



## How RCA Lost the LCD

### RCA owned the early patents but failed to commercialize the liquid crystal display

By Benjamin Gross  
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In September 1967, Richard Klein and his boss, Lawrence Murray, traveled to RCA's central research facility in Princeton, N.J. It was a familiar trip for Klein, an associate engineer at the company's semiconductor division in nearby Somerville, whose work with light-emitting diodes kept him in close touch with solid-state researchers in Princeton. On this occasion, though, Murray assured him he was going to see something new.

Sure enough, upon arriving in Princeton, Klein and Murray were escorted to a room where electrical engineer George Heilmeier presented them with a seemingly ordinary piece of glass attached to a power supply. Then Heilmeier flipped a switch, and a familiar black-and-white image suddenly appeared on the previously transparent square. "It was a TV test pattern," Klein recalled. "The thing pops up, and I almost fell over!"

Once Klein had recovered, Heilmeier explained that this prototype was a new form of display that relied on an obscure class of compounds called liquid crystals. Since the 19th century, chemists had known about these strange materials, which flowed like a liquid but retained the optical properties of a crystalline solid. But nobody was quite sure what to do with them.

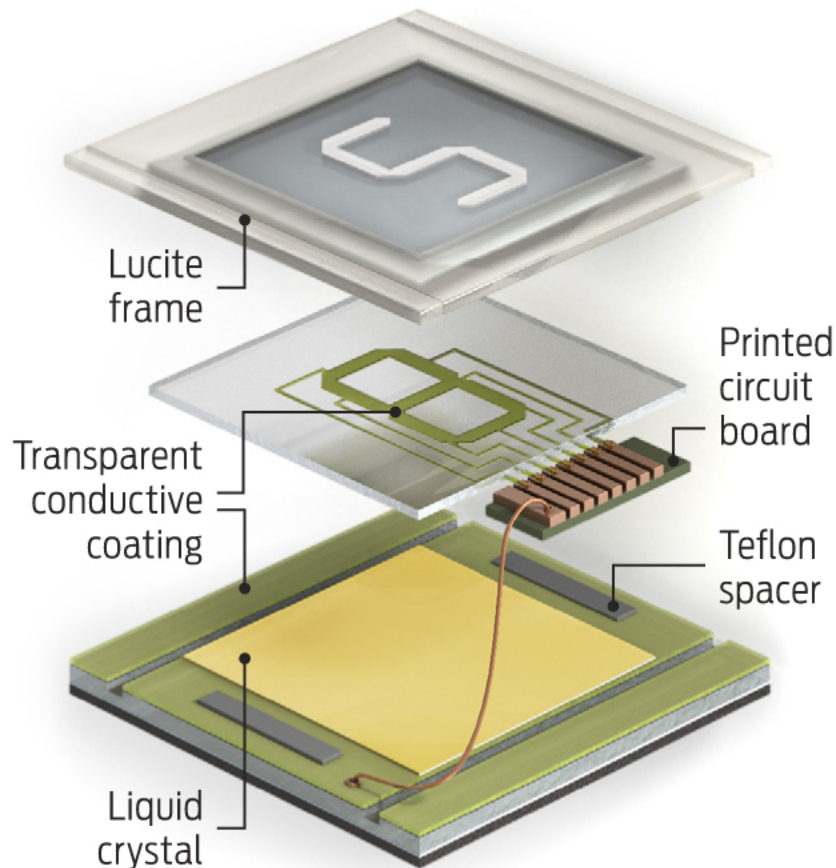
Then, in 1962, RCA researcher Richard Williams hit upon the idea of using the crystals in some type of display, and he succeeded in getting the material to electronically modulate the passage of light. Fifty years ago this month, Williams filed for what would become [RCA's first patent on the new technology](#). Heilmeier and his colleagues then spent several years expanding on Williams's findings. Now they wanted to work with their Somerville colleagues to transform these liquid crystal displays (LCDs) into commercial products.

Murray's group in Somerville had done research on electro-optic phenomena, and so it was well suited to introduce liquid crystals to a division more comfortable with silicon. Klein was given the job of examining the technology from a manufacturing perspective, a task he embraced enthusiastically.

Just eight months after the Princeton demonstration, RCA vice president James Hillier trumpeted the LCD's fine qualities at a high-profile press conference at the company's New York City headquarters. Hillier predicted that the electrically triggered opalescence observed in Heilmeier's prototypes would find its way into a wide range of products—perhaps even portable flat-screen televisions. "You could take such a set to the beach," he joked, "and, in between bikini watching, see the Mets on TV figure out a new way to lose a ball game."

The press latched on to Hillier's far-out predictions, and for the remainder of the 1960s and into the early 1970s, it seemed like RCA, the company responsible for the commercialization of both black-and-white and color television, was again poised to

revolutionize the field of electronic displays. Yet in 1976, less than a decade after the LCD's unveiling, RCA sold off its liquid crystal operation, and key personnel associated with the project left the company. What began as an American innovation would mature under the auspices of firms in Europe and Asia.



**THE NUMBERS:** In RCA's early dynamic scattering numeric readouts, a layer of liquid crystals was placed between a conductive backplate and a front plate with seven segments made of conductive coating. The printed circuit board applied voltage to any given segment, causing dynamic scattering in that part of the cell. To render the numeral 5, it applied voltage to five segments. Illustration: Emily Cooper

Today, liquid crystals are one of the most widespread technologies of the information age and the foundation of a multibillion-dollar industry. Nevertheless, RCA's abrupt exit from the field has largely obscured the pioneering contributions of its chemists, physicists, and electrical engineers. The events and decisions that drove the company to abandon its efforts are worth revisiting for what they reveal about the unpredictable nature of innovation—and about the tendency of large corporations to fail to capitalize on it.

The trail of research that led Klein and Murray to Princeton had its start across the Atlantic nearly 80 years earlier. In 1888, a plant physiologist named [Friedrich Reinitzer](#) at the Charles University in Prague was investigating chemical derivatives of carrots when he noticed that one compound—cholesteryl benzoate—behaved strangely when heated. At 145.5 °C, the substance changed from a solid into a cloudy liquid, and at 178.5 °C, the

cloudy liquid became transparent. That is, the material seemed to possess two melting points. Other pure substances, of course, melt at just one temperature.

At a loss for an explanation, Reinitzer sent his findings along with a sample to Otto Lehmann, a physical chemist working in Aachen, Germany. Lehmann confirmed that in its cloudy state, cholesteryl benzoate kept its fluidity. He also noticed that it refracted polarized light like a solid crystal, indicating a higher degree of molecular organization than an ordinary liquid. Lehmann coined the term *fliessende Krystalle*, or “flowing crystals,” to describe such substances.

Within two decades, European scientists reported [more than 200 compounds](#) exhibiting similar behavior. The majority of RCA’s LCD investigations years later would concentrate on “[nematic](#)” liquid crystals, which are composed of elongated, rod-like molecules whose long axes run in parallel. That structure allows the molecules to slide past one another like matches in a matchbox and to easily realign when subjected to an electric field.

Despite much theoretical interest in their behavior, few attempts were made to commercialize liquid crystals. Most scientists considered them little more than laboratory oddities. Even in the early 1960s, it was not obvious that RCA would be the company to finally move liquid crystals out of the laboratory and into the real world.

At the time, RCA had only just started to recoup its decade-long investment in color television, and research managers in Princeton had authorized exploratory work to develop a replacement for the cathode ray tube. But the engineers assigned to that project did not consider liquid crystals suitable for such a product. In fact, RCA’s initial work on the technology that would become the LCD began as one of those small-scale, open-ended investigations that big corporate labs of that era routinely funded, with no obvious commercial payoff.

Physical chemist Richard Williams wasn’t even thinking about displays when he started experimenting with liquid crystals in April 1962. He was more interested in their electro-optic properties. In particular, he wanted to understand how applying electric fields altered the wavelengths of light absorbed by nematic materials. In one experiment, he placed a few grams of a liquid crystal called para-azoxyanisole between two Pyrex slides whose inner faces were lined with a transparent, electrically conductive coating. When he subjected the liquid crystal to a field of 1000 volts per centimeter, he saw [a curious “crinkling effect,”](#) with a corresponding increase in light absorption. When he removed the voltage, the sample returned to its settled, transparent state.

Before he began these experiments, Williams had envisioned a high-speed light shutter that would, for example, protect a pilot from being blinded by the flash of an atomic bomb. However, after showing the crinkling effect—which he termed domain formation—to his colleagues, he realized that liquid crystals could be used as electro-optic elements in displays, and he composed a patent detailing his ideas.

Despite this early success, he found it difficult to persuade engineers of his new display’s practicality. Among other drawbacks, the materials had to be heated to over 117 °C. In the absence of room-temperature liquid crystals, he moved on to other projects.

In all likelihood, Williams’s decision would have marked the end of liquid crystal research at RCA had it not been for Heilmeyer, who was searching for a way to modulate laser light for use in telecommunications. Existing crystalline modulators were either difficult to synthesize or required too much power. Heilmeyer thought Williams’s liquid crystals offered an alternative, and in July 1964 he proposed replacing the solid crystals with a pleochroic dye—one whose color depended on its orientation to polarized light—dissolved in a liquid crystal solvent. He would then place this mixture into a “sandwich

cell” similar to Williams’s, between two pieces of conductive glass. Heilmeier suspected that when a field was applied across this solution, the liquid crystal molecules would realign, causing the dye molecules to rotate and generate a color change when viewed with polarized light.

Subsequent experiments confirmed Heilmeier’s prediction. Applying just a few volts across the solution could switch its color—for example, from red to transparent. Heilmeier referred to this as the “guest-host” effect, the dye being the “guest” and the liquid crystal the “host.” In a series of tests, he applied conductive coatings to the glass in different patterns, along with strategically placed insulating photoresists. In this way, he could produce static images.

(Today’s LCDs are, of course, much more sophisticated, incorporating thousands of picture elements, or pixels, that are individually activated by a corresponding number of thin-film transistors. Each pixel serves as a light shutter, selectively allowing the passage of polarized light. The pixels’ high switching speed, measured in microseconds, and tiny size, with widths of tenths or even hundredths of a millimeter, and the inclusion of red, green, and blue filters for an otherwise white backlight enable modern LCD televisions to present full-color moving images—far beyond the simple patterns offered on RCA’s early displays.)

Heilmeier, an ambitious 28-year-old, made the rounds at RCA’s Princeton lab, demonstrating [the guest-host effect](#). His strategy paid off: By March 1965 his superiors agreed to establish a seven-member LCD research group. This team would more than double in size by the time RCA introduced the LCD to the public three years later.

The researchers soon realized that the guest-host approach had serious shortcomings: The dyes and hosts were unstable, the polarizing filters sharply diminished the display’s brightness, and the entire apparatus had to be heated to maintain the liquid crystal phase. Then in May 1965 came a breakthrough: Heilmeier observed what he called [the dynamic scattering effect](#), which required neither dyes nor polarizers. In this incarnation of the “sandwich cell,” the sheet of liquid crystal material started off transparent and then turned milky white when a voltage was applied.

Heilmeier and his colleagues hypothesized that this effect was due to ions disrupting the orderly arrangement of liquid crystal molecules under an electric field, like boats pushing their way through a logjam. Later researchers confirmed that the molecules were realigning parallel to the glass plates until a charge buildup caused them to spin, leading to turbulence that randomly scattered light and caused the display to turn opalescent [see illustration, “[LCD Approaches](#)”].

Dynamic scattering became the Princeton LCD group’s main research priority, and they immediately started working on incorporating the effect into small displays capable of producing static images or simple animations.

By the time Richard Klein saw Heilmeier’s prototype in Princeton, the LCD group had taken several important steps toward this goal. Most notably, they had synthesized materials derived from anisylidene p-aminophenyl acetate that exhibited nematic behavior at room temperature, a breakthrough that made commercial applications possible. The group had also built several prototypes, including an electronic clock with a liquid crystal readout and [a cockpit display](#).

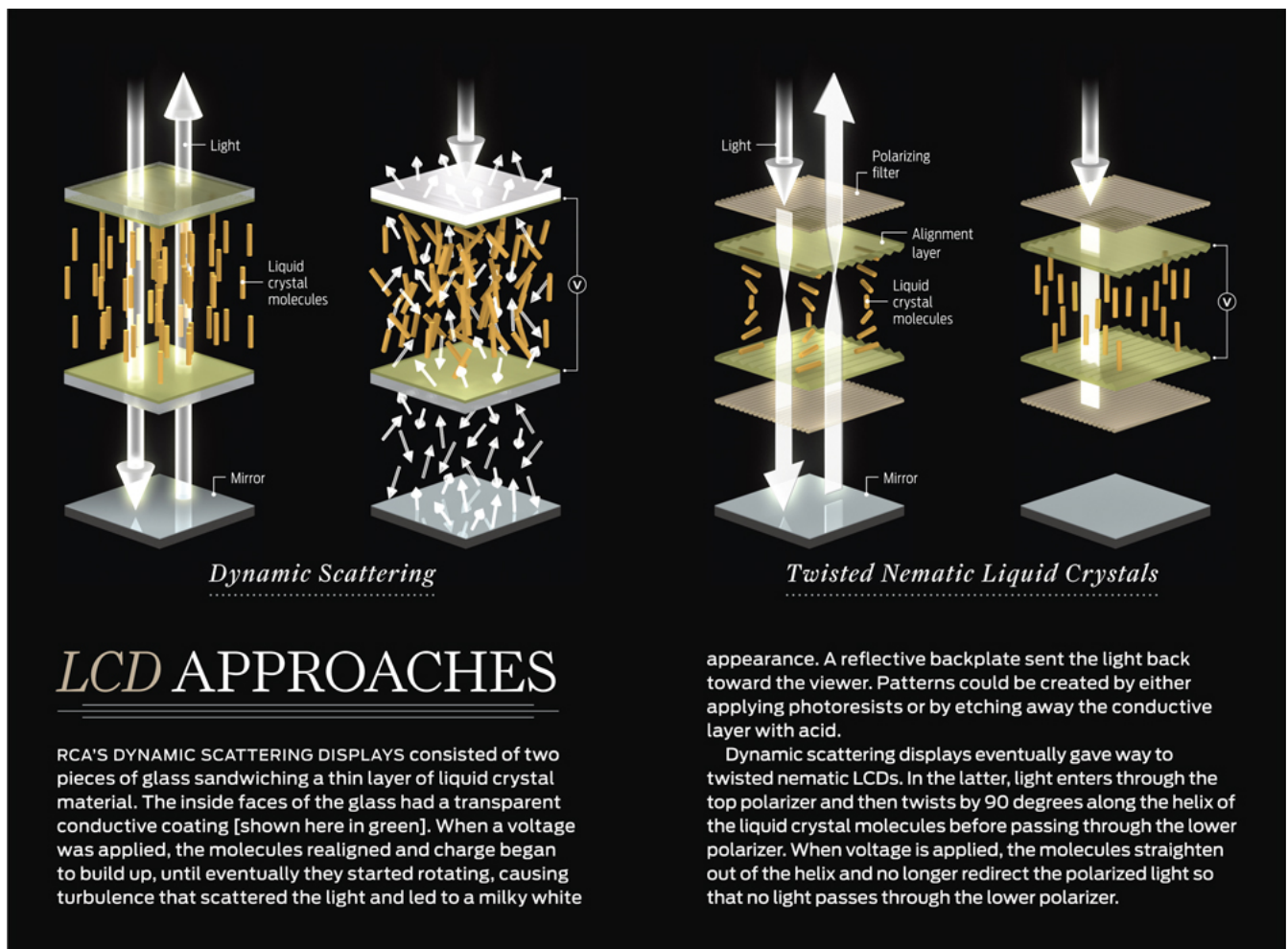


Illustration: Emily Cooper

But as much as Klein respected what his Princeton colleagues had done, it was clear that a great deal of work remained before Heilmeyer's LCDs would be ready for sale. Klein and his team would eventually transform nearly every aspect of LCD fabrication. These changes included new procedures to generate larger batches of room-temperature liquid crystals and improved techniques to fill and seal the displays.

In 1969, the liquid crystal operation moved to a warehouse in Raritan, N.J., which offered sufficient space for RCA's first LCD assembly line. Auspicious as this move appeared, uncertainty loomed over the project. Despite Klein's best efforts, executives in New York discounted the technology's commercial potential. And so, rather than directly financing the LCD's development, they told the Raritan operation to pursue external funding. Klein's team eventually lined up three contracts. The first was with a public relations firm called Ashley-Butler, which offered RCA US \$100 000 to construct an animated display to advertise soft drinks, aspirin, and other products. Veeder Root Co., a producer of gauges and mechanical counters, matched that sum in exchange for a liquid crystal readout for gasoline pumps. And Jervis Corp. supplied \$50 000 for an automobile rearview mirror that used dynamic scattering to reduce headlight glare.

The Raritan engineers delivered all three products on time. Still, RCA executives continued to deny the group funding, which worried members of Klein's team, as did the company's unwillingness to endorse what Klein and Heilmeyer felt was an obvious LCD product: the electronic wristwatch.

They were not the first to propose such an idea. In the 1965 paper articulating his eponymous law, Gordon Moore had noted that only the lack of a display that could be driven directly by integrated circuits prevented the [construction of an electronic watch](#). LCDs met that criterion, and RCA engineers had already filed a patent application for the concept based upon their dynamic scattering clock. Meanwhile, though, an internal marketing study concluded that the digital LCD watch was at best a long-term prospect. That conclusion did not prevent Heilmeier from pitching the idea to executives, even as Klein assembled mock-up watch displays.

Despite these efforts, the two men would soon face additional opposition from a particularly imperious manager.

Until the end of 1968, the semiconductor division had allowed Klein's group to work with minimal supervision. Shortly before the establishment of the Raritan plant, however, company officials decided that the liquid crystal project needed a more formal management structure. In place of Murray and his laissez-faire style, they named Norman Freedman, who had helped design the assembly lines that produced the first color television tubes.

Freedman was a forceful manager who insisted on maintaining complete control over all aspects of his projects. This approach proved disastrous for the LCD, because it alienated personnel whose support was needed to nurture the emerging technology. Freedman refused to allow collaboration between the LCD facility in Raritan and the semiconductor division in Somerville. "We were told explicitly, 'You may not talk to anybody in integrated circuits,'" Klein recalled. "And we talked to our friends in integrated circuits under the table, and they were told by their managers, 'You are not to cooperate with these guys.' And it was because they all hated Norm." Freedman also promoted outside personnel over veterans like Klein and disregarded input from the liquid crystal researchers in Princeton.

Compounding tensions between Princeton and Raritan was a growing pessimism within Heilmeier's team over RCA's ability to commercialize the LCD. Several researchers, including Heilmeier's long-time technician Louis Zaroni and organic chemist Joel Goldmacher, left the company to join Optel, an LCD start-up firm. Others felt that dynamic scattering had reached its limits and moved on to other projects. Between 1968 and 1970, the number of personnel assigned to LCD research in Princeton dropped by half, to just eight people. In 1970, an exasperated Heilmeier, frustrated with managers who, in his words, viewed liquid crystals "more as a threat than an opportunity," [applied for a White House fellowship](#) and departed RCA for a new career in government service.

Heilmeier's decision left the LCD without its strongest advocate at a critical juncture. There were great pressures within RCA stemming from a 1969 order to make computing the company's main strategic priority. That edict came from RCA's CEO (and later chairman) [Robert W. Sarnoff](#), who had succeeded his legendary father, David. RCA had been designing and selling its own computers since the early 1950s, and its [Spectra 70 systems](#) were for a time competitive with IBM mainframes. Sarnoff's new strategy spurred a rapid expansion of computer-related projects; in Princeton nearly half the staff was drafted into computer research. Though he harbored no illusions of outselling IBM, Sarnoff vowed his firm would become the nation's No. 2 computer maker.

It didn't. Just two years later, in 1971, RCA sold its computing division to Sperry Rand. The resulting \$490 million write-off was the largest such loss to that point suffered by an American business. The news reverberated throughout the corporation, and all projects suddenly fell under scrutiny. The LCD effort was particularly vulnerable. The already

dwindling Princeton team shrank to a paltry half dozen, and the majority of the staff at Raritan was laid off. Among the latter group was Richard Klein, who landed a new job with Ashley-Butler, the underwriter of RCA's advertising displays. Freedman, the manager responsible for the liquid crystal operation's isolation from the rest of RCA, retained his position.

The computer crisis did not kill the liquid crystal operation—not immediately, anyway. What remained of the Raritan group was reabsorbed into the main semiconductor division, and in 1972 RCA announced plans to produce a new line of dynamic scattering numeric readouts. By then, however, it was too late.

In affirming its commitment to Heilmeyer's technology, RCA was out of step with an increasingly crowded field of LCD manufacturers, including start-ups like Optel and more established electronics companies like Texas Instruments. Most of these firms had phased out work on dynamic scattering displays, whose reliance on reflective backplates led to washed-out images in direct sunlight, in favor of new "twisted nematic" displays, whose contrast actually increased when viewed under similar conditions [see sidebar]. Ironically, one of the coinventors of this technology, [Wolfgang Helfrich](#), claims to have conceived of the idea while working at RCA. Helfrich recalled presenting it to Heilmeyer, only to have it rejected because it used polarizers. A disappointed Helfrich left RCA to join a liquid crystal group at the Swiss pharmaceutical firm Hoffmann-La Roche, where he and [physicist Martin Schadt](#) soon constructed a twisted nematic LCD.

Eventually, RCA came around and established a facility dedicated to the production of twisted nematic displays. But much like the Raritan operation that preceded it, the new factory had to fund itself through external contracts; Robert Sarnoff's failed computer venture had left the firm financially wounded and even more wary of side projects. If there was an upside, it was that the LCD had become a more established technology, and firms that hesitated to work with RCA in 1969 were now willing to invest in liquid crystals. Yet RCA's leadership continued to view LCD manufacturing not as the possible future of its display business but as a drain on company profits. In 1976, they sold the entire liquid crystal operation to Timex, which saw the purchase as a means of expediting its entry into the digital watch market.

Few were surprised by RCA's withdrawal from the industry, nor should they have been. For while it was not always obvious, RCA's LCD program had been suffering a slow death since its public unveiling in 1968. Insufficient funds, tensions between scientists and manufacturing personnel, and shortsightedness among both managers and researchers all contributed to its ultimate collapse.

Nevertheless, it would be a mistake to treat RCA's foray into LCD production as an unmitigated failure. Despite ceding its advantage as the industry's first mover, the company had a lasting effect on the course of electronic display development. The sale of its factory to the United States' largest watchmaker, for example, positioned the LCD to become the display of choice in digital timepieces.

RCA also played a crucial role in the [emergence of the international liquid crystal industry](#). Around the time that it introduced LCDs to the public, RCA was also negotiating agreements with a number of European and Japanese TV makers that wanted to license its patents related to the manufacture of color cathode ray tubes. As an inducement, RCA executives would offer licenses on some of its new inventions, including the LCD. Licensees frequently visited RCA's labs, where they would witness demonstrations of the company's liquid crystal technology. Despite frustration among RCA researchers that others were capitalizing on their ideas, company leaders expressed no concern that such arrangements might foster the emergence of new competitors. By the early 1970s, Japanese corporations

were already encroaching on the U.S. radio and television markets. Soon firms like Sharp, Seiko, and Sony would do the same with liquid crystals.

Today, companies in Japan, South Korea, and Taiwan dominate the LCD industry. Meanwhile, the corporation that started it all has faded from memory, purchased by General Electric in 1986. Nevertheless, RCA's technological legacy can be seen in every LCD wristwatch, calculator, laptop, and television. All of these screens trace their origins to that firm's laboratories and factories. As much as they are portals to the digital future, liquid crystal displays are also reminders of a past filled with possibilities for the once-dominant American electronics industry. And in their story are lessons for any technology company willing to learn them.

### **The Road to Twisted Liquid Crystals**

The dynamic scattering displays developed at RCA were used in the first liquid crystal wristwatches and calculators. The devices' bright white readouts were well suited for indoor use, but their reflective backplate made them hard to read in sunlight. RCA physicist Wolfgang Helfrich [right] devised a new LCD configuration to solve this problem.

Scientists already knew that you could align the molecules in a nematic liquid crystal by placing them on a glass plate that had been rubbed in one direction with a piece of paper. If you placed the liquid crystal between two such plates and rotated one plate by 90 degrees, the molecules nearest to each plate retained their original orientation, while those in the middle formed a helical structure. This helix, it turned out, could rotate the plane of polarized light.

Helfrich's plan was to sandwich this "twisted" liquid crystal between two pieces of conductive glass and then bookend the glass plates with a pair of crossed polarizers. Normally any light passing through the first polarizer would be blocked by the second, but in this case the helix rotated the light so it could proceed through the cell. If you then applied a voltage, the liquid crystal molecules would align themselves with the field, demolishing the helix and preventing light transmission.

Twisted nematic displays used less power than their dynamic scattering counterparts and had higher contrast in direct sunlight. According to Helfrich, Heilmeyer rejected the idea due to its reliance on polarizers. Helfrich left RCA to develop the concept elsewhere. At Hoffmann-La Roche, he and Martin Schadt constructed a functional twisted nematic display in November 1970. A few months later, James Fergason of the International Liquid Xtal Co. filed a patent on a similar device, which he said he had developed in December 1969. Between them, Helfrich, Schadt, and Fergason confirmed the viability of the twisted nematic display and set the stage for the emergence of the modern LCD industry.

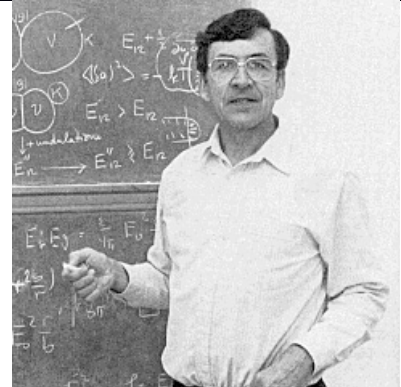


Photo: Freie Universität Berlin