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Celebrating holography anniversaries: a historical perspective

Augusto Beléndez*[a,b], John T. Sheridan[c], Inmaculada Pascual[b,d]
[a]Depto. Física, Ingeniería de Sistemas y Teoría de la Señal. Univ. Alicante. Carret. San Vicente del Raspeig s/n. 03690 San Vicente del Raspeig–Alicante. Spain; [b]I.U. Física Aplicada a las Ciencias y las Tecnologías. Univ. Alicante. Spain; [c]School of Electrical and Electronic Engineering. College of Arquitecture and Engineering. University College Dublin (UCD). Belfield, Dublin 4. Ireland; [d]Depto. Óptica, Farmacología y Anatomía. Univ. Alicante. Spain

ABSTRACT

The year 2022 marks the 75th anniversary of Dennis Gabor's invention of the holographic method, what he called "microscopy by reconstructed wave-fronts", as well as the 60th anniversary of the publication in 1962 of two seminal papers in the field of holography: the introduction of the reflection hologram by Yuri Denisyuk, and the description of the holographic process from the point of view of communication theory by Emmett Leith and Juris Upatnieks. Within the framework of these celebrations, a historical review of the origins of holography is presented with special emphasis on the contributions of Gabor, Denisyuk and Leith to the development of holography.

Keywords: Holography, hologram, Gabor, Denisyuk, Leith.

1. INTRODUCTION

The year 2022 marks three important anniversaries for holography: the 75th anniversary of the invention of holography by Gabor [1] and the 60th anniversary of the publication in 1962 of two seminal papers in the field of holography: the introduction of the reflection hologram by Yuri Denisyuk [2], and the description of the holographic process from the point of view of communication theory by Emmett Leith and Juris Upatnieks [3]. But how did holography begin to take its first steps? To answer this question, it may be interesting to consider what Paul Davies (b.1946) wrote in the Introduction to Feynmann's book "Six Easy Pieces" [4]. Davies points out that science is often thought of as an impersonal, dispassionate, and completely objective enterprise, unlike all the other human activities are dominated by the fashions, whims and personalities of the people who carry them out. Science is supposed to follow established rules of procedure and rigorous testing so that it is the results that count, nor the people who achieve them. This is far from the truth, and Davies added: *"Science is a people-driven activity like all human endeavour, and just as subject to fashion and whim."* The beginnings of holography are a clear example of all this.

Although in the development of holography we can find numerous heroes and even the odd villain, the truth is that there were three main protagonists [5-9]. Dennis Gabor, a Hungarian engineer based in England, inventor of holography in 1947 and who received the Nobel Prize in Physics in 1971 "for his invention and development of the holographic method" [10]. However, Gabor's original idea would have remained a *white elephant* [11], a superfluous object without any application, if it had not been for the appearance of two new actors on the scene: Yuri Denisyuk in the former Soviet Union and, above all, Emmett Leith in the United States. There were also three places, and very different ones, where the holography took its first steps. An industrial laboratory of an electrical engineering company in Rugby, England; a state scientific institute working on projects for the Soviet navy in Leningrad, in the former Soviet Union; and a classified laboratory of the University of Michigan, also working on classified projects, in Willow Run, near Ann Arbor, in the United States [5,11].

However, it was not until the invention of the laser in 1960 and its commercialization in 1962 that holography proved to be a highly productive and attractive area of research. Since then, the many applications of holography in many different

*a.belendez@ua.es; https://www.ua.es

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scientific and technical areas have given rise to “hot topics” [12,13] and the basic principles involved in hologram recording and reconstruction continue to give rise to exciting innovations in a wide range of areas: three-dimensional imaging, holographic interferometry, pattern recognition, image processing, holographic portraits, communications, optical elements, head-up displays, acoustic holography, particle detection, optical storage, solar energy conversion, optical encoding, digital holography, security, packaging, sensing, etc.

2. DENNIS GABOR AND THE MICROSCOPY BY RECONSTRUCTED WAVEFRONTS

Dennis Gabor (in Hungarian: *Gábor Dénes*, 1900-1979, Figure 1) was born in Budapest on 5 June 1900 into a wealthy family. His father was the director of the most important mining company in Hungary, and he introduced his sons to science and technology. In 1910, at the age of ten, Gabor filed his first patent on an airplane merry-go-round, the first of his more than 60 patents [14]. Between 1910 and 1918 he attended the Royal Hungarian State Secondary School, today known as János Xántus Secondary School, where there is a plaque commemorating Gabor as a student (Figure 2). Gabor recalls that it was at the age of 15 that his love of physics began, even before he reached university. He himself said in his autobiography [15], written on the occasion of the Nobel Prize award, that his lifelong love of physics began suddenly when he was 15 years old, as it was then that he started learning physics on this own with Chwolson’s *Lehrbuch der Physik*, the greatest physics textbook of the time. Due to this he had problems in class because he almost knew more physics and mathematics than the professors themselves.

Gabor belongs to a generation of brilliant Hungarians born between the end of the 19th and the beginning of the 20th century, known as *The Martians* [16]. In addition to Gabor, we can name the mathematician and computer science pioneer John von Neumann (1903-1957), nuclear physicist Leo Szilard (1898-1964), and 1963 Nobel Prize winner in Physics Eugene Wigner (1902-1995), among others.

Figure 1. Dennis Gabor in 1973. Lindau Nobel Laureate Meetings.

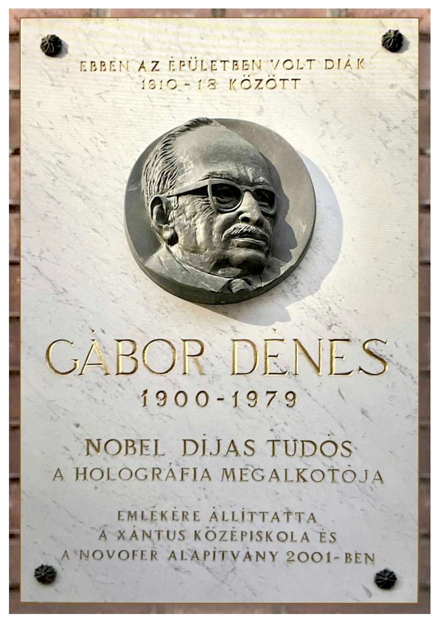


Figure 2. Dennis Gabor commemorative plaque. Xántus János Secondary School. Markó Street No. 18-20, Budapest (A. Beléndez photo).

In 1918, at the age of 18, Gabor is mobilized and sent to northern Italy to an artillery post in the Austro-Hungarian army. However, at the end of October 1918 Hungary signs the armistice and leaves the First World War, and Gabor returns to Budapest [17]. This year he enrolled at the Technical University of Budapest to study mechanical engineering, partly convinced by his father and partly because, although he was fascinated by physics, he himself noted the following years that when he had to start his university studies, he decided to study engineering instead of physics, because being a physicist was not yet a profession in Hungary at that time, and he added *“...with only half-a-dozen physics university chairs—who could have been presumptuous enough to aspire to one of these?”* [15]. He spent two years at the Technical

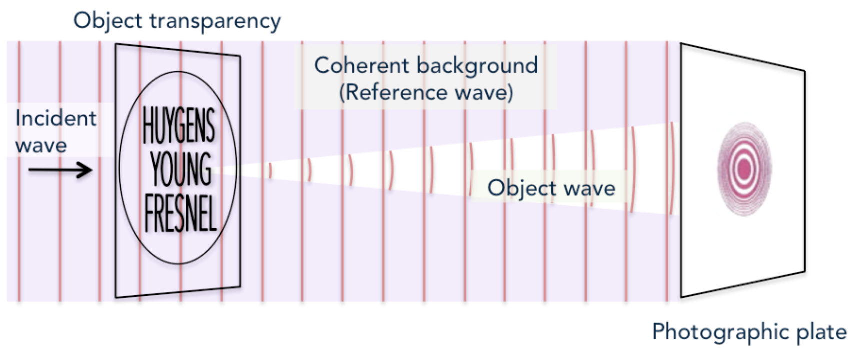
University of Budapest, but did not complete his studies in mechanical engineering, and in 1921 he went to the *Charlottenburg* Technical University in Berlin (now Technical University of Berlin), where he obtained a diploma in electrical engineering in 1924 and a doctorate in engineering in 1927 [17].

At the Technical University of Berlin he met Leo Szilard and Eugene Wigner who, together with Gabor, had started their studies at the Technical University of Budapest and now Szilard and Wigner were studying chemical engineering in Berlin. The three of them coincided with John von Neumann who was also studying chemical engineering in Berlin, although he later finished his studies in Zurich. The four of them were friends, they were from the Hungarian student group in Berlin, and they shared many things. One of the things they did when they felt bored with the engineering lectures at the Technical University of Berlin was to attend the weekly physics colloquia at the other university in Berlin and the Prussian Academy of Sciences [15]. At that time there were professors in Berlin, Einstein, Planck, Nernst and von Laue, and every week there were physics colloquia with discussions at the end, and the four friends, Gabor, Szilard, Wigner and von Neumann, attended practically all of them during their time in Berlin, and it was there that they really learned physics.

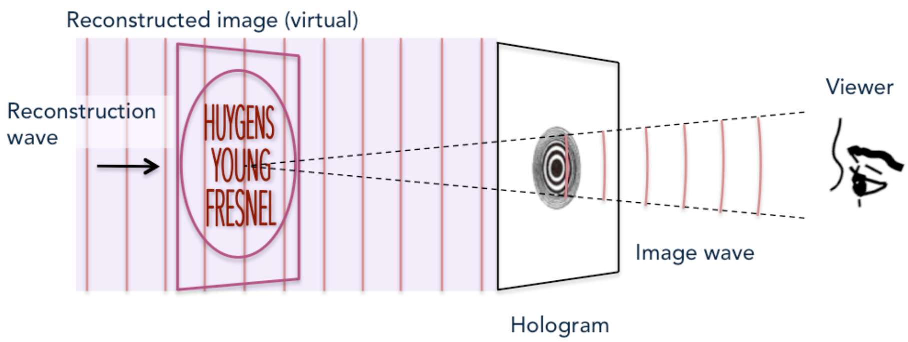
In 1927, after completing his doctoral thesis, Gabor started working for a technology company, Siemens and Halske, in Berlin, where he began to develop some of his inventions. He worked in the applied physics laboratory of the company on various technological developments. In 1933, with Hitler rise to power, the Siemens company did not renew his contract and Gabor had to leave Berlin and returned to Budapest where he stayed for a year until 1934, when he emigrated to England to work for the British Thomson-Houston Company in Rugby, an electrical engineering company where he worked in their research laboratory. He stayed there for almost fifteen years. Dennis Gabor also did some quite outstanding research in communication theory and signal processing in the 1940's [18], and his results are still in active use today. In 1946 he published a very important 29-page paper entitled "Theory of Communication" [19], which has three parts. Gabor presents in Part 1 a new method of analyzing signals is presented in which time and frequency play symmetrical parts, and which contains "time analysis" and "frequency analysis" as special cases. In other words, Gabor was not only a pioneer in electrical engineering or holography, but also in communication theory. On 1 January 1949 Dennis Gabor left the British Thomson-Houston Company and was employed as a lecturer at Imperial College, London, where he remained until his retirement in 1967.

Throughout his life, Gabor worked on many subjects: cathode ray oscillographs, high-pressure lamps, plasma physics, stereoscopic cinematography, electron microscopy, communication theory, holography, etc. On these subjects Gabor published more than a hundred papers and filed sixty-two patents between 1928 and 1971 [14,17,20]. Throughout his life Gabor always said that he was an engineer and inventor rather than a scientists, although most of his work was related to applied physics. But Gabor was also an humanist in the purest Renaissance sense [5]: a voracious reader, writer and essayist, a man concerned with the technological society of the late 20th century and a member of the Club of Rome. From 1958 he devoted much of his time to studying the future of our industrial civilization and published several books, including "Inventing the Future" [21], in which he noted that *"the future cannot be predicted, but it can be invented."*

But let's go back to 1947, when holography began to take its first steps in an industrial laboratory of the British Thomson-Houston Company. Gabor was working on improving the quality of the images obtained with the electron microscope, as the systems were not perfect enough. His limitation was related to the spherical aberration of the microscopes magnetic lenses. Gabor wondered how to improve these images and asked himself: *"Why not take a bad electronic picture, but one that contains the whole information, and correct it by optical methods?"* [22]. The answer to this question occurred to him while he was waiting for a tennis court on a fine day at Easter 1947 [1,22], and was to consider a two-step process: recording and reconstruction (Figure 3). In the recording step, an incident wave would illuminate an object transparency, giving rise to an object wave, and the interferential image would be produced between the object beam and a coherent background (reference beam), an image that would be stored on a photographic plate. He called the interferogram obtained a "hologram", from the Greek word *holos*, "the whole", as it contains the total information (amplitude and phase) of the object wave. In the reconstruction step, he would illuminate the hologram with a wave similar to the reference wave, and as it diffracted through the hologram, the original wavefront would be reconstructed, giving a virtual image of the object, which he could correct to obtain a good image. He called this procedure "Microscopy by reconstructed wavefronts" and it was published in Nature in 1948 in a short paper of just over a page entitled "A new microscopic principle" [23]. The object for the first hologram was a circular transparent slide 1.4 mm in diameter and bearing the names of three physicists, Huygens, Young and Fresnel (Figure 4), whom Gabor considered important for having laid the foundations of his wavefront reconstruction technique. Gabor made the first hologram using a mercury vapor arc lamp with a filter, one of the best coherent light sources before the laser.



(a)



(b)

Figure 3. (a) Recording and (b) reconstruction of an in-line hologram (Gabor's hologram).

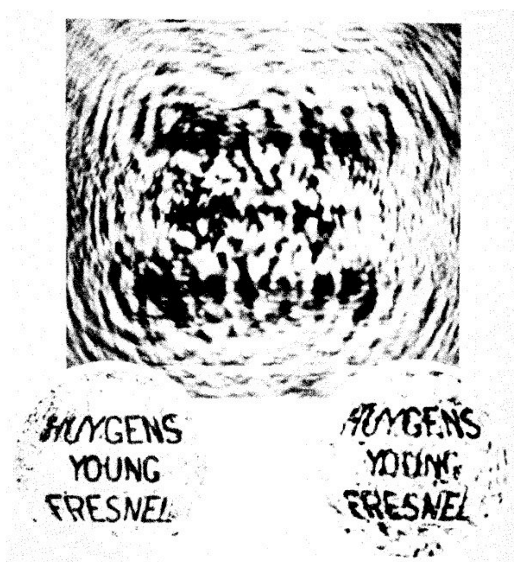


Figure 4. First holographic reconstruction (1948) [23]. This figure is a part of the Nobel Prize lecture of Dennis Gabor [22]. Copyright © The Nobel Foundation 1971.

On 15 June 1948 Gabor wrote a letter to Max Born [24] with copies of two papers. One of them on "Theory of Communication" and about the second he says the following: *"But the short one is a new thing, and I have no doubt that it is my luckiest find yet"* and further on he writes *"These results have made me happier that anything I have done in the last 20 years."* He was already aware that his technique could be something important. In 1949 he presented a more extensive paper reported by Sir Lawrence Bragg, director of the Cavendish Laboratory, entitled "Microscopy by reconstructed wave-fronts" [25], which contains the mathematics of holography and in which Gabor said that *"the name* *'hologram' is justified because the photograph contains the total information required for reconstruction the object, which can be two-dimensional or three-dimensional."* Figure 5 shows the hologram, the reconstructed image and the original in which he had included, in addition to the three previous names, the names of other famous physicists: Newton, Faraday, Maxwell, Kirchhoff, Planck, Einstein and Dirac.

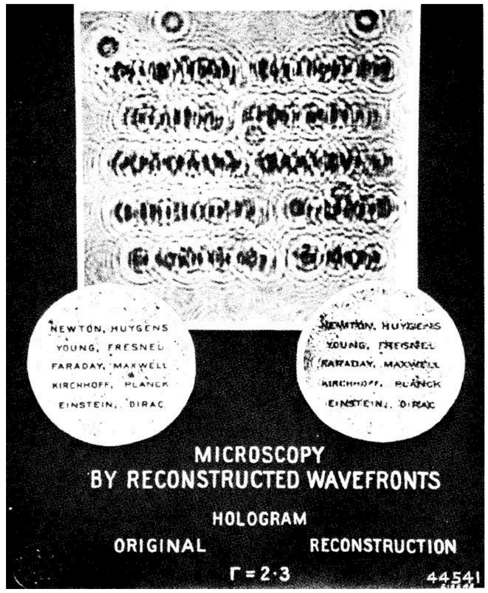


Figure 5. Another example of early holography. D. Gabor, Proc. R. Soc. Lond. A 197, 454-487 (1949) [25]. This figure is a part of the Nobel Prize lecture of Dennis Gabor [22]. Copyright © The Nobel Foundation 1971.

As it has already noted, in January 1949 he was recruited as a professor at Imperial College London largely because of the wide acceptance of his idea of wavefront reconstruction among important physicists in that years as Lawrence Bragg (1890-1971), Max Born (1872-1970) and Charles Galton Darwin (1887-1962), director of the National Physical Laboratory (NPL) and grandson of the evolutionist Charles Darwin [6]. Another important fact for the dissemination of Gabor's technique worldwide is its appearance in the first edition of the book "Principles of Optics" by Max Born and Emil Wolf (1922-2018) published in 1959 [26]. In the chapter titled "Elements of the Diffraction Theory" there was a section devoted to "Gabor's method of imaging by reconstructed wave-fronts."

In the following years Gabor's technique was studied by a few researchers such as Gordon Rogers (1916-2006) [27], a former doctoral student of Lawrence Bragg and that published several papers on Gabor's method. Between 1950 and 1956 holography was also studied in the United States by Paul Kirkpatrick (1894-1992) [28] at Stanford University and his doctoral students Hussein El-Sum (1925-1978) [29] and Albert Baez (1912-2007) [30]. El-Sum presented the first doctoral thesis on holography in 1952 [31]. This year 2022 marks also the seventieth anniversary of the first doctoral thesis on holography. Another researcher who became interested in holography in those early years was Adolf Lohmann (1926-2013) [32] in Germany. Gabor was invited in 1954 to give a talk in Gottingen on his wavefront reconstruction. Lohmann was one of the attendees at the talk. Then he became interested in the subject and he started working on holography. Lohmann published several papers on holography until 1957 and then abandoned the subject, only to take it up again in the 1960s when he invented "computer generated holograms" [33].

Between 1948 and 1955 around 50 papers were published on Gabor's method [5]. However, only small and blurry images were obtained and by 1954 Gabor was frustrated to the point of despair, especially because the hologram reconstruction stage was imperfect. Gabor's method results in an on-axis hologram whose image quality is rather poor, because the observer receives two waves, a diverging one (the virtual image) and a converging one (the real image), in addition to the transmitted wave. We can contemplate either the virtual image or the real image, but always with the other out of focus as a background. In 1955, after investigating various optical set-ups to minimize the effect of the conjugate image, Gabor abandoned his research into holography. In 1956, Gordon Rogers, perhaps the most enthusiastic supporters of Gabor's method, wrote a letter to Albert Baez in which he said: *"As far I am concerned, I am quite happy to let Diffraction Microscopy die a natural death. I see relatively little future for it, and I am looking forward to doing something else"* [5,34].

3. YURI DENISYUK AND THE WAVE PHOTOGRAPHY

Around 1958, when all the researchers who had started working on holography had already abandoned it, Yuri Denisyuk, a researcher working in the former Soviet Union, was reinventing holography in a different context [6]. Yuri Nicholaevitch Denisyuk (1927-2006, Figure 6) was born in Sotchi, on the Black Sea, on July 27, 1927, although as a child he went with his family to live in Leningrad (today Saint Petersburg). After graduating from the Leningrad Institute of Fine Mechanics and Optics in 1954, Denisyuk began to work at the Vavilov State Optical Institute in Leningrad, and where he continued to work for the next thirty-four years, the first years under the supervision of Alexander E. Elkin in the field of optical devices for the Soviet Navy [5]. In his spare time he was working on his doctoral thesis on what he called "wave photography". Denisyuk noted on more than one occasion that he was inspired after reading a book of science fiction short stories by Soviet writer Ivan Efremov [1,5,35]. In one of these stories, "Stellar Ships", two archaeologists are working on an excavation and they accidentally found a strange plate with a three-dimensional image. Denisyuk came up with the idea of creating such pictures by means of modern optics, as he was familiar with Lippmann's work on interference photography [36], and he began his experiments in 1958.

Figure 6. Yuri Denisyuk with his holographic reflection portrait (H. J. Caulfield, Ed., The Art and Science of Holography. A Tribute to Emmett Leith and Yuri Denisyuk, SPIE Press, Bellingham, Washington, back cover image (2004) [doi: 10.1117/3.2265060]).

In 1962 Denisyuk published the paper "On the reflection of optical properties of an object in the wave field of light scattered by it" [2] in which the basis of the reflection hologram was laid (Figure 7). A wave from a mercury lamp passes through a photographic plate, strikes the object and the wave reflected by the object interferes with the incident wave, giving rise to a standing wave pattern that can be photographed on the photographic plate. In the reconstruction, the photographic plate, once developed, is illuminated with white light and by looking through the hologram, the virtual image of the object is seen. The object appears in its original position and in the same color as the light used in the recording. The most coherent light sources available to Denisyuk were mercury lamps, so the holograms were of shallow objects, such as convex mirrors with large radii of curvature. Denisyuk was unaware of Gabor's work when he began and matured his ideas on wave photography. It was not until the early 1960s that he learned of the Gabor wavefront reconstruction through an article by Kirpatrick and El-Sum [29] (who also succeeded Leith, as will be seen later) and realized that his research and Gabor's work were related [1,5].

An important advantage of the Denisyuk hologram is that it can be reconstructed with white light, although the hologram had to be recorded with monochromatic light such as that from a mercury lamp or a laser. When a white light beam, which contains all visible wavelengths, impinges the hologram, it only reflects light of the wavelength that was used during the recording step, resulting in a monochromatic three-dimensional image.

Denisyuk's wave photography, initially received with great skepticism, played a major role in the future development of holography, as well as in some of its most important applications based on the reflection hologram such as recording holograms of three-dimensional objects. Denisyuk was awarded the Lenin Prize in 1970, the highest scientific distinction of the former Soviet Union, and he was elected a member of the Academy of Sciences of the Soviet Union.

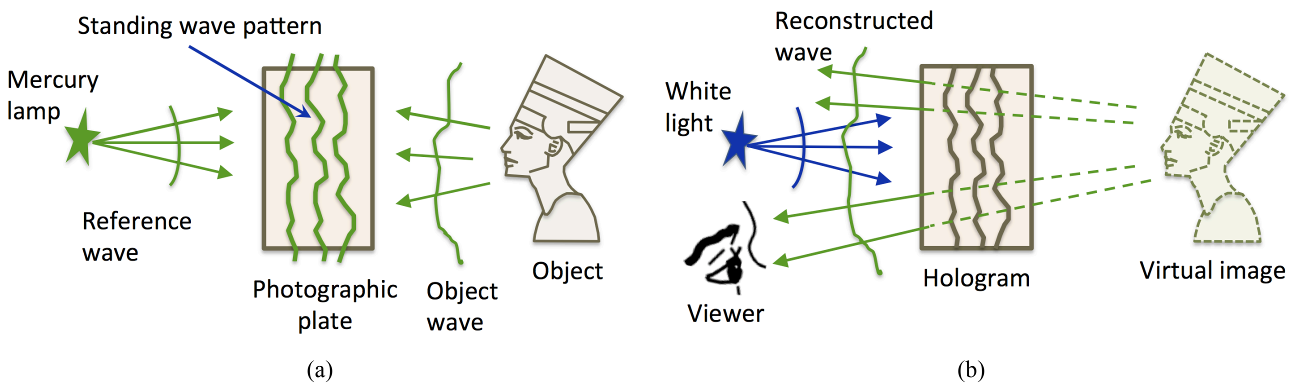


Figure 7. (a) Recording and (b) reconstruction of a reflection hologram (Denisyuk hologram) using a mercury lamp and a white light source, respectively.

4. EMMETT LEITH AND THE LENSLESS PHOTOGRAPHY

In 1971, in his Nobel Lecture, Gabor noted [22]: *"Around 1955 holography went into a long hibernation until the invention of the laser in 1960."* However, this statement is not entirely correct. Emmett Leith, the third main actor in this story, pointed out on more than one occasion that it was not true that holography research had disappeared between 1955 and 1962, but that it was carried out clandestinely in two different laboratories [5,8]. One of them, totally invisible to the West, was the Vavilov Institute in Leningrad, where Denisyuk worked on his wave photography, and the other was a classified laboratory at the University of Michigan, at Willow Run, near Ann Arbor, which worked on contracts for the US military and where Emmett Leith began to work on the "Michigan Project" related to Synthetic Aperture Radar (SAR) [37]. Emmett Norman Leith (1927-2005, Figure 8) was in Detroit, Michigan, on March 12, 1927. After graduating in Physics at the Wayne State University, in 1952 he joined the team that was working on the Michigan Project, where his initial task was to design the optical processor for data analysis [1]. During 1955 and 1956 Leith reformulated the theory of synthetic aperture radar in terms of physical optics. While analyzing the mathematics behind the process he found that he was recording an interferential pattern of radar waves in the photographs. Leith had just reinvented holography and between 1955 and 1956 he developed a complete theory of holography in the microwave region. In October 1956 Leith became aware of Gabor's work through a paper published by Kirkpatrick and El-Sum [29] and realized that it was related to his radar research. For both Denisyuk and Leith, the paper published by Kirkpatrick and El-Sum in 1956 was the link between their work and Gabor's earlier work on holography.

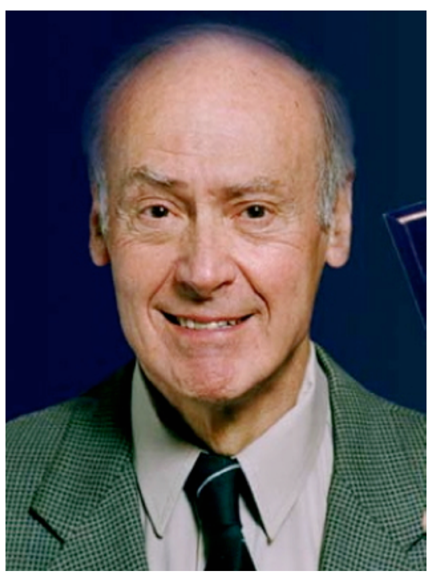


Figure 8. Emmett Leith (H. J. Caulfield, Ed., The Art and Science of Holography. A Tribute to Emmett Leith and Yuri Denisyuk, SPIE Press, Bellingham, Washington, back cover image (2004) [doi: 10.1117/3.2265060]).

In 1960 Juris Upatnieks (b.1936, Figure 9) began working with Leith and between them repeated some of Gabor's experiments, first using a mercury lamp as a light source and then a He-Ne laser. In 1962 they published "Reconstructed Wavefronts and Communication Theory" in which they pointed out [3]: *"A two-step imaging process discovered by Gabor involves photographing the Fresnel diffraction pattern of an object and using this recorded pattern, called a hologram, to construct an image of this object. Here, the process is described from a communication-theory viewpoint."* Applying communication theory to wavefront reconstruction, Leith and Upatnieks devised several methods to solve the problem of twin images that appears in Gabor's (on-axis) holograms. They devised the tilted reference beam technique. They had invented the off-axis hologram [38,39], known as the Leith and Upatnieks hologram, in which the object and reference waves impinge on the same face of the photographic plate, but not in the same direction as in the Gabor hologram, but their directions of propagation form a certain angle to each other, as can be seen in Figure 10.

Figure 9. Professors Juris Upatnieks and Emmett Leith adjusting optics. December 1963. HS8476, UM Information Services, News and Information Services (University of Michigan) Faculty and Staff Files, Bentley Historical Library, University of Michigan.

With the help of this new recording scheme, the virtual and real images are angularly separated in the reconstruction stage. This new recording scheme for hologram recording was then defined and made it possible to obtain holograms of diffusing objects. In December 1963 they published their results of holograms of two-dimensional objects under the name "lensless photography" [38], including holograms of transparent text on a black background and black and white photographs, and they stated: *"The extraneous twin image and other interfering terms have been eliminated."* The problem of twin images, which had plagued Gabor so much, had just been solved, which made holography a really useful technique.

On April 3, 1964, during the last session of the "Information Handling by Optics" conference of the Spring Meeting of the Optical Society of America, held at the Sheraton Park Hotel, Washington, D.C. [40]. Juris Upatnieks presented their work on holograms of three-dimensional objects. At the end of the fifteen-minute talk titled "Lensless, Three-Dimensional Photography by Wavefront Reconstruction", Upatnieks announced to the audience that they could see a hologram of a three-dimensional object in the hotel suit. Few attendees stayed to hear the presentation after Upatnieks' talk, as most rushed from the presentation room to the hotel suite to see what that 'hologram' looked like. It was the hologram of the train (Figure 11). It was not Upatnieks' talk but the observation of this hologram that really struck everyone at the meeting. We can imagine a long line of scientists, optics specialists, waiting anxiously for their turn. They were all confused and most of them found it impossible to believe what they were seeing: the little toy train looked real behind the photographic plate, as if it was really there [41,42]. Many of them though it was done with mirrors and a few asked Leith "*Where's the train?*" and Leith said them "*It's back in Ann Arbor*" [43]. The train actually never left there.

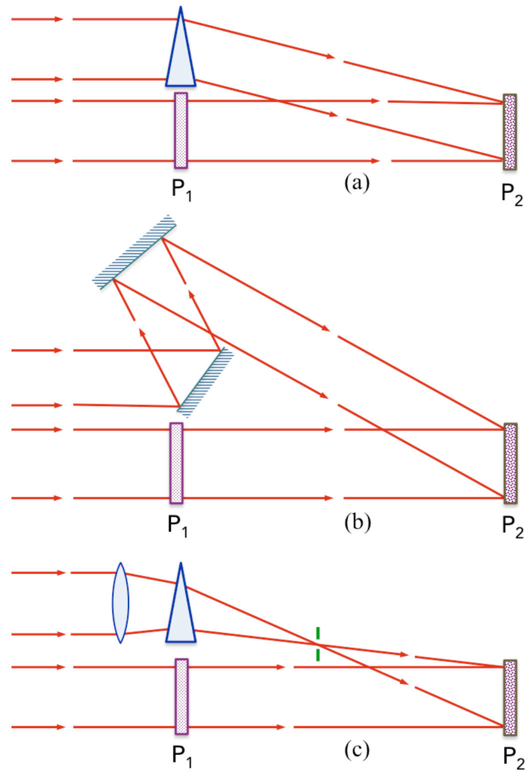


Figure 10. Early optical set-ups used by Leith and Upatnieks for recording off-axis two-beam holograms and avoid the twin-image problem. An object transparency located at plane P_1 is illuminated with coherent light from the left, and a Fresnel diffraction pattern image of the object is formed at plane P_2, where the photographic emulsion is placed for recording the hologram. In (a) a prism is used; in (b), a pair of mirrors are used; in (c), a lens, prism, and pinhole in combination are used. Adapted with permission from [39] © The Optical Society.

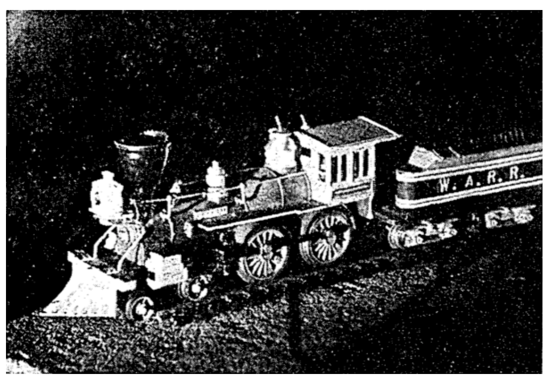


Figure 11. Photograph of a three-dimensional reconstruction of the *Toy Train* hologram. Emmett Leith and Juris Upatnieks, March 1964. Reprinted with permission from [39] © The Optical Society.

Leith and Upatnieks published these results in November 1964 in the Journal of the Optical Society of America under the titled "Wavefront Reconstruction with Diffussed Illumination and Three-Dimensional Objects" [39]. By combining laser light with the off-axis technique they had opened up the world of holography to the real world of three-dimensional objects. Off-axis holography had an enormous impact and was crucial to the advancement of holography as a truly useful technology. To such an extent was the role played by Leith in making holography a useful technique, that Gabor himself in his Nobel Lecture pointed out that the success of Leith and Upatnieks *"was not only to the laser, but to the long theoretical preparation of Emmett Leith, which started in 1955"* [22], and added that the results of Leith and his collaborators were brilliant. Some years later Leith modestly said: *"One day we came across Gabor's paper and simply out of curiosity decided to duplicate it"* [44].

5. …LET THERE BE HOLOGRAPHY, AND THERE WAS HOLOGRAPHY

Between 1947 and 1964 holography was a *collage* made from different perspectives [5]. Gabor's wavefront reconstruction devised as a method of image enhancement for the electron microscope which had interested only a few researchers and was later abandoned; Denisyuk's wave photography as a way of obtaining three-dimensional images which initially convinced few scientists; and Leith and Upatnieks' lensless photography, formulated from synthetic aperture radar and leading to holograms of three-dimensional objects. The exciting sight in 1964 of Leith and Upatnieks' three-dimensional hologram "explosively" revived interest in holography. Thanks to that little toy train, hundreds of researchers began to link the independent work of Gabor, Denisyuk and Leith, and in the years following the presentation of the hologram train, more than a thousand scientific papers on laser hologram recording were published [5]. It was necessary, however, to find a single name for this new field that would encompass what had previously been known in three different ways. Although Leith said that it was Gordon Rogers who coined the term "holography" from Gabor's "holograms" [45], it is not entirely clear who actually coined the term "holography" to designate this new area, but the truth is that holography, a field with extraordinary potential, had just been born.

The first exhibition of artistic holography took place in Michigan in 1968 and the second one in New York in 1970, while in 1971 a holography school started in San Francisco (USA), where scientists, engineers and artists could learn the new technique [46]. *"It's the intersection of art, science, and technology that makes holography so interesting"* [47,48], used to say Stephen Benton (1941-2003), a central figure of the development of display holography and who invented the type of hologram seen on millions of credit cards: the rainbow hologram [49]. Holography thus became an unusual example of a scientific field in which groups of people from very different backgrounds were involved in its development [50].

The year 2022 also marks the 50th anniversary of the first Gordon Conference on Holography and Coherent Optics, held in 1972 in Andover, New Hampshire, USA [5,51]. This first conference, organized by H. John Caulfield—and in which Caulfield himself was chairman and Brian J. Thompson was vice-chairman—, tried to structure the new discipline and defined its professional community. There were 83 attendees from the scientific holographic community (Figure 12) from universities, industrial research labs, and government labs. Among those attending this conference were Emmett Leith and Stephen Benton.

Figure 12. Photograph of the attendees at the First Gordon Research Conference on Holography and Coherent Optics. New Hampshire, USA, 17-21 July 1972 (courtesy of James D. Trolinger).

The *holographic explosion*, which originated thanks to the work of Leith and Upatnieks and other researchers at the University of Michigan, also rehabilitated the figure of Gabor, who went from being almost unknown to being invited to numerous meetings, and receiving honorary doctorates and numerous awards such as the Thomas Young Medal of the

Institute of Physics (1967), the Rumford Medal of the Royal Society (1968), the Michelson Medal of the Franklin Institute (1968), the IEEE Medal of Honour (1970), and the Holweck Prize of the French Physical Society (1971) [17].

In 1971 Gabor received the Nobel Prize in Physics "for his invention and development of the holographic method." Gabor, aware that the work of many other researchers had played a key role in this award, ended his Nobel Lecture with the following words [22]: *"I am one of the few lucky physicists who could see an idea of theirs grow into a sizeable chapter of physics. I am deeply aware that this has been achieved by an army of young, talented and enthusiastic researchers, of whom I could mention only a few by name. I want to express my heartfelt thanks to them, for having helped me by their work to this greatest of scientific honours."*

This paper not only does it intend to be an acknowledgment of the work of Gabor, Denisyuk and Leith, but also of all that *"army of young, talented and enthusiastic researchers"* who pioneered the development of holography.

6. ACKNOWLEDGMENTS

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