Engineering time: inventing the electronic wristwatch

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British Journal for the History of Science, Vol. 33, pp. 477-497, 2000

CAMBRIDGE
UNIVERSITY PRESS

North American Branch
40 West 20th Street
New York, NY 10011-4211
USA

Telephone 212 924 3900
Fax 212 691 3239

PUBLICATION PERMISSION

August 7, 2001

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Reference

Journal:	*British Journal for the History of Science*, Vol. 33 (2000)
Author:	Stephens, Carlene and Dennis, Maggie
Title:	"Engineering Time: Inventing the Electronic Wristwatch"
Selection/pp.:	477-497

Additional:

Use

Reprint Title:	Ultrasonics Ferroelectrics Frequency Control Society Website
Publisher:	Ultrasonics Ferroelectrics Frequency Control Society / Institute of Electrical and Electronics Engineers
Format	Internet World Wide Web website: http://www.ieee-uffc.org
Avail. Date:	2001 on

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BJHS, 2000, **33**, 477–497

Engineering time: inventing the electronic wristwatch

CARLENE STEPHENS and MAGGIE DENNIS*

Abstract. In the late 1960s teams of engineers working independently in Japan, Switzerland and the United States used newly created electronic components to completely reinvent the wristwatch. The products these groups developed instigated a global revolution in the watch industry and gave everyone, whether they needed it or not, access to the split-second accuracy once available only to scientists and technicians. This radical change in timekeeping technology was in the vanguard of a dramatic shift from a mechanical to an electronic world and raises important issues about technological change for scholars interested in late twentieth-century history. Examining the work of three teams of engineers, this paper offers a comparative approach to understanding how local differences in culture, economy, business structure and access to technological knowledge shaped the design of finished products and their acceptance by users.

Scarcely thirty years ago, three small groups of engineers in Japan, Switzerland and the United States completely reinvented the wristwatch with all new electronic components. For five hundred years, the watch had been mechanical, with a gear train powered by an unwinding spring. In the early 1970s it seemed unlikely that electronic watches would sell in large quantities. But today, when about 90 per cent of all watches made are electronic, a few craftsmen produce a small number of high-end mechanical pieces a year. Electronic wristwatches come in an enormous range of styles, some with analog dials and others with digital displays, and serve every whim and purpose. Battery-powered electronic wristwatches now give everyone, whether they need it or not, access to the split-second accuracy once available only to scientists and technicians.

The history of the electronic watch is worth a closer look. Its development during the 1960s was in the vanguard of a dramatic shift from a mechanical to an electronic world. The wristwatch was one of the first consumer products to make the transition, just as at the beginning of the nineteenth century, clocks were among the first consumer products made in factories by machine. A comprehensive history of consumer electronics has yet to be written, and the case of the electronic watch may suggest avenues of enquiry about how established industries and consumers interacted as electronics entered the market in the late twentieth century.[1]

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The authors wish to thank Robert Friedel and the two anonymous referees for their comments on an earlier draft of this paper as well as the Lemelson Center for the Study of Invention and Innovation at the National Museum of American History for funding their research. All photographs reproduced in this paper are courtesy of the Smithsonian Institution.

1 How the watch industry reacted to electronics and how consumers reacted to electronic watches suggest questions for further research in other areas of the history of consumer electronics, where no comprehensive history has been written. For specific aspects see, for example, Michael Riordan and Lillian Hoddeson, *Crystal*

Historically, clocks and watches of all sorts lie at an important crossroads of science, technology and society. Changes in timekeeping technology have influenced the character of scientific observation, aided the development of other machine technologies and brought significant revisions in the way people think about and behave in time. In contributing to the creation of time discipline and the abandonment of temporal cues from the natural world, the invention of the mechanical clock around AD 1300, for example, was one of the key points in turning Western civilization towards modernity.[2] Today, the ubiquity of electronic watches that display time's passage in hundredths of a second suggests that at least some people have devised specialized new uses for such tiny fragments of precise time, but the enduring importance of these new timekeepers for our relationship to time is still largely undocumented.

As significant as clocks and watches are, for most of horological history the details do not survive about how and why new technologies appeared. Nobody knows, for example, who invented the mechanical clock. Likewise, nobody knows who invented the mechanical watch about AD 1450, or even the modern wristwatch as the twentieth century turned. The first mechanical clocks were large weight-driven machines for public places. The key invention that enabled the gear train of such a machine to keep regular time was the escapement. To make portable timekeepers, such as domestic clocks or watches worn on the body, anonymous inventors in the early fifteenth century miniaturized the gear train and substituted the force of an unwinding spring for that of falling weights. The modern mechanical wristwatch was less a new invention than an adaptation. At the end of the nineteenth century, as accessories for sports like archery and cycling, women wore small watch movements – originally designed to be worn on a neck chain or lapel pin – in leather straps attached around their wrists. The electronic wristwatch involved inventing anew the internal components, methods for displaying time and manufacturing techniques.[3]

In addition, most published histories of timekeeping focus on improvements to

Fire: The Invention of the Transistor and the Birth of the Information Age, New York and London, 1997; Steven Lubar, *InfoCulture: The Smithsonian Book of Information Age Inventions*, Boston and New York, 1993; Bob Johnstone, *We Were Burning: Japanese Entrepreneurs and the Forging of the Electronic Age*, Boulder, CO and Oxford, 1999; Margaret Graham, *The Business of Research: RCA and the VideoDisc*, Cambridge, 1986. For the interactions between clocks and watches with American society in the nineteenth century, see Brooke Hindle and Steven Lubar, *Engines of Change: The American Industrial Revolution 1790–1860*, Washington, DC and London, 1986, 218–26, 233–4; and Michael O'Malley, *Keeping Watch: A History of American Time*, New York and London, 1990.

2 On the early history and significance of mechanical clocks see David Landes, *Revolution in Time: Clocks and the Making of the Modern World*, Cambridge, MA, 1983; Gerhard Dohrn-van Rossum, *History of the Hour: Clocks and Modern Temporal Orders*, tr. Thomas Dunlap, Chicago, 1996; Lynn White, Jr., *Medieval Technology and Social Change*, London, 1962, 119–28; Lewis Mumford, *Technics and Civilization*, New York, 1934 and 1963, 12–18; H. Alan Lloyd, 'Mechanical Timekeepers', in Volume 3 of *A History of Technology*, (ed. Charles Singer, E. J. Holmyard, A. R. Hall *et al.*), Oxford, 1957, 648–75; Aubrey F. Burstall, *A History of Mechanical Engineering*, New York, 1963, 142; D. S. L. Cardwell, *Turning Points in Western Technology*, New York, 1972, 18–19.

3 There exists a vast literature on clocks, watches and the internal technical history of improvements in timekeeping, much of which is written by and for collectors. Useful references on late twentieth-century timekeepers are Frederick J. Britten, *Britten's Watch and Clockmakers' Handbook, Dictionary and Guide*, 16th ed., (rev. and ed. Richard Good), London, 1978, 258–64; and Pieter Doensen, *Watch: History of Modern Wristwatch Design*, Ghent, 1994.

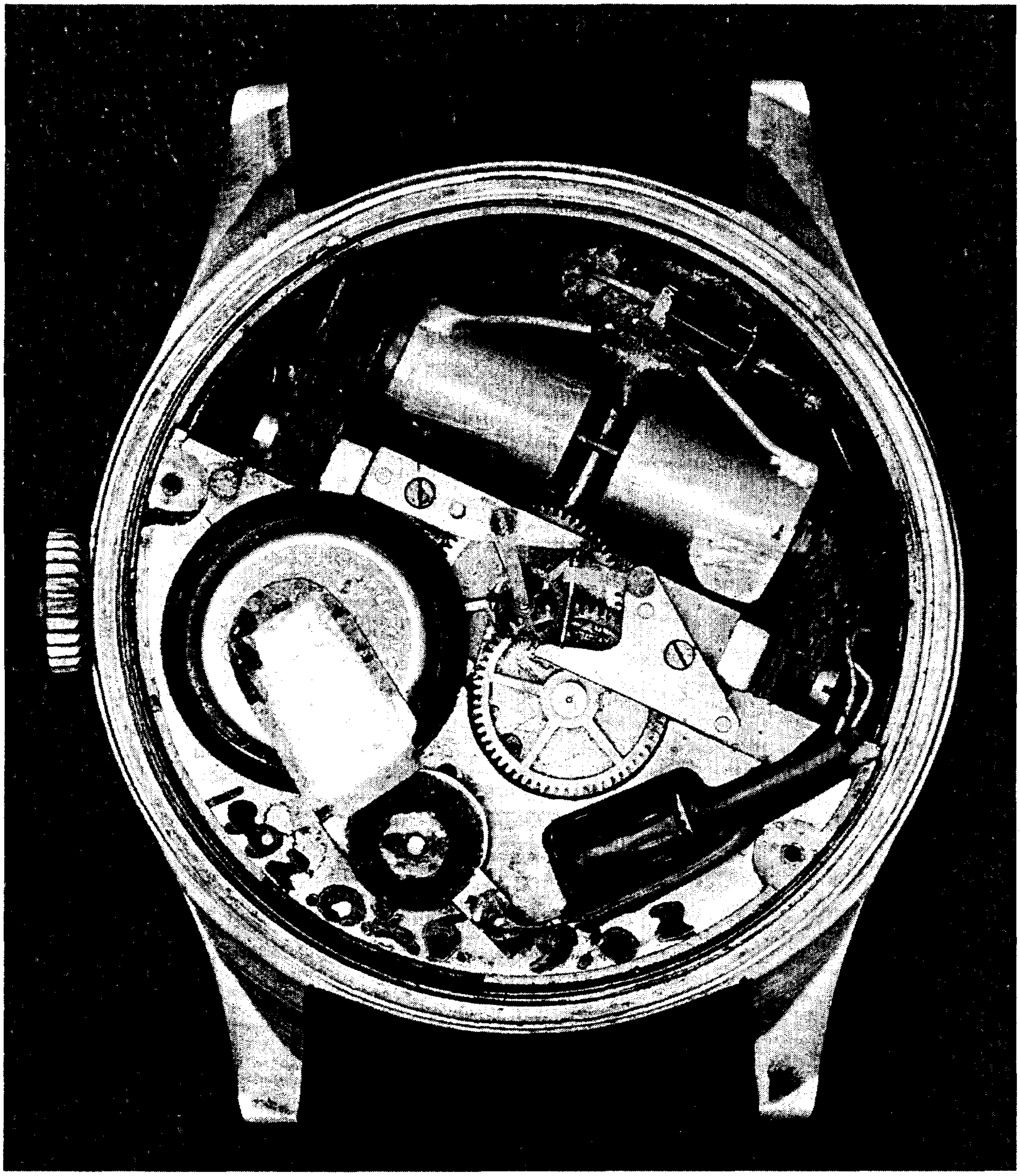

Figure 1. Bulova Accutron prototype, Model 8, *c.* 1957.

mechanical clocks and watches, and give scant attention to most of the twentieth-century changes relating to quartz and atomic standards. In contrast, what follows here documents for the first time who invented the electronic wristwatch and in what contexts they worked. Following engineers who worked simultaneously and independently in Japan, Switzerland and the United States, this story offers a comparative opportunity to show how local differences in culture, economy, business structure and access to technological knowledge shaped the design of finished products and their acceptance by users. This invention story is part of a larger study we have under way of the history of the electronic watch that will, we hope, offer important clues about how change happened in the late twentieth century, where it occurred and who controlled it.[4]

From a mechanical to an electronic world

All watches work essentially the same way. They have a part that vibrates regularly (as the pendulum swings in a clock), a means for counting and displaying those vibrations and a power source. In a mechanical watch, an unwinding spring drives a train of wheels and causes a balance wheel to swing back and forth, usually at a rate of five times a second. Another set of gears, called the motion work, reduces the swings to rotate a pair of hands at a regular rate, the minute hand once in sixty minutes and the hour hand once in twelve hours. In an electronic watch, a battery provides the power to sustain the oscillations of a quartz crystal, which vibrates thousands of times a second.[5] Circuits, substituting for mechanical gears, reduce these vibrations to regular pulses. The pulses can either drive a motor to rotate hands around a dial or translate into a numeric display.

For the watch to evolve from mechanical to electronic, its makers took many halting intermediate steps over roughly twenty years. In retrospect, there were clear signs already in the 1950s that watch manufacturers, in their perpetual pursuit of increasingly precise timekeepers, were eager to improve on the traditional mechanical wristwatch. Two significant announcements inspired the industry to competitive research and development. In the early 1950s, word of a joint venture between the Elgin Watch Company in the United States and Lip of France to produce an electromechanical watch – one powered by a small battery rather than an unwinding spring – touched off an innovative wave. Although the Lip–Elgin enterprise produced only prototypes, a competitor, the Hamilton Watch Company of Lancaster, Pennsylvania, brought to market in 1957 a workable electromechanical watch, powered by a tiny battery.[6]

Even more influential was the Bulova Accutron. Max Hetzel, a Swiss electrical engineer and outsider to the watch business, successfully substituted a tuning fork for the watch's vibrating balance wheel and, in this one insightful move, invented a timekeeper ten times more accurate than a well-adjusted mechanical watch. The epitome of the new generation of watch engineers, Hetzel was hired in 1950 by Bulova in Switzerland to develop

4 Our account of the electronic watch owes an enormous debt to the pioneering work of historian David Landes, who primarily sketched the Swiss efforts to make an electronic watch – what he called 'the quartz revolution'. See *idem*, op. cit. (2), 342–55, and his revisions in *L'Heure qu'il est*, tr. Pierre-Emmanuel Dauzat and Louis Évrard, Paris, 1987, 461–98. We extend the story of the first electronic watches to include a more detailed study of Japan and the United States, where similar efforts were going on simultaneously. We cover some of the same territory covered by journalist Bob Johnstone in his account of modern technology successes in Japan, *We Were Burning*, op. cit. (1), 61–144. Like Johnstone, we have conducted interviews with the participants to gather vital evidence that exists nowhere else. The material evidence of this invention story – the surviving body of prototypes, drawings and commercial watches – has also proved invaluable for informing this comparative investigation. Examples of the electronic watches discussed in this paper can be found in the History of Technology Division, National Museum of American History, Smithsonian Institution, Washington, DC.

5 The quartz is the watch's key precision element, and electronic watches containing a quartz oscillator are these days often called quartz watches. We use 'electronic' and 'quartz' interchangeably in this paper.

6 René Rondeau, *The Watch of the Future: The Story of the Hamilton Electric*, Corte Madera, California, 1992, 50.

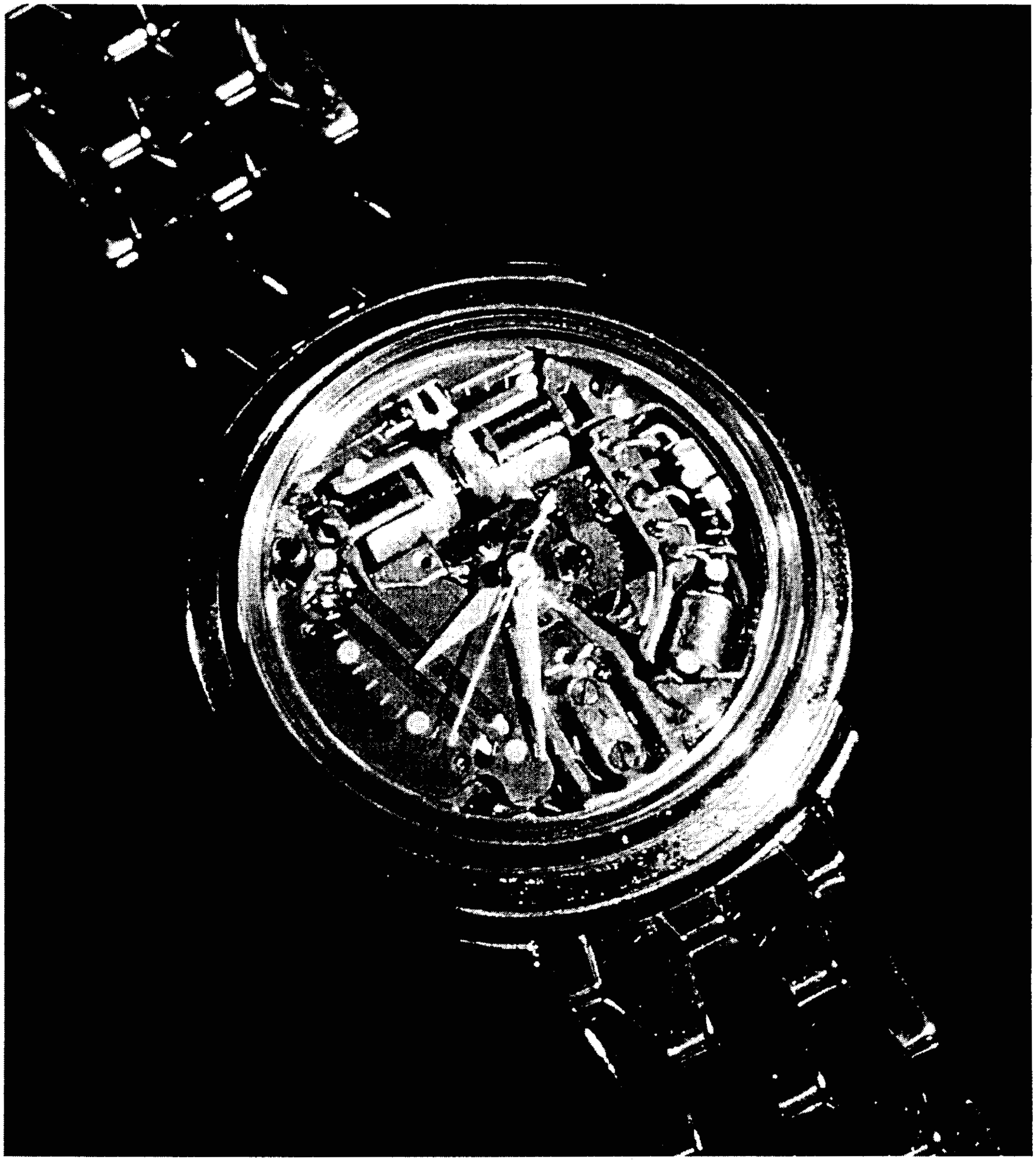

Figure 2. Bulova Accutron Spaceview, early 1960s.

automated manufacturing equipment for the company's facility in Biel. In 1952 company president Arde Bulova asked Hetzel to study the feasibility of the reported Elgin–Lip alliance to build an electric watch. Hetzel, who had learned what he knew about watches on the job, concluded from his research that the proposed electric watch would not be more accurate than any existing mechanical ones and suggested instead an acoustic frequency watch – one with a tuning fork oscillator. He developed the first prototype in Switzerland in 1955 and then moved to Bulova's New York operation in Jackson Heights to work on a commercial product with William Bennett (Figures 1 and 2). By October 1960

Bulova had announced the Accutron to the world. Vibrating 360 times a second, the tuning fork reportedly provided precise timing to within a few seconds per day. Advertising trumpeted the new watch's accuracy and novelty – 'It doesn't tick. It hums.'[7]

The post-war global watch industry

The Accutron was a powerful catalyst. Its prospects stunned the watch manufacturing community, by that time a mature industry with a centuries-old global market and deeply entrenched patterns of manufacturing, marketing and sales. Simultaneously in Switzerland, the United States and Japan the earliest efforts to make an electronic watch began. Introducing electronics to this tradition-bound industry posed a difficult challenge. Local differences in culture, economy, business structure and access to technical knowledge greatly influenced how the quartz watch developed in these three different settings. What each development group had in common was men like Hetzel – innovative electrical and electronics engineers, not watchmakers – who would do everything differently.

The Swiss watch industry had momentum and market share. By the early twentieth century the Swiss had created an organized, horizontally integrated watch industry of collaborative companies. The Second World War served to increase Switzerland's dominance in the world watch market. While other countries halted their watchmaking to make way for military production, Switzerland continued making watches and exporting them around the world. After the war, renewed consumer demand pushed their industry to full capacity. By the 1950s the Swiss commanded over 50 per cent of the world market for watches.[8]

In contrast, by that time the once-proud American watch industry was in serious trouble. A hundred years before, Americans had taught the world how to make watches by machine. The Depression put many firms out of business completely and caused major reorganizations among the surviving firms. Hamilton absorbed the Illinois Watch Company, for example, and Benrus and Gruen were reduced to designing cases and assembling watches with Swiss movements. The Second World War gave Hamilton, Elgin, Waterbury and Bulova a brief boost with military contracts for marine chronometers and timing fuses for artillery shells. But after the war, American companies struggled to retool for peacetime and Swiss imports became a flood. The Swiss bought Elgin outright. By the 1960s Hamilton, Bulova and Timex were the only companies manufacturing watches in the United States.[9]

7 Max Hetzel interview with authors, Deitingen, Switzerland, 15 April 1999; Press release, Bulova Watch Co., 25 October 1960, National Museum of American History, History of Technology Division Archives (hereafter NMAH-HOT); Bulova trade literature, 'Why you should wear Accutron instead of a watch', n.d., NMAH-HOT; Hetzel prototype 'Model 8', NMAH cat. no. 1992.0269.02.

8 Landes, op. cit. (2), 173.

9 To be accurate, Timex is not precisely an American company. It has been owned by a succession of Norwegian businessmen. See Kathleen McDermott, *Timex: A Company and Its Community, 1854–1998*, Waterbury, CT, 1998. For more on the post-war American watch industry, see M. Cutmore, *Watches, 1850–1980*, London, 1989, 160–72; Don Sauers, *Time for America: Hamilton Watch, 1892–1992*, Lititz, PA, 1992, 161–201; Edward Faber and Stewart Unger, *American Wristwatches: Five Decades of Style and Design*, West Chester, PA, 1988, 169–218.

Timex emerged from post-war retooling to dominate American watchmaking and unsettle traditional advertising and retailing worldwide. By using year-round advertising, the firm undermined the convention that watches were special gifts reserved for Christmas and graduation. By selling their low-priced watches in a variety of retail outlets, including drugstores, Timex redefined retailing venues. Between 1962 and 1974 the firm's share of the American market rose from one third to nearly half.[10]

Meanwhile, in Japan, Seiko, a firm that had been in the timepiece business since the 1890s, was also busy with post-war rebuilding. The company set themselves a very ambitious goal – to challenge Switzerland's reputation as the makers of the world's most precise watches. Although Seiko mechanical wristwatches were placed only 144th at the industry-renowned time trials in Neuchâtel, Switzerland in 1964, two years later three of the company's entries were placed in the top ten. During this time, production of watches in Japan doubled, while exports multiplied twenty-five times. By 1970 Seiko operated the world's largest watch company.[11]

Electronic components

The components for the electronic watch emerged from independent streams of research that stretched back over nearly a century. In the late nineteenth and early twentieth centuries, scientists had identified new materials like liquid crystals, which eventually composed watch displays, and discovered properties like piezoelectricity, the phenomenon that permits a piece of quartz to vibrate regularly when subjected to an electrical current.[12] During the Cold War, researchers in defence and aerospace technologies laid the basis for miniaturizing electronic circuitry. In the 1960s enterprising manufacturers applied the new research to the first electronic consumer products – televisions, calculators, hearing aids and watches.

At the heart of the historical transition is the story of how quartz became a timekeeping standard. Quartz vibrates regularly at thousands of times a second (more or less, depending on how it is cut and shaped). Electronic watches count those vibrations, divide them down to minutes, seconds and fractions of seconds, to show time on the dial or display. Quartz makes even the cheapest electronic watch many times more accurate than a well-maintained mechanical watch.

In 1927 a quartz crystal first went into service as a timekeeper when Warren Marrison, a telecommunications engineer at Bell Telephone Laboratories, developed a clock almost

10 McDermott, op. cit. (9), 173; Landes, op. cit. (2), 341.

11 For the origins of chronometry trials at Neuchâtel Observatory, see Eugène Jaquet and Alfred Chapuis, *Technique and History of the Swiss Watch*, London, 1970, 178–9, 190–5; Isadore Barmash, 'Seiko finds now is time to expand', *New York Times*, 26 February 1968; 'Making love to one wife', *Forbes*, 15 November 1970, 90.

12 On the discovery of liquid crystals see Paul Ukleja, 'Liquid crystals (physics)', in *Encyclopedia of Physical Science and Technology* (ed. Robert A. Meyers), 15 vols., Orlando, (1987), vii, 365–6; George Heilmeier, 'Liquid crystals – the first electronic method for controlling the reflection of light', *RCA Engineer* (1969), **15**, no pages; and James Ferguson, 'Liquid crystals', *Scientific American* (1964), **211**, 77–85. On the discovery of piezoelectricity see Susan Quinn, *Marie Curie: A Life*, New York, 1995, 111–12; *Dictionary of Scientific Biography*, s.v. 'Curie, Pierre'.

as big as a room that kept time using a crystal that vibrated a hundred thousand times a second when subjected to an electric current. Marrison's goal was not to invent a clock. He was in search of ways to monitor and maintain precise electromagnetic frequencies that carry radio and telephone messages. But he did realize the potential of his invention for improved timekeeping and proposed that quartz clocks be used in astronomical observatories to serve as time standards.[13]

In the 1940s observatories and scientific laboratories did in fact replace mechanical standards with quartz. Twenty years earlier, a new kind of mechanical timekeeper – the free-pendulum clock – had enabled scientists to prove that Earth does not keep uniform time. They showed that it speeds up and slows down as it orbits the Sun and wobbles on its axis as it spins – a day varies in length by tiny fractions of a second. Such deviations were immeasurable before astronomers could compare their celestial observations with free-pendulum clocks. And the deviations prompted the search for a new standard of defining the second. For centuries time had been defined in terms of the Earth's rotation relative to the Sun and other stars, and since early in the nineteenth century astronomers had defined the second as 1/86,400 of a mean solar day. Quartz clocks proved more accurate than any mechanical timekeeper, gaining or losing only a second in three years. In contrast the most accurate mechanical clocks might gain or lose three seconds per year.[14]

Although in Marrison's work quartz proved useful for large precision clocks, its advantages for personal timekeepers were not realized until engineers began investigating its possibilities for electronic watches. Before then, a crystal industry, born in the garage workshops of ham radio operators, had grown in the United States to machine natural quartz into appropriate shapes for frequency controllers in communications devices. The Second World War increased military demand for quartz oscillators, but supply shortages and difficulties with production techniques plagued the fledgling industry. After the war, manufacturers developed methods for growing synthetic quartz and new machinery for cutting smaller quartz oscillators, but it was not until the early 1970s, when Juergen Staudte invented a means of producing quartz oscillators using photolithography, that mass production became feasible.[15]

Almost as important as quartz to the electronic watch is the integrated circuit. Without tiny circuits, portable quartz timekeepers are impossible. In the quartz watch, the integrated circuit sustains the oscillations of the quartz crystal, divides the frequency down to one pulse per second and drives the display.

13 Warren A. Marrison, 'The crystal clock', *National Academy of Sciences Proceedings* (1930), **16**, 504. See also W. R. Topham, 'Warren A. Marrison – pioneer of the quartz revolution', *National Association of Watch and Clock Collectors Bulletin* (1989), **31**, 126.

14 See, for example, the quartz standard built at the US Naval Observatory in the early 1930s, NMAH cat. no. 319994, and mechanical, quartz and atomic standards at the Royal Greenwich Observatory in Derek Howse, *Greenwich Time and the Longitude*, London, 1997, 163–80. The Shortt free-pendulum clock, the most precise mechanical clock then available, was accurate to within plus or minus ten milliseconds per day, according to J. D. Weaver, *Electrical and Electronic Clocks and Watches*, London, 1982, 35.

15 On the development of quartz crystal fabrication, see Virgil Bottom, 'A history of the quartz crystal industry in the USA', *Proceedings of the 35th Annual Frequency Symposium* (1981), 3–12; Juergen Staudte, interview with the authors, Cedar City, Utah, 4 February 1999; Juergen Staudte, 'Subminiature quartz tuning fork resonator', *Frequency Control Symposium* (1973), 50–4.

Conceived in 1952 by G. W. A. Dummer at the Royal Radar Establishment at Malvern and then realized in 1959 independently by Jack Kilby at Texas Instruments and Bob Noyce at Fairchild, the earliest integrated circuit solved a problem then troubling the computer industry, but its usefulness for watches was limited. Watch engineers needed integrated circuits with much lower power demands than these first circuits.[16] Just as the first electronic watches were in development, C-MOS (complimentary metal oxide semiconductor) circuits became available in the late 1960s. C-MOS circuits consume a hundred thousand times less power than ordinary chips because the current flows intermittently – only when the circuit switches from on to off, or off to on.[17] C-MOS circuits were developed at RCA under the direction of Gerald Herzog, who was in search of ways to amplify audio signals. Funded by the Air Force and NASA, Herzog's team had prototype devices by 1964, and RCA began selling its first C-MOS circuits in 1967.[18] Quartz watch engineers in labs around the world realized, when they learned about the new circuits with their low power demands, that they had the perfect solution for electronic watches dependent on small batteries.[19]

The first electronic watches

The Accutron announcement spurred rival watch companies to develop competitive products they hoped would surpass the accuracy Bulova was claiming for its new tuning-fork watch. Since the seventeenth century, when astronomers and navigators made demands for precision timekeepers, accuracy had long been the goal of clock and watch design. In more modern times claims to greater accuracy had been the focus of watch advertising, especially for the Swiss. In 1960 the Accutron became the latest front-runner in the ongoing competition among watch companies.[20]

In the ferocious global watch wars that ensued, only a few existing watch companies marshalled the resources to rise to the challenge. In the three cases that follow, firms cast about for alternatives to the Accutron's new precision, and in the end found themselves extending their traditional operations to accommodate the new electronics.

In Japan, Seiko had begun to explore the possibility of an electronic watch before any of its global competitors. The firm organized a team in 1959, led by Tsuneya Nakamura, to investigate the feasibility of a watch more precise than the best mechanical watch then

16 Riordan and Hoddeson, op. cit. (1), 254–75; T. R. Reid, *The Chip: How Two Americans Invented the Microchip and Launched a Revolution*, New York, 1984, 23; and Ernest and Stuart MacDonald, *Revolution in Miniature: The History and Impact of Semiconductor Electronics*, Cambridge, 1978, 108–9.

17 George Gilder, *Microcosm: The Quantum Revolution in Economics and Technology*, New York, 1989, 145.

18 Johnstone, op. cit. (1), 67–75.

19 The first watch batteries were developed in 1954 by the National Carbon Company (later Union Carbide) for Hamilton's first electric watch. See Rondeau, op. cit. (6), 34–5; Hamilton Watch Company, 'From sundial to electric watch', *Timely Topics*, January/February 1957, 8–9.

20 As David Landes has pointed out (op. cit. (2), 344–5), 'it has always been the rule that the quality of instruments of time measurement is a function of their precision. This was a point that had long been a feature of Swiss watch advertising, with its emphasis on chronometer certification by Swiss observatories. In making this assertion, Bulova was saying in effect that it was offering a better product – better than all but the very best of mechanical timepieces'.

available.[21] The project was a good match for Nakamura's ambitions. The young manager dreamed of creating the ideal watch – one that never stopped, never broke and was accurate and beautiful.[22]

Nakamura's group initially set its sights on developing a desktop quartz clock. And they had a deadline – Seiko had just been named official timekeeper of the 1964 Tokyo Olympics. Just in time, the team developed a portable quartz chronometer for timing Olympic events.[23]

Their next goal was to develop even smaller products. To design these watch prototypes, the ten-man team had to completely reinvent themselves. They were mechanical engineers desperately in need of electronics training. At that time in Japan, it was common for an employee to stay for his entire career with the same company. In turn, Japanese firms did not hire new staff with specific skills to work on new projects, they retrained their existing workforce. A company larger and richer than Seiko might have sent employees to American universities to acquire new skills, but Nakamura's team did not have that luxury.[24] Driven by a desire to overtake the Bulova Accutron and the Swiss, these engineers zealously conducted exhaustive literature searches on oscillators, circuits and power sources. They did their research by trial and error.[25]

The engineering problems were many. Probably the greatest challenge was to develop a circuit that would divide the pulses of the vibrating quartz and drive the hands. Seiko's solution, in the days before appropriate integrated circuits were available, was a hybrid circuit composed of seventy-six transistors, twenty-nine condensers and eighty-four resistors, hand-soldered to the movement at 128 points.[26]

Their first commercial product, the Seiko Astron SQ, went on sale in Tokyo on Christmas Day 1969 (Figure 3). It was the first quartz watch ever sold anywhere in the world. Some writers, alleging the watch was pulled off the market, deem the Astron a technical failure.[27] But according to Seiko officials, the company never intended to make more than the initial two hundred pieces. Seiko management, regarding the Astron as only

21 Kohtaro Kuwata and Junjiro Shintaku, 'Business strategy for de-maturity: a case of Seiko in the watchmaking industry' (paper presented at the Mitsubishi Bank Foundation Conference on Business Strategy and Technological Innovation, Ito City, Japan, 13–15 July 1985), 12.

22 Recently retired, Tsuneya Nakamura rose to be president of Seiko Epson. His reminiscences on the quartz watch were given in an interview with the authors, Suwa, Japan, 24 June 1999.

23 Although Seiko had built a much larger quartz clock for the Japanese broadcasting company NHK in 1958, no one in the firm had experience with miniaturizing quartz technology. Johnstone, op. cit. (1), 65; 'Seiko: highlights of over 100 years of leadership in watchmaking', *Horological Journal* (1994), **136**, 556–8; Tsuneya Nakamura interview.

24 Johnstone, op. cit. (1), 76.

25 Nakamura interview; Masahiro Kurita, interview with the authors, Suwa, Japan, 24 June 1999.

26 Ryo Hirata, Seiko Institute of Horology, letter to author Stephens, 10 November 1997; Seiko Astron module, NMAH cat. no. 1998.0248.02, and watch replica, NMAH cat. no. 1998.0248.02.

27 'Seiko quartz crystal watch is first to reach consumers', *American Horologist and Jeweler* (1970), **37**, 20. Bob Johnstone (op. cit (1), 66) calls the Astron a 'kludge', a system made up of poorly matched components. See also Landes, op. cit. (2), 344. These judgements of the Astron appear to be based on comparisons with today's standard quartz watch, which has vastly different components. As Hans-Joachim Braun reminds us, definitions of success and failure in the development processes of new technologies are 'messy'. 'Whether such an innovation can be called a "success" or a "failure" depends', he wrote, 'on the firm's business intentions'. See his 'Introduction: symposium on "Failed Innovations"', *Social Studies of Science* (1992), **22**, 215.

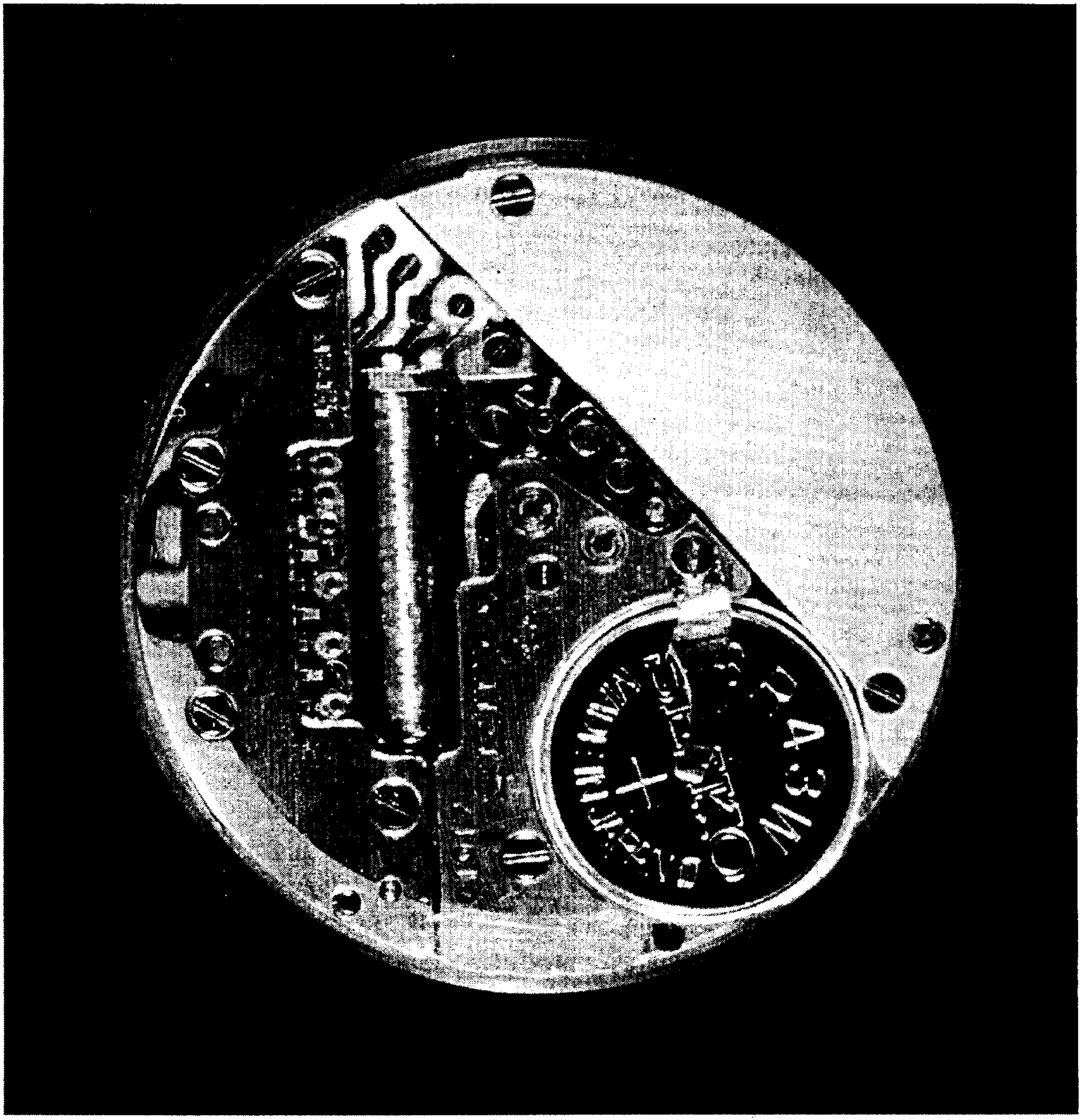

Figure 3. Seiko Astron SQ module, 1969.

a first step in the development process, continued to support the research and development. Improved models soon followed.[28]

After decades of dominating the Japanese market, Seiko found it had to stretch to make much more accurate watches to compete with the Swiss in the world market. As Nakamura recalls, Japanese consumers were satisfied with Seiko's mechanical watches, and this complacent domestic market allowed the company to devote time and money to the quartz effort.[29] For these reasons Seiko was willing to take the risk on a new product that might ultimately be a technical or commercial failure.

28 Nakamura interview, op. cit. (25).

29 Nakamura interview, op. cit. (25).

In contrast to Seiko, the effort to develop a quartz watch in Switzerland did not happen within a single established watch company. The Swiss watch industry was horizontally integrated in hundreds of small companies. Only one or two of the firms at that time had the resources to tackle research and development independently, and they were not inclined to direct their efforts towards electronics.

In 1962 the president of the Swiss Chamber of Watchmaking, Gerard Bauer, had the Bulova Accutron on his mind. He urged the establishment of a research laboratory in Neuchâtel, the heart of the country's watchmaking district, to study the possibilities of alternatives to mechanical timekeeping. He did so even though the Swiss watch industry already had a well-established research arm in Neuchâtel, the Laboratoire Suisse de Recherches Horlogères (LSRH – the Swiss Laboratory for Horological Research) near the campus of the city's university. For over twenty years, the LSRH had investigated problems in materials science, studied the physical behaviour of watch parts and surface treatments, developed atomic standards and distributed time frequencies, and taught advanced science to the country's promising young watchmakers. But Bauer foresaw a need for a real change of direction. The result was the CEH (Centre Electronique Horloger), funded by a reluctant consortium of shareholding Swiss watch companies and housed in the same building as the LSRH.[30]

Bauer's associate Roger Wellinger was in charge of hiring a staff for the lab. His challenge was to find well-qualified engineers. At that time the electronics industry and university training in the new field did not exist in Switzerland. Wellinger scoured companies in the United States, and American firms in Switzerland, for Swiss-born engineers with a background in electronics. The Swiss who became project leader was Max Forrer, a Stanford Ph.D. physicist working at General Electric in California. He recalled how his initial scepticism at Wellinger's recruitment pitch ultimately turned to great enthusiasm. 'It was a high-risk affair', he remembers telling himself when he accepted the job, 'but if we were successful, it could be something a little bit extraordinary'.[31]

Once organized, the CEH staff faced scepticism and professional jealousy from the very traditional Swiss watch industry. The lab's shareholders were a great source of consternation for Forrer's team. Since the shareholders represented many companies, they had little interest in pursuing a unified goal. A number of the companies joined the consortium only grudgingly. The team worked in secrecy, lest one of their larger, richer shareholders learn how to make electronic watches and decide to abandon the CEH effort in favour of developing their own product. There were also plenty of critics who simply did not believe it was possible, or even necessary, to build an electronic watch.[32]

The most vexing technical problem they faced, according to another engineer, Henri Oguey, was the problem of developing components that could be integrated with each

30 Eugène Jaquet and Alfred Chapuis, *Technique and History of the Swiss Watch*, London and New York, 1970, 260; René Le Coultre, 'The genesis of the Beta' (English translation of speech given on the twentieth anniversary of the first quartz watch), n.p., 1987, 3.

31 Max Forrer, interview with the authors, Neuchâtel, Switzerland, 20 April 1999; Forrer recently retired as the head of what CEH became – CSEM (Centre Suisse d'Electronique et de Microtechnique), a successful microelectronics lab in Neuchâtel, the hub of Switzerland's 'Silicon Lake'.

32 Max Forrer interview, op. cit. (31).

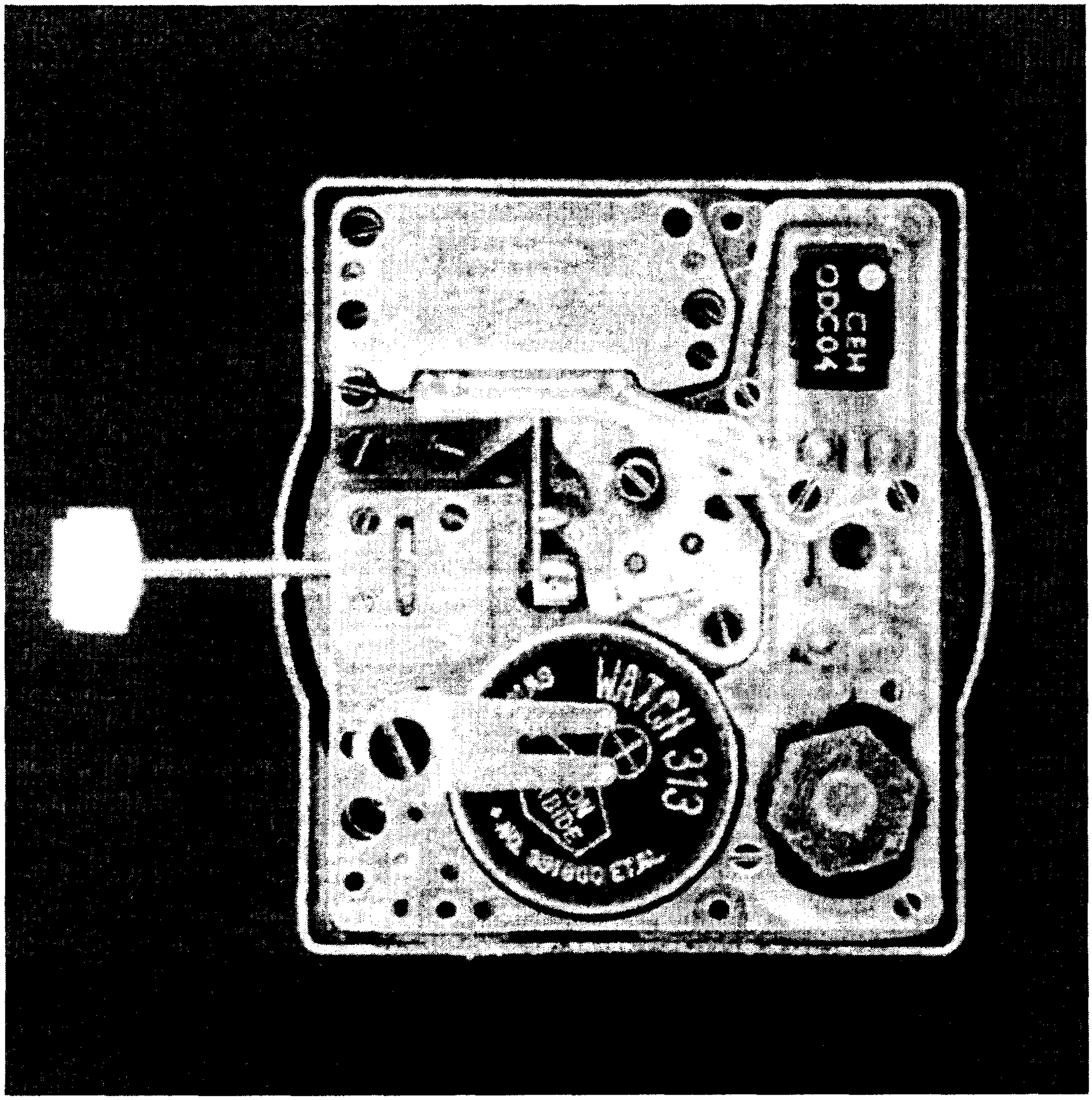

Figure 4. Beta 21 module, 1970.

other into a system that would keep time. Swiss-born Oguey, who had previously worked at IBM in both Zurich and New York, recalls, 'the problem was to consolidate the needs of electronics with the needs of mechanics'. He described how the lab staff set to work on two different prototypes, with two different kinds of motors to drive the gears that turn the watch hands, each with its own peculiar circuit. These prototypes were called Beta 1 and Beta 2.[33]

The CEH prototypes, along with Seiko's quartz prototype entries, made their public debut at the time trials at the Neuchâtel Observatory in 1967. The observatory had held competitions since 1877 and afforded chronometer-makers and watchmakers, mostly from

33 Henri Oguey, interview with the authors, Neuchâtel, Switzerland, 20 April 1999.

Switzerland, an opportunity to show off their best timekeepers. Similar demonstrations of Swiss technical prowess occurred at the Geneva Observatory and, for the British watch market, Kew Observatory outside London. How the competition measured excellence changed over time, but what the trials measured never varied: the best watch was not the most accurate, but the most constant. A finely adjusted mechanical watch may gain or lose as much as twenty seconds a day, but if it does so consistently day after day, at the same daily rate, it is considered a perfect watch. By 1967, the first year watches with quartz oscillators participated in the competition, a score of zero was considered perfect. Such a watch would run with no variation over days of testing, despite changes in position or temperature. Ten of the CEH's prototypes scored close to that, with the top score 0.152, and the Seiko entries came right behind in eleventh and thirteenth place (another CEH product came in twelfth). Together the quartz watches outperformed all mechanical watches submitted, the best of which, an Omega watch, rated 1.73.[34]

With this public performance, the quartz watch was still far from a reality. Seiko's Astron was still two years away, and the CEH engineers returned to their lab to develop a commercial product, a process that took three more years.[35]

Forrer's team was frustrated with the slow pace. Manufacturing had to be distributed among the shareholding companies, several of which took their time to respond. All-new production lines had to be created, and staff at each facility needed training. One thousand watches had to be completed before any announcement of the product could occur. Finally, in 1970, watches containing the Beta 21 electronic module, descendant of the Beta 2 prototype, went on sale under the brand names of sixteen different Swiss watch companies (Figures 4 and 5).[36]

The Swiss effort to invent an electronic watch was risky and unconventional. As the electronic watch project began, Swiss mechanical watches dominated world markets, and excellence in watchmaking was a large component of Swiss national identity. From their position of market strength, and with a national watch industry organized broadly and deeply to foster mechanical watches, many in the industry thought that moving into electronics was unnecessary. Forming a consortium was an established method for addressing needs in Switzerland and in the horizontally integrated watch industry. But the forming of the CEH brought tensions to the industry and obstacles to Forrer's team, obstacles that delayed the Swiss from having the world's first quartz watch for sale. For a group of electronics engineers to change centuries of tradition was indeed revolutionary.

By American standards, the Japanese and Swiss efforts to invent an electronic watch were unconventional in their approach to acquiring capital and technical knowledge. In contrast, the experience at the Hamilton Watch Company in Lancaster, Pennsylvania most closely follows what historians of technology consider a conventional narrative of

34 The performance of the quartz entries actually caused the end of the annual chronometry competition. See Landes, op. cit. (2), 345–55; Jaquet and Chapuis, op. cit. (30), 232. For competition results in 1967, see Canton of Neuchâtel, 'Arrêté concernant les prix du concours de chronomètres à l'Observatoire cantonal en 1967', 13 February 1968, 6; we thank Max Forrer for this reference.

35 Le Coultre, op. cit. (30), 7–8.

36 Forrer interview, op. cit. (31); Le Coultre, op. cit. (30), 9; Doensen, op. cit. (3), 140; Beta 21 module, NMAH cat. no. 1999.0294.01. and Bulova watch with Beta 21 module, NMAH no. 1999.0124.01.

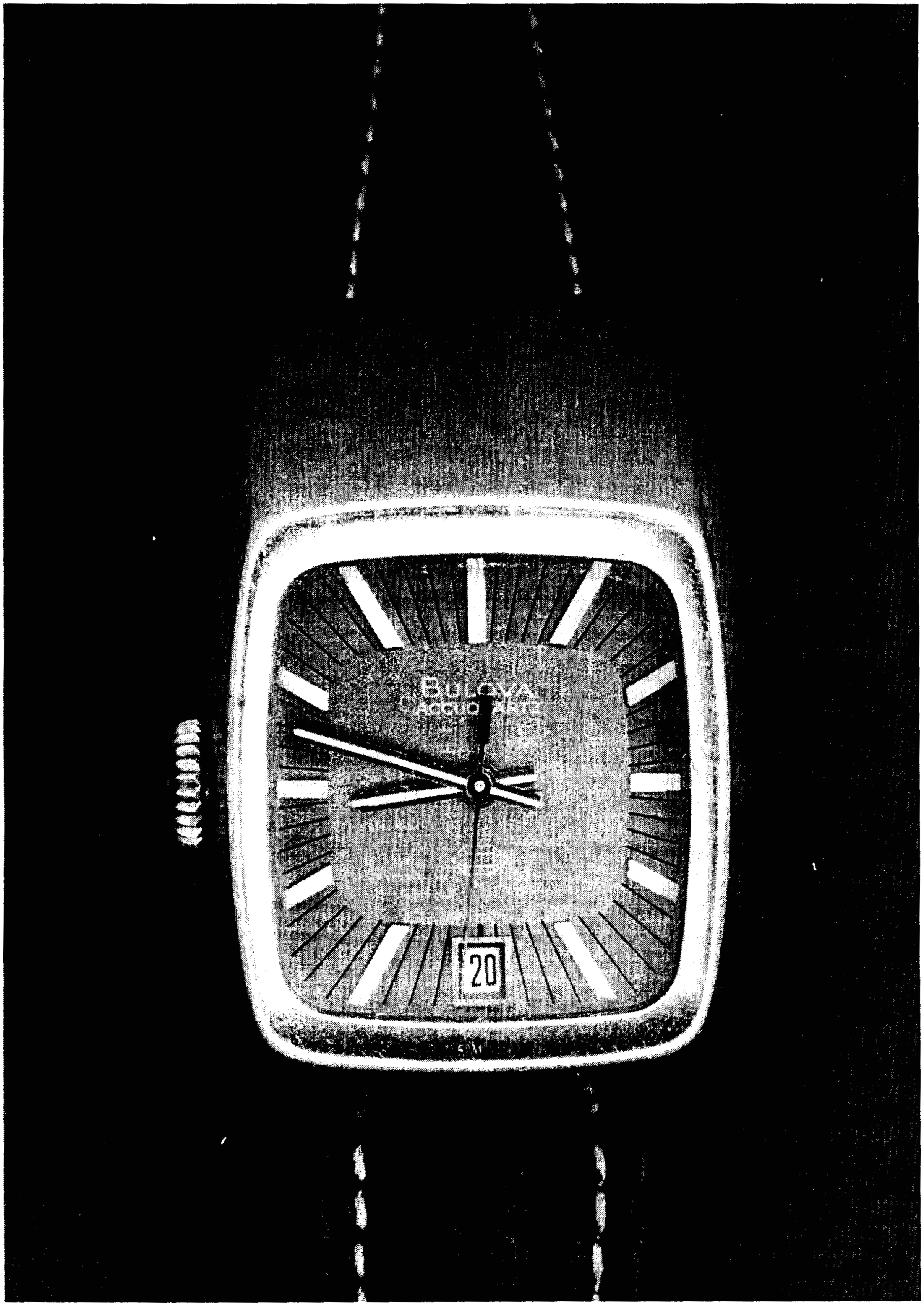

Figure 5. Bulova Accuquartz wristwatch containing Beta 21 module, 1970.

technological change – including attracting industry outsiders, partnering with other firms and exploiting military connections.[37]

In 1967 Hamilton began an effort to develop a quartz analog watch, one with conventional hands and dial like the Swiss Beta 21 and the Seiko Astron. Ongoing technical problems with battery contacts on Hamilton's electric watch, on the market already for a decade, and competition from the Bulova Accutron challenged Hamilton to explore an all-electronic watch.[38]

However, Hamilton's quartz analog project was short-lived. It soon became clear to Hamilton developers that both Swiss and Japanese quartz analog watches were about to hit the market, well before Hamilton could have a product ready. In need of something completely new to stay competitive, Hamilton changed course to try to build the world's first electronic digital watch.

To produce this digital watch Hamilton joined forces with a Dallas electronics company, a spin-off from Texas Instruments called Electro-Data, and moved John Bergey from its military products division to the watch division to head the team that would develop a digital watch. With a degree in engineering from Pennsylvania State University, Bergey had gone to work at Hamilton after three years in the US Air Force. He joined project engineer Richard Walton, who had come to Hamilton to debug the electric watch and then moved to the recently abandoned quartz analog project. In the midst of their development work, George Thiess at Electro-Data approached Hamilton to market his own product – a digital watch with an LED (light-emitting diode) display. Hamilton believed it could get its new watch to market more quickly with help from Electro-Data, and they soon signed a contract for Electro-Data to produce six prototypes.[39]

Electro-Data's design for the watch was problematic and it took over a year to build. Walton made frequent trips to Garland, Texas to check on the progress that Electro-Data's electrical engineer Willy Crabtree was making. Walton remembers that Crabtree and Thiess developed a leaky 4-volt wet cell battery that burned his wrist. 'It became a badge of honor to have this red mark on your wrist', Walton recalled, 'because it meant at one time you wore one of the prototypes'. The six prototypes were finally completed, and on 6 May 1970 a press conference in New York announced the Pulsar to the world. No dial and hands for this space-age gadget. Red numbers flashed the time at the push of a button.[40]

Developing a viable watch began right after the press conference. The watches unveiled there were still cranky prototypes that failed to work most of the time. Since the prototypes

37 See, for example, Nathan Rosenberg, *Inside the Black Box: Technology and Economics*, Cambridge, 1982, 3–29; Govindan Parayil, 'Models of technological change: a critical review of current knowledge', *History and Technology* (1993), **10**, 105–26; Robert Fox (ed.), *Technological Change: Methods and Themes in the History of Technology*, Amsterdam, 1996; Rudi Volti, *Society and Technological Change*, New York, 1988.

38 Richard S. Walton, 'Electronic Watch Investigation: Phase I', (Hamilton Watch Company internal document, 9 January 1968), 10, NMAH-HOT.

39 John Bergey, interview with the authors, Lancaster, PA, 29 October 1998; Development contract between Hamilton Watch Company and Electro-Data, 1 December 1969, NMAH-HOT.

40 Richard Walton, interview with the authors, Tempe, Arizona, 7 January 1999; press release, Hamilton Watch Company, 6 May 1970, NMAH-HOT.

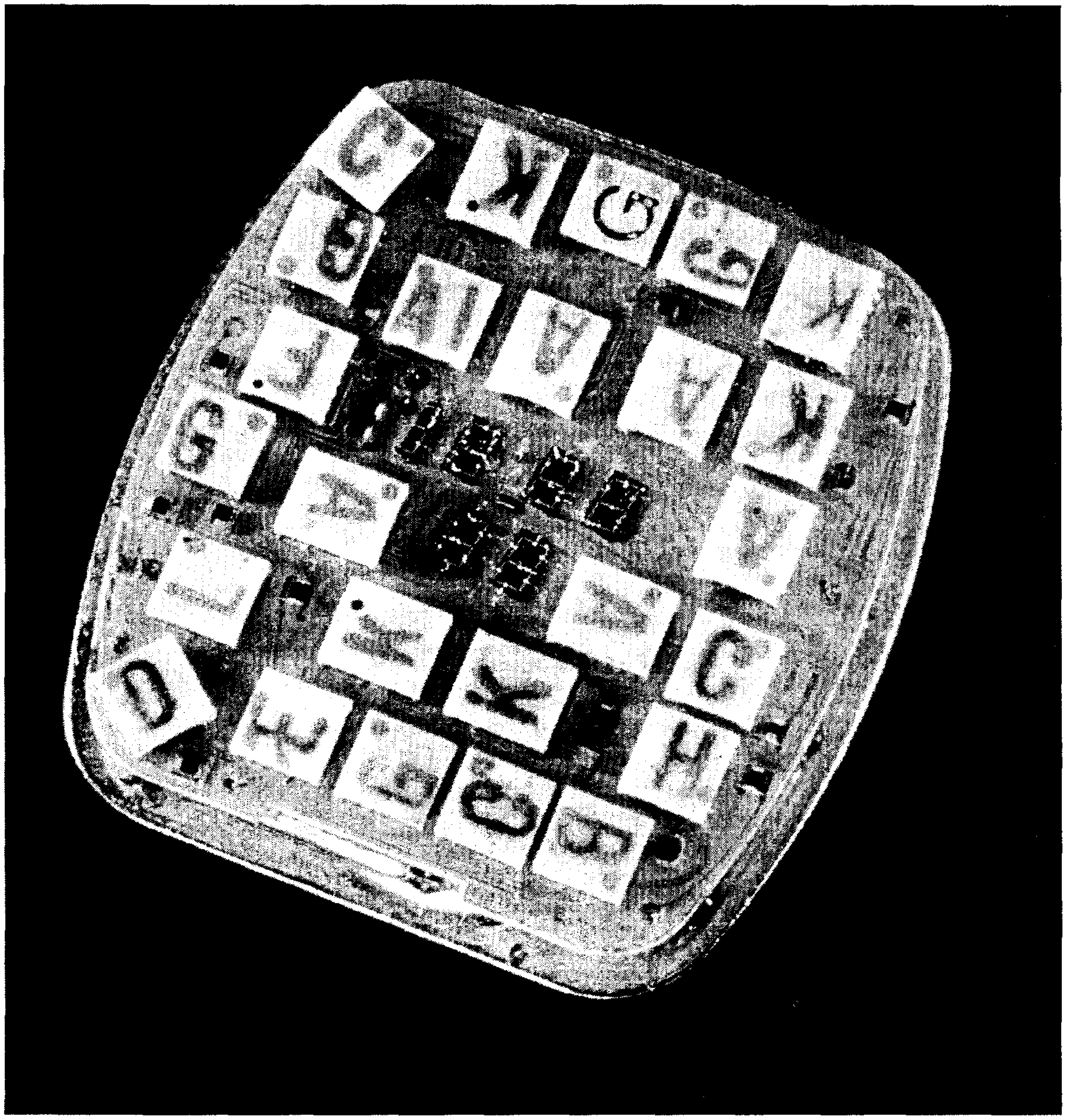

Figure 6. Hamilton Pulsar module, 1972.

were composed of many circuits wire-bonded by hand, the design was far from ready for economical manufacturing. A single-chip module took two more years to get to market. Components came from a variety of suppliers – RCA provided the C-MOS chips, Monsanto the LED displays and Clark Crystal the quartz oscillators. When consumers could finally purchase the Pulsar in 1972 the watch cost $2100 – the price of a small car (Figures 6 and 7).[41]

41 Bergey interview, op. cit. (39); Richard Walton interview, op. cit. (40); Willy Crabtree interview with the authors, Dallas, Texas, 3 June 1999; *Wall Street Journal*, 4 April 1972, 9. Hamilton Pulsar watch, NMAH cat. no. 1994.0354.02, and Hamilton Pulsar modules NMAH cat. nos. 1994.0354.01 and 1999.0030.01.

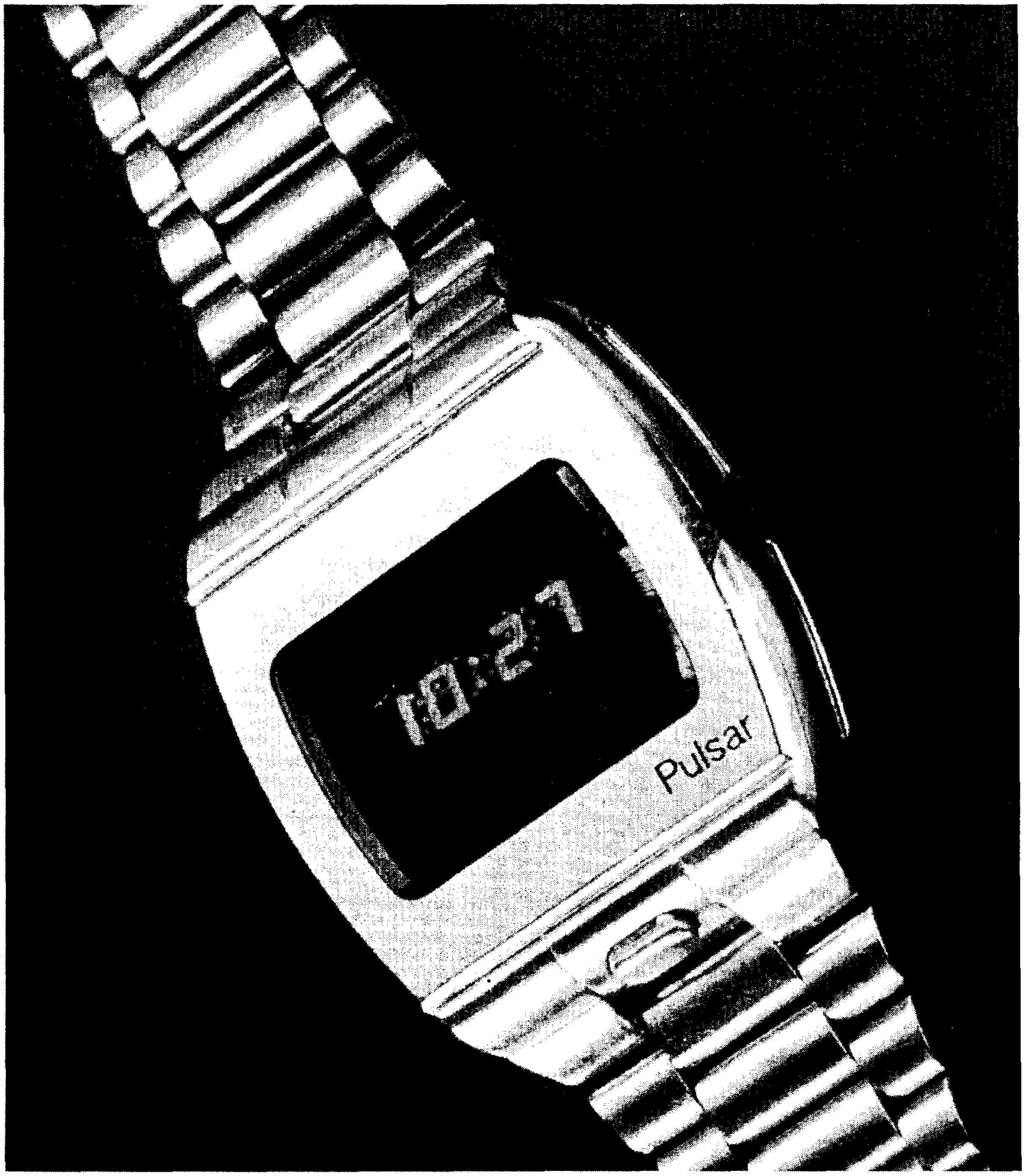

Figure 7. Hamilton Pulsar wristwatch with LED display, 1972.

Hamilton was clearly behind in the international competition for a quartz watch when Bergey's team undertook the digital watch project. They rapidly caught up and in fact for a while defined the cutting edge of electronic watch technology. The American company appeared to have won the overwhelming advantage in the global watch wars: access to microelectronics know-how and materials generated in the laboratories of American industries geared up for the Cold War and the space age.

Aftermath

The revolutionary transition from mechanical to electronic timekeeping was not simply established with the introduction of a few quartz watches. The Astron, the Beta 21 and the Pulsar – the names suggesting the space age in which they were conceived – were only the very beginning.

These newfangled electronic watches met with a different kind of reception at every turn. Horological trade journals and the popular press in the early 1970s indicate that the watch industry was not sure what to make of these new timekeepers. Many saw quartz watches as novelty items and predicted that, if they survived at all, they would occupy only a small percentage of the watch market.[42]

Tempted by the prospects of electronic watches, American semiconductor companies – Texas Instruments, Fairchild and National Semiconductor, for example – energetically entered the watch market with their own products. By the mid-1970s about forty American companies were mass-producing electronic watches.[43] Competition among these companies quickly forced prices down. Price wars ensued, and very inexpensive electronic watches flooded the market.

The Hamilton Watch Company was one of the casualties. Hamilton sold its watch division to the Swiss in 1974, and its separate Pulsar division – called Time Computer, Inc., continued until 1977 – when Rhapsody, Inc., an American jewellery firm, bought it. Rhapsody in turn sold the name 'Pulsar' to Seiko in Japan.

The Swiss watch industry, despite its head start, was slow to respond to the market potential of the quartz watch. Wedded to long-standing values of customer service and trained repairmen, the manufacturers relied on their leadership in mechanical watches to carry them along while they attempted to fit their old ways of conducting business with the new technology. But between the mid-1970s and 1983, the Swiss watch industry saw its portion of the world watch market drop from 30 per cent to 10 per cent, in terms of the number of units sold. A worldwide economic recession, technological changes and severe international competition forced the Swiss industry to make structural changes, primarily the creation of the ASUAG (Allgemeine Schweizerische Uhrenindustrie AG)–SSIH (Société Suisse de l'Industrie Horlogère SA) consortium (later restructured by businessman Nicolas Hayak under the name SMH – Société Suisse de Microélectronique et d'Horlogerie SA). ETA, a subsidiary of the group, and its president Ernest Thomke and chief engineer Jacques Müller came up with a brand new product that helped the Swiss watch industry regain some of its market share – the Swatch.[44]

Conventional mechanical watches typically have more than 125 parts. When Swatches

42 Examples include 'Quartz watch muddle continues', *American Horologist and Jeweler* (1973), **40**, 47; 'How can traditional watch industry deal with untraditional watches', *American Horologist and Jeweler* (1976), **43**, 10; 'WMJDA conventioners will tackle quartz marketing; other problems', *American Horologist and Jeweler* (1976), **43**, 18; 'The quartz revolution: what's it all about?' *American Horologist and Jeweler* (1976), **43**, 36.

43 The Electronic Watch Market, New York, 1975, 112.

44 The Swiss had always led the market in fine watches. The success of Swatch, a competitive, inexpensive product, spurred industry recovery by allowing the Swiss watch industry to compete in the more lucrative inexpensive watch category. See *The Market for Watches and Clocks*, New York, 1988, 121–4; and 'Swatch', *Encyclopedia of Consumer Brands* (Detroit, 1994), **2**, 530–2.

appeared in 1983 they had just fifty-one parts, far fewer than any other analog quartz watch. Major investments in automated production processes lowered manufacturing costs. The ultimate throwaway watches, the new Swatches were sealed into plastic cases and deliberately designed to be irreparable. Recovery for the entire reorganized industry began with the Swatch, and Switzerland is once again the world's leading watch exporter in terms of total value.[45]

By the late 1970s first Japan and then Hong Kong firms overtook the Americans and the Swiss by manufacturing more, ever cheaper, quartz watches. These companies ignored traditional marketing methods long established in the watch industry, which had included selling watches only through jewellers, creating product lines in established price niches and building brand-name recognition. With a whole new line of products that in no way resembled traditional watches, Asian manufacturers threw the entire relationship between makers, buyers and sellers into disarray. Concentrating on low-end modules that cost pennies to make, by 1978 Hong Kong exported the largest number of electronic watches worldwide.[46] The American watch industry was irreparably damaged. US semiconductor companies pulled out of the watch market entirely. With the sole exception of Timex, the few remaining traditional watch companies went out of business and sold their brand names to foreign competitors.

While the semiconductor companies' actions and cheap labour in Asia greatly contributed to the reorganization of the worldwide watch industry, consumers helped shape the way quartz watches were subsequently designed. The first watches were sold as luxury products for men. They were indisputably the most accurate timekeepers ever available to consumers. But the technologies they used were still experimental, and the watches unreliable. As prices dropped, quality did not necessarily improve. In the United States, customers returned faulty watches in record numbers. The return rate for digital watches in 1976, for example, was 30 percent.[47]

Sustained interactions between watch designers and watch users brought significant changes to the ultimate product. Consumers had a list of complaints they found particularly vexing. Extremely short battery life was at the top. In the early 1970s, batteries were relatively large, electronic circuits were power-hungry, and watch cases were bulky to accommodate the module. Consumer disapproval prompted the development of smaller batteries and forced manufacturers to find new ways to make extremely low-power circuits and displays. By the mid-1970s watches could run on smaller batteries, the cases shrank in size and manufacturers could offer models targeted to women buyers. In addition to battery problems, in the earliest models the quartz oscillators were extremely sensitive to hard knocks. Techniques for encapsulating the crystal and protecting it from shocks had to be developed. Moisture was also the enemy of electronic components, and water-resistant case designs became a priority.[48]

45 'The Swiss put glitz in cheap quartz watches', *Fortune*, 20 August 1984; *The Market for Watches and Clocks*, op. cit. (44), 121.

46 *The Market for Watches and Clocks*, op. cit. (44), 125.

47 'Digital watch complaints are soaring says Bulova', *American Horologist and Jeweler* (1976), 43, 54.

48 'Digital watches: the technologically chic way to tell time', *New York Times*, 31 December 1975; David Rorvik, 'Present shock', *Esquire*, July 1973, 168–9.

Consumers also criticized digital displays. LED displays required the wearer to push a button to light up the time display. Once the novelty wore off, watch wearers found the push-button a nuisance. By 1977 LED display watches had fallen out of favor, largely because of this feature. Liquid crystal displays, developed in the early 1970s, provided watches with a continuous time indication, but consumers complained that they could not read them in the dark. Manufacturers tried several solutions, including small incandescent bulbs for backlighting, but the battery drain was prohibitive.[49]

Consumers squared off for and against digital time. Time displayed in digits, some said, signalled a much more accurate, objective and abstract 'scientific' time. Digital time looked modern, like space-age instrument panels. Advertising of the period made much of this. But ultimately many consumers questioned the need for digital watches. Some worried that digital displays made telling the time too easy for children, that future generations would lose forever the ability to tell time by the traditional clock dial. For a while the relative merits of digital and analog time-telling preoccupied educators. But by the mid-1980s sales figures showed buyers were shifting away from watches with digital displays back to the conventional dial.[50] Behind the dial of most new watches, though, hummed an electronic heart.

49 Robert Nelson, 'The future of LCD watches', *Horological Times* (1983), 7, 20.

50 Press release, Hamilton Watch Company, 6 May 1970, 'Hamilton introduces Pulsar – a wrist computer programmed to tell time', NMAH-HOT; advertisement, Texas Instruments, n.d., 'TI 501: a combination of space-age styling and precision timekeeping at a price you can afford', NMAH-HOT; Verne Jeffers, 'Using the digital clock to teach the telling of time', *Arithmetic Teacher*, March 1979, 53; William J. Friedman and Frank Laycock, 'Children's analog and digital knowledge', *Child Development*, April 1989, 357–67; *The Market for Watches and Clocks* (New York, 1992), 1, 86.