PROC. N.S. INST. SCI. (1996)
Volume 41, Part 1 & 2, pp. 1-12.

Alexander Graham Bell's optical disc recordings and other inventions

Dan Hutt

The latter part of the 19th century is known to historians as the Gilded Age of Invention. The flurry of inventions created by Alexander Graham Bell is characteristic of the period, when a handful of seemingly heroic individuals laid the groundwork for 20th century technology. While the technological and economic conditions were right for commercialization of the telephone, many of Bell's other ideas such as the optical disc recording faded into obscurity. Unlike his contemporary Thomas Edison, who strictly invented to exploit perceived market demand, Bell's activities were driven by the sometimes random forces of his curiosity. We discuss many of the creations of Nova Scotia's most illustrious resident inventor.

La fin du XIX^e siècle est considérée par les historiens comme l'âge d'or des inventions. La multitude d'inventions d'Alexander Graham Bell est caractéristique de cette époque où une poignée de valeureux chercheurs ont pavé la voie à la technologie du XX^e siècle. À une époque où la technologie et la situation économique étaient propices à la commercialisation du téléphone, bon nombre d'autres idées de Bell, comme l'enregistrement sur disque optique, ont été reléguées dans l'ombre. Contrairement à son homologue de l'époque, Thomas Edison, dont les inventions répondaient aux seuls besoins pressentis du marché, Bell était surtout animé par une curiosité sans bornes. Un grand nombre des inventions du plus illustre résident de la Nouvelle-Écosse seront abordées ici.

After the telephone

In July 1877, Alexander Graham Bell married Mabel Hubbard and the newlyweds set off on an eighteen month honeymoon in England. Bell's famous telephone patent, number 174,465, had been granted just the year before and he was already making money from the fledgling Bell Telephone Company. In Europe, Bell enjoyed celebrity status, invited to speak at learned societies and meeting Queen Victoria and other heads of state and dignitaries. But even on his honeymoon, Bell was already thinking about ways to improve the telephone. He recognized that a weakness of the telephone described in the patent was its magneto-inductive transmitter, which was not powerful enough for long distance communication. A practical variable resistance transmitter would have to be developed which could modulate the large currents necessary for long distance telephony.

Bell was also aware that powerful adversaries had taken notice of the telephone and were hard at work, trying to circumvent his patent (Carlson, 1994). The giant Western Union Telegraph Co. had hired the famous inventor Thomas Edison to out-do Bell and any other claimants to the telephone idea (Bruce, 1973). Even before the Bells' returned from their honeymoon, Edison had applied for a patent for the variable resistance carbon button transmitter in February, 1878.

Optical communication and photoacoustics

Upon his return, Bell immediately set to work to out-invent Edison and come up with his own improved transmitter. Although Bell never did make a useful transmitter (the Bell Telephone Company bought a transmitter patent from Emile Berliner in1878), along the way he was introduced to the element selenium, a material whose resistance depends on the amount of light falling upon it. Bell used the photoresistive property of selenium as the basis for an optical communication system that could transmit a voice message hundreds of meters on a beam of light. Although the "photophone" as Bell called it, faded into obscurity, Bell still goes down in history as being the first to demonstrate wireless voice communication (Fig. 1) (Hutt et. al., 1993).

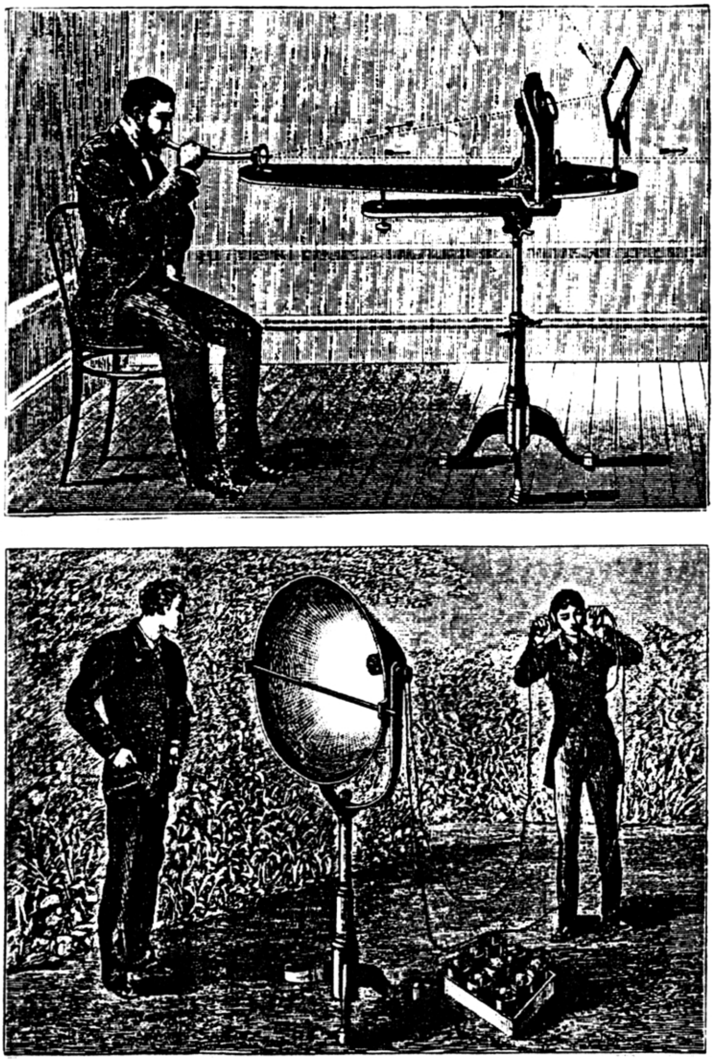

Fig 1 Optical communication in 1880: Bell's photophone. The left panel shows Bell sitting at the transmitter which projects a beam of modulated sunlight to the receiver shown on the right. (Courtesy of Heritage Canada Alexander Graham Bell National Historic Site)

While working on the photophone, Bell noticed that pulses of intense sunlight focussed on the surface of an object, caused many materials to emit pulses of sound. The intensity of the sound depended on the intensity of the light, and on the type and dimensions of the material. This photoacoustical effect is due primarily to the coupling of heat from the surface of the object that has absorbed some of the radiation to the air near the object's surface. The slight pressure change associated with local heating of the air is a sound wave. Bell created light pulses by chopping a beam of sunlight with a rotating, slotted wheel. With pulse frequencies in the hundreds of hertz, an audible tone could be heard emanating from the object.

While studying the photoacoustical properties of many, sometimes amusing things (Fig. 2), Bell theorized about the propagation of heat pulses into materials. He thus became the first person to describe the basic idea for the technique known today as "thermal wave imaging" (Thomas et. al., 1993). In this nondestructive testing technique, a modulated source of infrared light irradiates the surface of an object causing a wave of heat energy to propagate into it. The thermal wave is reflected and scattered by subsurface defects and when some of the thermal wave is reflected back to the surface, a temperature distribution is created that can be visualized with an infrared camera. Analysis of the infrared image of the objects surface yields information about its underlying structure.

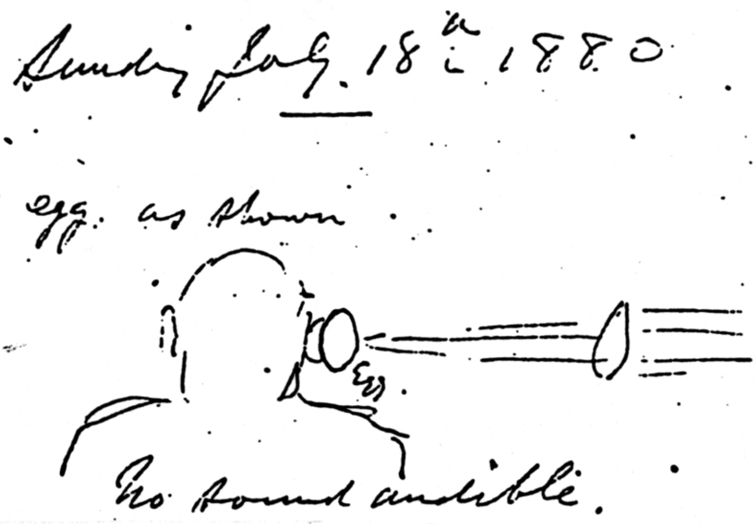

Fig 2 Sketch from Bell's notebook dated July 18, 1880 showing photoacoustical analysis of an egg. Result: "no sound audible".(A. G. Bell Lab Notes, Vol. 2 p. 63 (1880))

Later, Bell studied how the intensity of the sound emitted by objects depended on the wavelength of the light used to stimulate them. He discovered that some materials respond more to the red and infrared part of the spectrum while others did not have a notable spectral dependence. Bell proposed that the wavelength dependence of the sound be used to classify materials. Then Bell and his assistant, Sumner Tainter, built a device which they called the "spectrophone" but which was really the world's first photoacoustic spectrometer (Fig. 3). Bell is now recognized as the father of the very important field of photoacoustic spectrometry (Rosenwaig, 1980). Today, you may encounter photoacoustics when you have your car inspected; it is the technique used to analyze the exhaust of a car engine.

The induction balance

On July 2, 1881, the newly elected president of the United States, James Garfield was shot and wounded by a would-be assassin. It was widely publicized that the bullet in Garfield's body could not be located and that the president's life was in danger. Bell immediately set to work adapting an "induction balance" which he had experimented with while studying inductive interference on telephone lines. The induction balance consisted of two flat coils of wire, one connected to a battery via an electro-mechanical interrupter (i.e. "buzzer") and the other connected to a telephone receiver. The intermittent current flowing through the first coil could induce an audible tone in the telephone receiver via the second coil. The coils could be carefully positioned or "balanced" so that their mutually induced currents cancelled out and the telephone receiver was silent. A conducting material brought into the vicinity of the balanced coils would perturb the balance and thus be detected by causing a tone to be heard in the telephone (Bell, 1882).

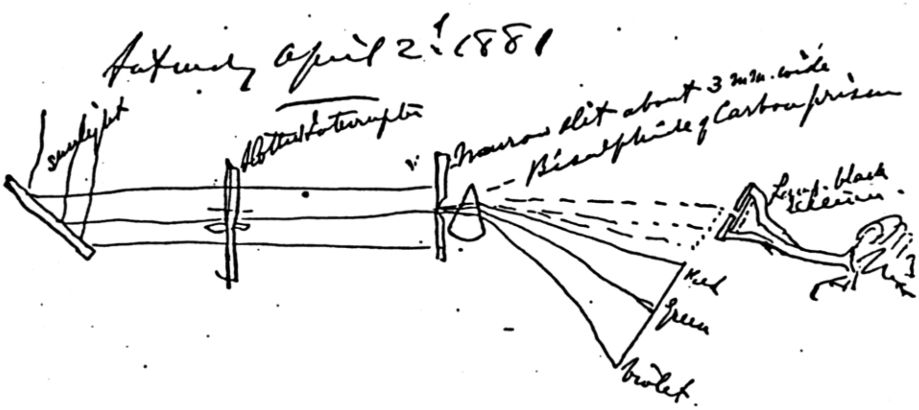

Fig 3 Sketch from Bell's notes dated April 2, 1881 showing the spectrophone concept: the world's first photoacoustical spectrometer. (A. G. Bell Lab Notes, Vol. 4 p. 17 (1881))

In their Washington laboratory, Bell and Tainter worked furiously throughout the summer of 1881 as the president's condition deteriorated. They experimented with bullets in their mouths and in their armpits, trying to increase the sensitivity of the induction balance. Finally, they tested the apparatus on the president in late July with negative results. On August 1 they tried again, this time getting a faint response from the lower abdomen, where doctors had suspected the bullet to be. Garfield died soon after. An autopsy showed that the bullet was located too deep within his body to have been detected by the induction balance. It also showed that the bullet was safely encysted; what probably killed Garfield was not the bullet but infection caused by the probing fingers of his physicians.

Bell and Tainter doggedly continued improving the induction balance until in October they successfully demonstrated it on Civil War veterans who still bore bullets in their bodies. Bell never patented the induction bullet probe, not wanting to profit from a life-saving device but it was used commercially by others until the discovery of x-rays in 1896 (Kuhfeld, 1991).

Another induction balance tangent was the "audiometer". By displacing the two coils of an induction balance a given distance along a scale, an audible tone of well defined intensity was produced in the telephone receiver. Bell used the device to test the hearing of hundreds of school children. He discovered residual hearing in many children thought to be completely deaf. Any capability to hear, no matter how slight, could be exploited to teach the child to speak. He also discovered that among pupils in public schools, a large percentage suffered some degree of hearing impairment and some, who were considered dull-witted, were actually unable to hear their teacher properly (Bruce, 1973). In recognition of this work, the scale of relative sound intensity, the bel was named after him (Pierce, 1981). Today the decibel, which is one tenth of a bel, is well known.

The Michelson-Morley experiment

In 1880 Bell was awarded the Volta prize by the French government in recognition of the invention of the telephone. With the 50,000 francs he received with the prize, Bell founded the Volta Laboratory in Washington DC with his long-time associate Sumner Tainter and Bell's cousin Chichester Bell who had trained in England as a chemist. The Volta laboratory was established for the purpose of "prosecuting inventions and researches for their mutual benefit" (Tainter, undated) and was one of the world's first industrial laboratories.

Bell also invested in another research endeavour with proceeds of the Volta prize. Shortly after receiving the prize in Paris, he heard about a young physicist who had a reputation for being an excellent experimentalist. The young man had proposed a simple yet ingenious experiment designed to confirm the existence of ether, a massless medium commonly believed to pervade the universe. Ether had been postulated to exist as the medium for propagation of light waves and gravitational force.

In November 1880, Bell offered Albert A. Michelson $500 to carry out his experiment. By observing the interference of light beams on an optical table that could be rotated in a vat of mercury, Michelson and his colleague Edward Morley, expected to show that light travels more slowly in the direction of the Earth's movement around the sun than when travelling in the opposite direction. The relative motion of the Earth sweeping through the ether would change the apparent velocity of light. What Michelson and Morley found instead, was that the velocity of light was exactly the same no matter what direction it was measured in. This result was in violation of the theory of ether and ultimately was recognized as the first experimental evidence of Einstein's theory of relativity. Michelson won the 1907 Nobel prize in physics for this work.

In terms of the scientific value derived, Bell's support of the Michelson-Morley experiment may represent one of the best placed grants ever for scientific research. In fact, Michelson only used $200 of the $500 Bell had given him. Bell told him to keep the rest for further experiments (Bruce, 1973).

The graphophone

Whatever the Volta associates had in mind when they first formed the laboratory, a potentially money making challenge was proposed by Bell's father-in-law Gardiner Hubbard. An executive of the American Bell Telephone Co., Hubbard and a few business partners had bought the rights to Thomas Edison's phonograph which had been patented in 1877. In its original form, the phonograph was so difficult to use and had such poor sound quality that Hubbard's company, the Edison Speaking Phonograph Co., found itself with a marvelous but unmarketable product. Hubbard, who originally told his son-in-law that he bought the phonograph patent to discourage Edison from pursuing work related to telephony, now urged the Volta associates to improve the phonograph and make it commercially viable (Tainter, undated).

Bell, who had privately expressed great disappointment that he had not been the one to invent the phonograph, now had an opportunity to do to Edison what Edison had done to him with the telephone; take a brilliant but imperfect invention and turn it into a successful product. The Volta associates attacked the phonograph and five years later had developed the graphophone, the first commercially successful sound recording machine. In the graphophone, the tin foil of Edison's phonograph was replaced with wax cylinders resulting in higher fidelity in recording and better durability in playing. Instead of indenting or embossing the recording surface as in the Edisonian phonograph, the recording stylus of the graphophone cut a groove into the wax, removing material from the groove instead of displacing it. Finally, a "floating" or flexible playback stylus was introduced, an innovation that lasted a century in the recording industry.

Optical disc recordings

Now that vinyl records have been replaced with the compact disc, it would seem that the last lingering influence of Edison's phonograph and the Volta laboratory's graphophone have finally disappeared from recording technology. Instead of a groove whose undulating walls physically represent the waveform of the recorded sound, the recording on the surface of a compact disc is represented by a series of microscopic pits that look like the dot-dash pattern of Morse code. A computer in the CD player interprets the digital code and transforms it into the audio signal. Another distinguishing feature of the CD is that it is read optically. A tiny laser inside the CD player is focussed on the surface of the CD and as the disc turns, the light reflected off the series of pits is read by a detector which feeds the digital code into the CD player's computer. Not only can a lot more information be stored on a CD but there is no longer any physical contact between a stylus and the recording surface, so a CD lasts much longer than an old-fashioned vinyl record.

Incredibly, some of the ideas inherent in the CD were actually experimented with by Bell and the Volta associates. They demonstrated and patented a technique to photographically record sound on a glass disc (Bell et. al., 1886). Tainter recorded in his notes (Tainter, 1881) that he recognized the advantages of a disc format recording over the cylinders used in the graphophone because of the possibility it offered to replicate the recordings. A disc recording based on a photographic process would be easy to reproduce and would never wear out due to contact with a stylus, just like today's compact disc.

To record sound using light, the Volta associates used a system of mirrors and a lens to concentrate a beam of sunlight on a vertical glass plate. A fine stream of ink was directed against the glass plate (the ink then dribbled off the plate into a container below). The ink nozzle was fixed to a "sounding board" or small plate which picked up sound vibrations. By speaking loudly at the sounding board, the sound vibrations were transmitted to the nozzle which caused the ink jet to jiggle. The patch of ink on the glass plate therefore oscillated in size and position in accordance with the vibrations of the speaker's voice. By passing the beam of sunlight near the edge of the ink patch, the width of the beam was modulated in a way analogous to the sound vibrations.

The modulated light beam was then focussed onto the surface of a glass disc inside a narrow, light-tight box through a small slit cut in the side of the box. The glass disc was about 35 cm in diameter and was coated with a gelatine-bromide photographic emulsion. During a recording, the glass disc rotated and simultaneously moved sideways behind the slit so that the light traced out a spiral pattern and intensity fluctuations were recorded photographically along the spiral. That is how the world's first optical recordings of sound were made over a century ago.

Two different methods were used to encode the light variations on the disc. In the "variable density" technique, an image of a slit near the vibrating patch of ink was projected onto the disc. This resulted in a constant width spiral pattern with variations in the degree of exposure of the photographic recording (Fig. 4). In the "variable-area" technique, an image of the edge of the ink patch was projected onto the disc resulting in a jagged, saw-toothed spiral where the sound waveforms are represented by the shape of the pattern on the edge of the spiral (Fig. 5).

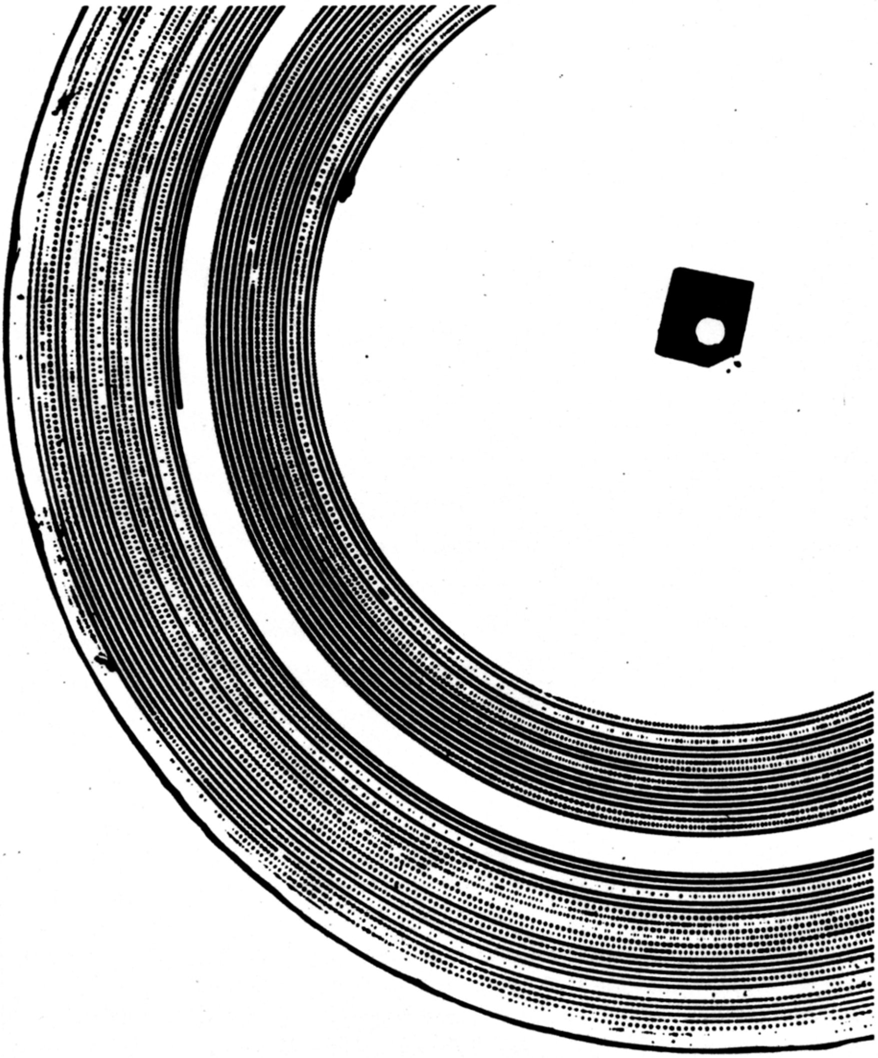

Fig 4 Section of a variable density optical recording. (Courtesy of National Museum of American History)

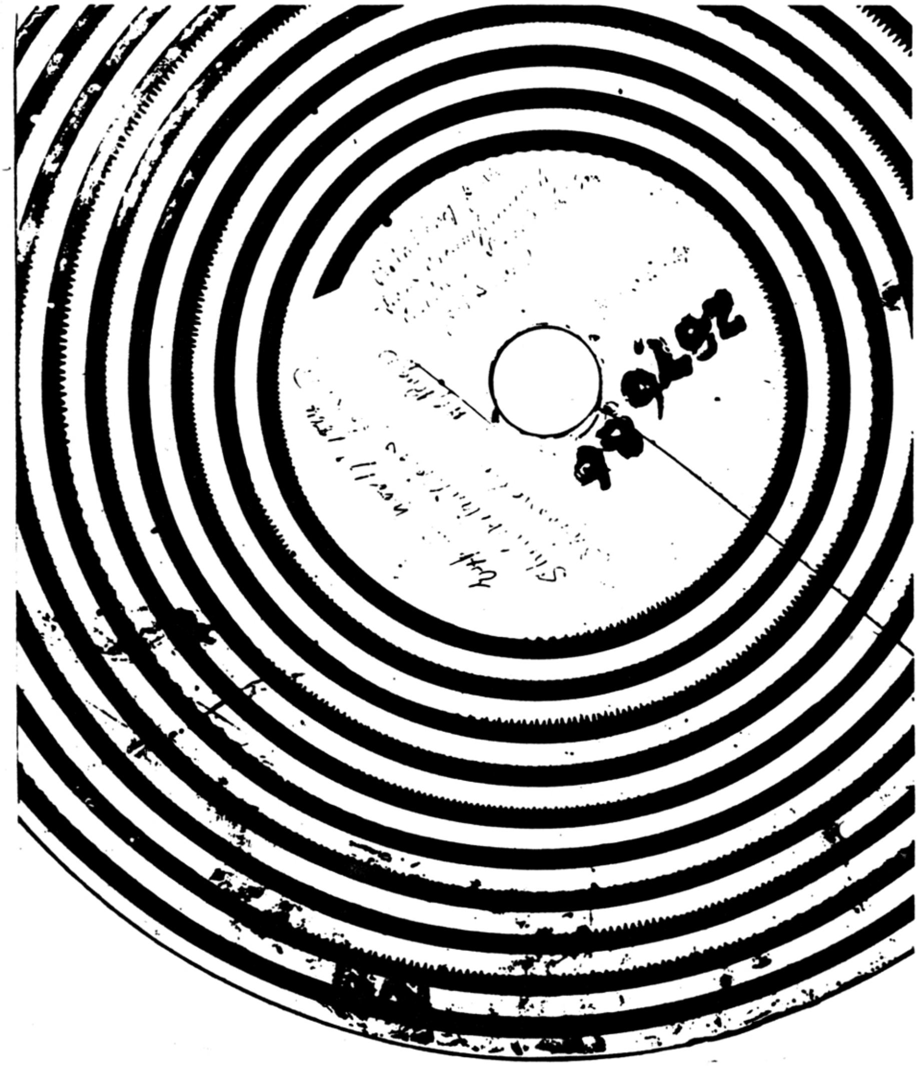

Fig 5 Section of a variable width optical recording showing waveform of the word "barometer". (Courtesy of National Museum of American History)

Of the 32 patents awarded the members of the Volta laboratory, the patent for the optical recording technique (US patent No. 341-213) is one of only four where Alexander Graham Bell's name appears first, therefore it must have been of special interest to him and was likely his idea (Newville, 1959). However, it is hard to know what the inspiration for this invention was or what the Volta associates thought its potential was, because key notebooks of Sumner Tainter pertaining to its development were lost in a fire (Tainter, undated).

Among Tainter's remaining papers, there is a handwritten script with the following solemn declaration (Harvey, 1982):

> "This recording has been made by Alexander Graham Bell in the presence of Chichester A. Bell on the 15th of April, 1885 at the Volta laboratory, 1221 Connecticut Avenue, Washington D. C. In witness whereof, hear my voice - Alexander Graham Bell."

Whether or not this message was intended for recording on an optical disc is unknown but the date, April 15, 1885, is during a period when the optical recordings were being made successfully and seemed to be the main interest of the laboratory.

The discovery of the above quotation prompted Floyd Harvey of Bell Laboratories to attempt to "play back" some of the better discs in an attempt to find a recording of Alexander Graham Bell's voice. Harvey built an apparatus to scan a beam of light through a copy of some of the discs onto a light detector so as to retrieve the audio signal. Unfortunately, most of the sounds recovered were unintelligible except for one disc which contained the word "barometer" repeated several times. Not only is this single, mundane word disappointing, but there is no indication as to whose voice uttered it. To this day, there are no known recordings of the voice of the man who invented the telephone and contributed greatly to the world's recording industry.

Today, the remaining optical disc recordings are stored at the National Museum of American History, Smithsonian Institution in Washington D. C. Unfortunately, the discs have deteriorated a great deal leaving little hope that any sound that might have been recorded on them can be recovered. However, there are a few discs that are in relatively good condition. Two of these (shown in Figs. 4 and 5)have been copied and replicas of them can be seen at the Alexander Graham Bell, National Historic Site in Baddeck, Nova Scotia.

In November 1885, Chichester Bell decided to return to England thus precipitating the end of the Volta laboratory. Investors, including Bell's father-in-law Gardiner Hubbard, formed the American Graphophone Company and bought the Volta laboratory patents pertaining to the graphophone. Sumner Tainter was hired as chief of research and product development. The optical recording technique was nearly forgotten, but in the 1920's, researchers at the Western Electric Company and Bell Telephone laboratories used the principle described in Bell's expired optical disc patent to create the modern motion picture sound track (Kellogg, 1955).

•

Aviation

In the summer of 1885, Bell and his family visited Nova Scotia for the first time. They became enchanted with the picturesque village of Baddeck in Cape Breton and, seeking refuge from the terrible heat and humidity of Washington summers, decided to build a summer home nearby. The expansive house which the Bells' called Beinn Bhreagh (Gaelic for "Beautiful Mountain") was soon the center of the family's social life for half of each year.

At Beinn Bhreagh, Bell attacked one of the last great challenges of modern times, the development of, in his words "a contrivance for mechanical manned flight". The realm of cranks and science fiction in 1898, Bell approached the problem of flight by studying the performance of kites. He succeeded in developing some fantastic kite forms (Fig. 6) and did learn how to optimize lift through use of multiple cells based on a tetrahedral unit cell. Unfortunately, Bell did not recognize the obstacle represented by the enormous drag of kites, an obstacle which would render motorized flight impossible.

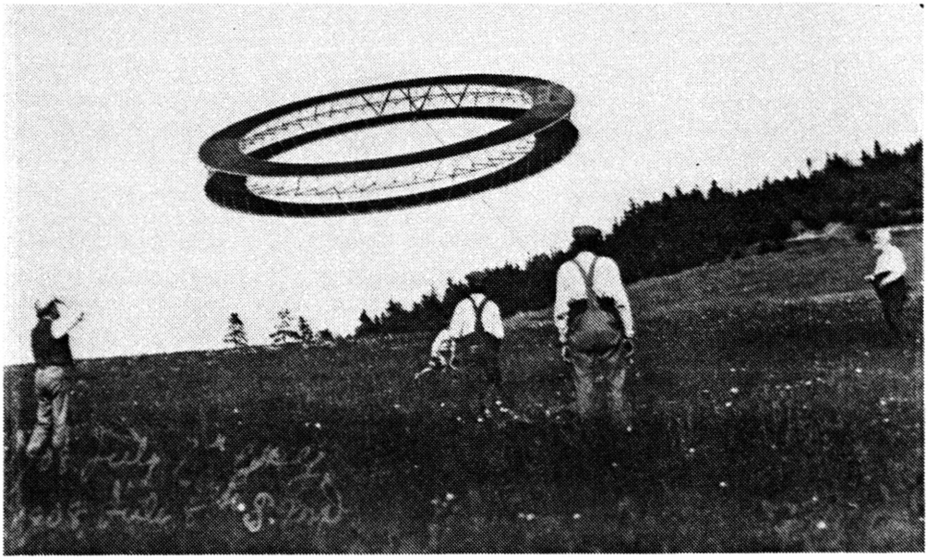

Fig 6 Kite experiments at Beinn Bhreagh, 1908. (Courtesy of Heritage Canada Alexander Graham Bell National Historic Site)

On December 17, 1903, Wilbur and Orville Wright made the first manned flight in a powered heavier-than-air craft at Kitty Hawk, North Carolina. To safeguard their patent applications, the Wrights kept details of their airplane secret and shunned publicity for nearly two years. Nonetheless, Bell heard irrefutable testimony that the Wright brothers had flown soon after the fact. He accepted the disheartening news and then carried on with the perfection of his tetrahedral kites.

In the autumn of 1906, Bell hired a brilliant young engineer, Frederick "Casey" Baldwin who convinced him to give up the kites and try a winged glider design. Eventually, on March 12, 1908, Casey Baldwin made the first public flight in North America in the biplane "Redwing" (Parkin, 1964). On July 4 of the same year the group, which called itself the Aerial Experiment Association, won the Scientific American trophy for the first flight of one kilometer with a plane called the "June Bug" piloted by Glenn Curtiss. Bell, Baldwin and their AEA associates went on to make significant contributions to aviation including the invention of ailerons, the flaps on the trailing edge of wings, used for lateral control of the aircraft.

A lifetime of inventing

By the turn of the century, the Gilded Age of Invention was waning, slowly displaced by the modern age of industrial research. For example, at Bell Telephone laboratories, teams of specialists were applying fundamental science to the problems of psychoacoustics, information theory and electrical engineering to develop the world's telephone network. Although Bell often thought of working on improvements to the telephone, he found himself left behind in the technical intricacies of his own invention.

After the aviation work, Bell and Baldwin continued their collaboration at Beinn Bhreagh and went on to develop hydrofoils that streaked across the Bras D'Or lakes, one of which held the world marine speed record of 113 km/hr for ten years. Bell continued to busy himself with many other experiments, intrigues and investigations at Beinn Bhreagh. At the age of 75 he received his last patents, with Casey Baldwin, for features related to the hydrofoil. Bell died later that year on August 2, 1922.

Today, the kites, airplanes, hydrofoils and other mementos from Bell's Nova Scotia summers can be examined at Heritage Canada's Alexander Graham Bell National Historic Site in Baddeck located within sight of Beinn Bhreagh.

References

Bell, A. G. 1882. "Upon the electrical experiments to determine the location of the bullet in the body of the late President Garfield", Proc. Am. Assoc. Adv. Sci., pp. 1-58.

Bell, A. G., Bell, C. A. and **Tainter, C. S.** 1886. "Reproducing and recording sounds by radiant energy", US patent No. 341-213.

Bruce, R. V. 1973. "Alexander Graham Bell and the Conquest of Solitude", Cornell University Press, Ithaca.

Carlson, W. B. 1994. "Entrepreneurship in the early development of the telephone: How did William Orton and Gardiner Hubbard conceptualize this new technology?", Business and Economic History, Vol. 23.

Harvey, F. K. 1982. "Mementos of early photographic sound recording", Society of Motion Picture and Television Engineers (SMPTE) Journal, March 1982, pp. 237-244.

Hutt, D. L., Snell, K. J. and **Bélanger, P. A.** 1993. "Alexander Graham Bell's Photophone", Optics & Photonics News, June 1993, pp. 20-25.

Kellogg, E. W. 1955. "History of sound motion pictures: First Installment", Journal of the SMPTE 64, pp. 291-302.

Kuhfeld, A. W. 1991. "For whom Bell toils: Medical imaging by telephone", IEEE Engineering in Medicine and Biology, March 1991, pp. 88-89.

Newville, L. J. 1959. "Development of the phonograph at Alexander Graham Bell's Volta Laboratory", U. S. National Museum Bulletin 218, Paper 5, pp. 70-79, U. S. Government Printing Office.

Parkin, J. H. 1964. "Bell and Baldwin: Their development of aerodromes and hydrodromes at Baddeck, Nova Scotia", U. Toronto Press, Toronto.

Pierce, A. D. 1981. "Acoustics: An Introduction to its Physical Principles and Applications", McGraw-Hill, Toronto.

Rosenwaig, A. 1980. "Photoacoustics and Photoacoustic Spectroscopy", John Wiley and Sons, Toronto.

Tainter, S. undated. "The talking machine and some little known facts in connection with its early development", unpublished manuscript, National Museum of American History archives.

Tainter, S. 1881. Home Notes Vol. 1, pp. 1-3.

Thomas, R., Lawrence, D., Favro, D., Kuo, P.-K. and **Bruno, R.**, 1993. "Using thermal wave imaging to see below the surface", Photonics Spectra, pp. 148-150.

About the author:

Dan Hutt is an expatriate Nova Scotian and a graduate of Dalhousie University in Physics. He works in the field of atmospheric optics at the Defence Research Establishment Valcartier near Quebec City.