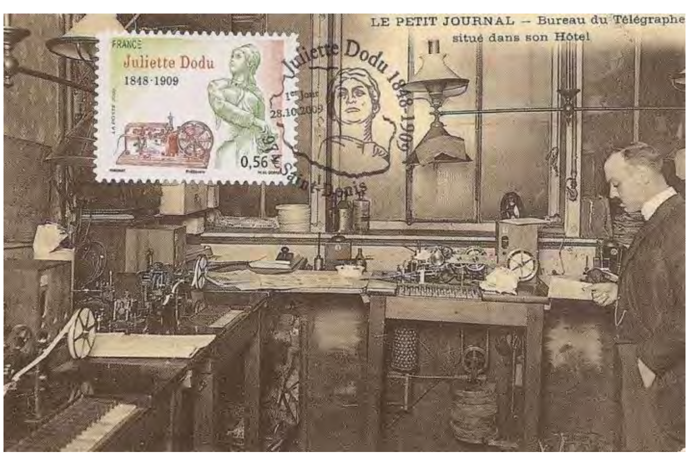


2.4. Other images

Some of these images give a hint about the country where the instrument was used.

Some postcards





Some telephone cards

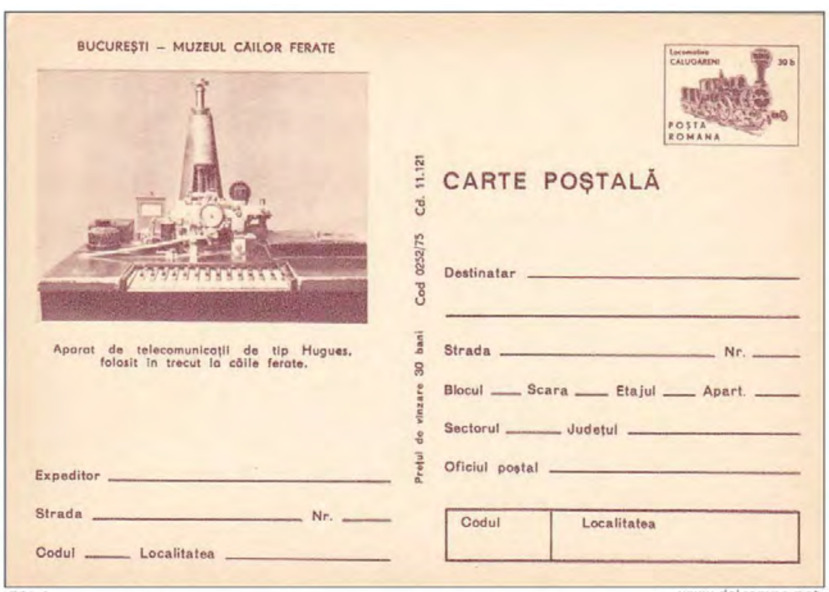
On the 140th anniversary of the Kirov telegraph *(Kirov is a city)*
From the history of the development of the telegraph
David Eduard Hughes (1831 - 1900)
Letterprinter Telegraph Instrument from D. Hughes in 1855
(Translation made by my soul-mate Hendrik Sack)

Some other images


An operator using a Hughes Printing Telegraph at the Central Telegraph Office, London, 1900


Hughes-Saal des Telegraphenamts zu Nürnberg
(Teilansicht)

Central Museum of Telecommunications
A.S. Popov
Telegraph
(Translated by my soul-mate Hendrik Sack)



BIBLIOGRAPHY & SOURCES

[1] "BEFORE WE WENT WIRELESS - DAVID EDWARD HUGHES FRS - HIS LIFE, INVENTIONS, AND DISCOVERIES". Ivor HUGHES & David Ellis EVANS, 2011, 386 p.

[2] HTTP://DAVIDEDWARDHUGHES.COM/ Ivor Hughes' website.

[3] "PROFESSOR DAVID EDWARD HUGHES" The great article from Ivor HUGHES in the AWA Revue (the Journal of the American Wireless Association) volume 22, 2009 . This is a pdf document -24 p.-that can be downloaded from [2]

[4] "ETUDE DE TELEGRAPHE HUGHES". Louis BOREL, 1873, 404 p.

[5] « COURS SUR L'APPAREIL HUGHES ET LES LIGNES SOUTERRAINES » 2m éd., E. MONTORIOL,1909, 480 p.

[5] « NOTICE POUR SERVIR SUR L'APPAREIL HUGHES ». Admin. des Telegraphes (B), 1913, 111 p plus planches ('planches' could be translated as 'oversized drawings').

[6] "HANDLEIDING VOOR DE BEOEFENING VAN DEN TECHNISCHEN KANTOORDIENST … DE HUGHES TOESTEL". Hoofdbestuur der P&T (NL), 1920, 119 plus 12 'planches' (In Dutch).

[7] My video clip, showing a working Hughes telegraph, can be seen via:
https://youtu.be/zJCfhbPAv9c or https://www.youtube.com/watch?v=zJCfhbPAv9c or
https://www.telegraphy.eu/pagina/movies/HUGHES.mp4

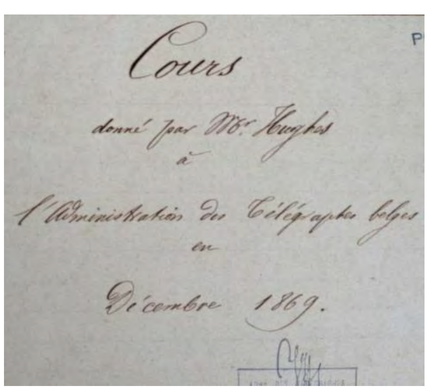
[8] There is also a chapter on Hughes in my second book > 436 pages (in Dutch, but with 650 images(in an "international language" ;o) , downloadable (free) via:
http://www.telegraphy.eu/pagina/boek/TELEGRAFIE%2025%20APRIL%20Fons.pdf

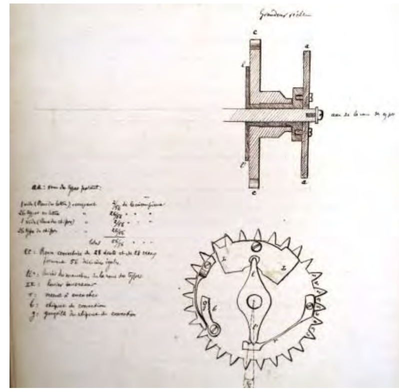
[9] ("MANUEL DE TÉLÉGRAPHIE HUGHES - G. Mazeman", 1981)

[10] ("DER HUGHESAPPARAT - K. Schröter", 1920)

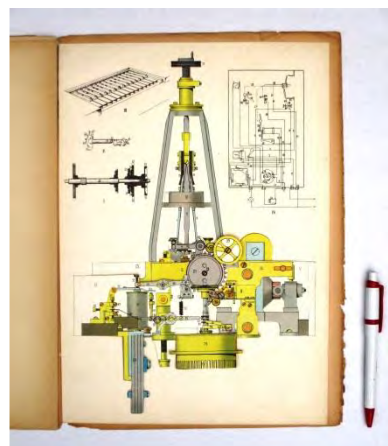
[11] "HANDLEIDING VOOR DE BEOEFENING VAN DEN TECHNISCHEN KANTOORDIENST AFBEELDINGEN". Rijkstelegraaf (NL), 1901, 74 p. plus planches.

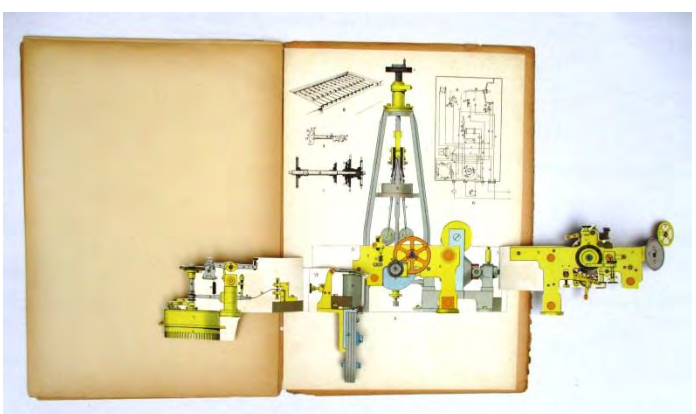
[12] "COURS DONNÉ PAR MR. HUGHES À L'ADMINISTRATION DU TÉLÉGRAPHES BELGES EN DÉCEMBRE", 1869, 100 p.
This is a remarkable handwritten book including some fine handmade drawings. I cannot say for sure if it is an original or some kind of a copy. See the following photographs.





[13] "SIJTHOFFS BEWEEGBARE MODELLEN – TYPENDRUKTELEGRAAF VAN HUGHES" This is a pretty "fold-out, multi-layer diagram" that presents about all elements of the Hughes telegraph. It is made of 10 parts that are covering each other but that can be unfolded so that one can see the underlying parts. See the next photographs.





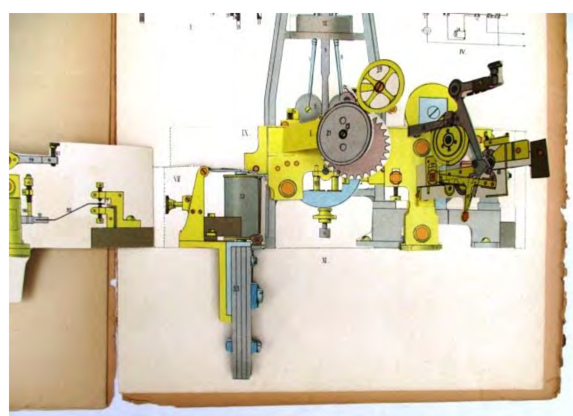


PHOTO CREDITS

Page 1: A Hughes telegraph from my collection.
Page 2 & 3: Three photos: AWA article Ivor Hughes > [3] > DEH papers.
Page 4: Book by Ivor Hughes > [1] > technical illustrator Carole Ruzicka.
Page 5: Book from Montoriol, 1909 > [5].
Page 7: Science Museum, London
Page 8: AWA article Ivor Hughes > [3] > DEH papers
Page 9: My De Jongh microphone
Page 10: AWA article Ivor Hughes > [3] > DEH papers.
Page 13: From my own second book 'The Internet of the 19-th century'[8].
Page 13 and 14: Photographs taken by Ivor Hughes in the Smithsonian Museum, Washington DC.
Pages 15-21: All 24 photos taken by myself from instruments in my collection.
Page 22: Book "Handleiding …" [6].
Pages 23- 25: All 19 illustrations in my collection.
Pages 27-28: From the books [12] & [13] in my collection.

ACKNOWLEDGMENTS

As explained in the introduction above Ivor HUGHES has been holding my hands when I was typing. Thank you again, Ivor, for your kindness in giving me your authorisation to copy a lot of paragraphs out of your AWA article, your book and your website.

My thanks go also to my friend Bill BURNS for having corrected (again) my 'Flemish(Dutch) English. People with interest in History of the Atlantic Cable & Undersea Communications must check his great website: http://atlantic-cable.com

Fons VANDEN BERGHEN (and Ivor Hughes)
HALLE (B)
In December 2018

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