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AN EYE-WITNESS REPORT ON HOW THE CD CAME ABOUT

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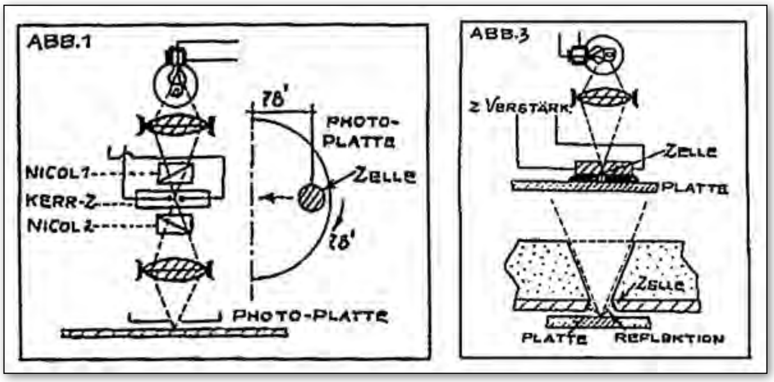
The Compact Disc was a smashing success. It pushed the traditional 45 and 33 RPM vinyl records off the market in an astonishingly short period of time. But the struggle to develop the CD and to get it on the market was just as fascinating.

The various technologies employed in the Compact Disc (CD) player, including laser optics, a-spherical lenses, digital signal processing, integrated circuitry, nano-scale injection molding are truly revolutionary by itself. Interestingly, the basic idea to write and read information to and from a disc by optical means was not new, as can be seen in Fig 1 taken from a 1931 article published in *Funkschau*. The pictures are not very clear, as would have been the signal produced for being limited by noise, preventing practical implementation of this reflective disc. Nevertheless, the transmission version of this scheme has been successfully employed in reading the sound track of the first 'speaking pictures'.

The optical scheme of the Compact Disc player is very similar to the one published in *Funkschau*, see Figure 2. However, the devil is in the detail. In a CD player, the light source is a laser, *i.e.*, a real point source. So, in case of perfect optics, the read-out spot, which is the image of the point source on the disc, is of minimum, diffraction limited size. In formula, $D = \lambda/NA$, with D the spot diameter, λ the laser wave length, and NA the numerical aperture of the objective lens (NA equals the refractive index n times the sine of the convergence angle α).
The Compact Disc itself looks quite different from the 1931 example. The audio signal is digitally coded instead of stored as the audio wave itself. The signal is not derived from reflectivity variations in a photographic material



▲**FIG. 1:** Original 1931 figures, showing the idea behind the reflective audio disc recorder. **Left:** Recording method. Lamp light is focused onto a small spot on the disc where the spot size is determined by the pinhole just above the information plane. A Kerr cell is placed in the optical path between two crossed polarizers. By applying a voltage across the Kerr cell generated by the audio signal, the intensity of the light spot on the disc is modulated and the audio signal is recorded onto the photographic material. **Right:** Reading set up. The lower part of the panel shows the details of the detector geometry. The spot size is limited by a pinhole. Variations in local reflectivity are measured by a ring-shaped detector, in this case a photoelectric Selenium detector.

but from a relief pattern, a succession of 'pits' and 'lands'. Digital coding means that the audio signal has undergone a series of processing steps: first, the audio signal is transformed into 16-bit samples; second, parity bits are added (for error detection and correction); and third, the bit train is transformed into an information track on the disc, consisting of pits and lands of discrete lengths of 3, 4, … ,11 units, where one unit corresponds to 0.3 μm on the disc. The bit rate and bit density are constant. This means that the scanning speed is constant (1.3 m/s), and that the angular frequency of the disc gradually decreases during play-back (the reading head is moving from inside to outside of the disc).

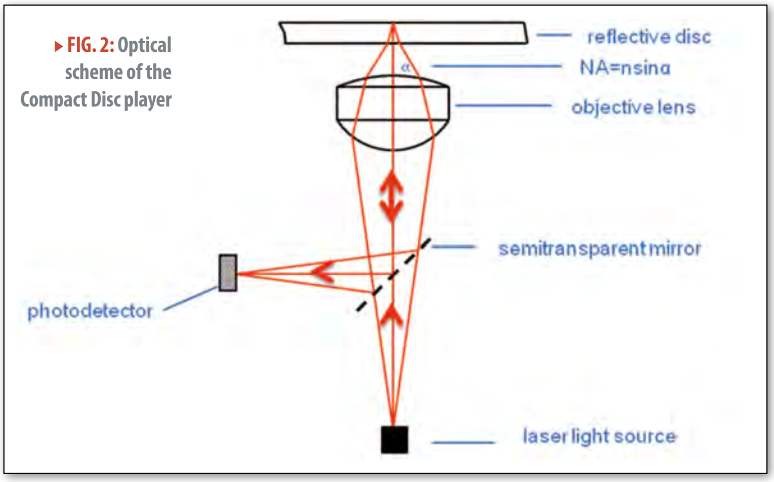
Two companies, two cultures

In this brief history, I should like to share my personal experience of CD development. Such experience often makes innovation real fun. I myself became involved in CD development in 1979, directly after Philips gave its first public demonstration of a CD prototype player and after Philips had toured Japan in search of allies to join into the development of the CD as a successor of the LP record. Sony was the company that responded most eagerly to this invitation, and Philips and Sony agreed on a joint development of a miniature-sized digital audio disc. The two companies realized that a common format would be necessary to convince the other Consumer Electronics companies to join at a later stage. As an optical engineer, I was present at all meetings between Sony and Philips to forge a common format.

I remember our first technical meeting very well. Management had instructed us to be completely open: "one cannot blow with one's mouth shut". However, we as scientists and engineers, knew very well how much effort it had cost us to achieve a reliable prototype and – as is often the case amongst engineers – we doubted whether our management really knew what they were doing. The more so, because Japan at that time was in a similar position as China is today: its industry was growing fast and it was changing from a low-cost producer into a high-tech competitor. So, at that first meeting, mistrust was the overriding emotion at our side. Later, I heard from my Japanese counterparts that they had similar reservations about the wisdom of their own management.

Looking back, I think our first meeting actually went pretty well, although we did not achieve very much in technical terms: we made a good start in team building with engineers that belonged not only to a different company, but also to a different culture. We succeeded in doing so at a time (1979) when the world was certainly not 'globalized'. Initially, I felt as if those guys came from another planet. Indeed, they came from 'the Far East'. Soon however, we discovered that engineers are pretty much the same all over the world, with similar emotions: proud of their expertise, sincere about their problems, eager to explain their own solutions, and willing to learn and to appreciate the solutions of others. Soon, we found a way of working together that turned out to be very effective: we challenged each other's assumptions, and we agreed that we should not accept technical proposals out of politeness or kindness: we accepted only the best solutions, based on data, not on theories.

We quickly established a pattern of regular 2- or 3-monthly meetings, either in Japan or in Holland, and within 2 years we reached a complete agreement on the format that is now called the CD. The problem we had to solve was rather straightforward: find the best solution in reliability and information density for a small digital, read-only disc. The technical solution was less straightforward: while we both had developed our prototypes step-by-step, when reconsidering our solutions we realized that every new choice was leading to another new issue. Obviously, the most direct solution to increase information density is to increase the NA, and to reduce the wave length of the optics. However, as Fig 3 shows, the disc substrate is part of the objective lens, so any variation in thickness d will



▸**FIG. 2:** Optical scheme of the Compact Disc player cause spherical aberration ($\Delta d \times NA^4/\lambda$), and any tilt angle will cause coma ($\varepsilon \times d \times NA^3/\lambda$) with Δd the thickness deviation, and with ε the tilt angle of the disc substrate. Because of the strong dependence on NA, a small increase in NA directly results in more stringent disc tolerances. As a result, we had very tough discussions about realistic disc tolerances, because we had only a few preliminary disc samples available of rather uncertain quality. In the end, we agreed on NA= 0.45, but with strong reservations on both sides, especially from our media engineers.

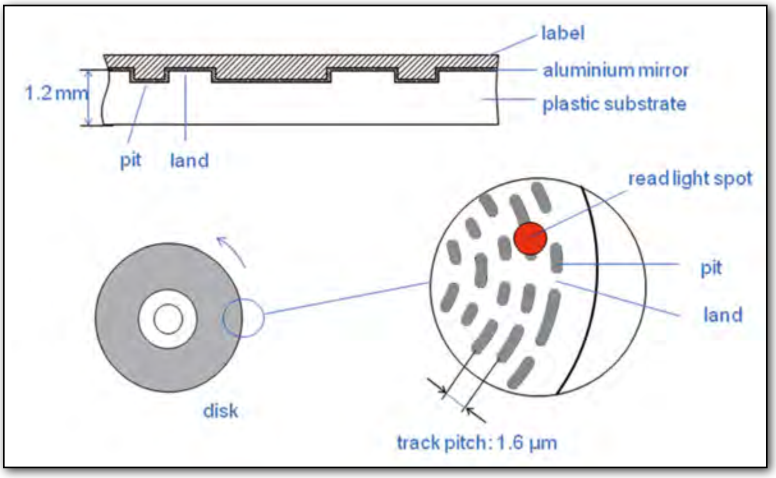
On the selection of wave length a similar problem ensued. The only diode lasers available at the time were prototype samples designed for fiber communication, operating at a wave length of 820 nm. Pressed by the need for the highest data capacity, we decided to agree on 780 nm as the wave length for CD, a decision that was based on a very limited number of 780 nm laser prototypes. During our joint experiments on the bits/mm² attainable, lots of test discs with different land/pit sequences were exchanged. In a quick succession of meetings between the Philips and Sony engineers, we improved each time on our previous results in information density and detection robustness. In the end, we concluded that for maximum information density, pits and lands had to have a minimum length of 3 units with one unit as quantization size. We also found that it was absolutely necessary to choose a 'channel code' where pits and lands were evenly distributed over the disc. Only in that case, we would be able to filter away the effects of severe scratches and fingerprints on the disc.

In a similar way we confronted each other with different Error Correction schemes. Error correction is an integral part of any digital storage of communication system. Usually, a trade-off must be made between three parameters: correction performance, the relative number of parity bits, and cost. In line with our different initial target markets, also here Sony and Philips had different priorities. Sony was pushing for the most powerful scheme, while Philips was very critical on cost. Depending on the algorithm, a balance had to be struck between correction capability for large defects – like scratches and fingerprints – and small ones, such as random errors like noise. Because the two companies used discs and players that were still very much under development, we had to assess what level of quality could be achieved later in mass production. A lot of guess work! In the end we agreed on a scheme that combined good correction of large disc errors with a limited RAM size, using a structure with continuous data input and output, instead of the conventional block structure. This is a solution that works well for a continuous data stream like Audio, practical at a time when memory space was scarce.

Fixing sizes

I remember tough discussions taking place between our two companies on the parameters for the quantization level of the audio samples. Philips' priority was a small disc, fitting not only in Hifi decks, but also in mobile applications like the automobile and the so-called ghetto blasters. These markets were much larger than the stationary Hifi market. With a small disc of about half an hour playing time in mind, Philips wanted to limit the number of bits per sample to 14 bits. Sony was adamant in achieving perfect Audio Quality. I remember that in one of our meetings Toshi Doi tried to convince us of the necessity to choose 16 bit quantization. He did so by recording soft triangle music at both 14 bit and at 16 bit resolution: we were supposed to hear the difference. Frankly speaking, none of us heard any difference at all, but Sony's message was loud and clear: the new format must not compromise on sound quality!

We had settled on a 11.5 cm diameter disc, until Sony's president, Mr Ohga, — a former opera singer — put a new requirement on the table: the playing time had to be 74 minutes. This new requirement came out of the blue for all of us. In earlier meetings, we had worked on the basis of a maximum playing time requirement of one hour. What we did not know was that Ohga had promised his conductor friend Herbert van Karajan that his version of Beethoven's Ninth Symphony would fit on one CD only. No discussion was possible: at the highest level, a



▲ FIG. 3: Details of the CD surface structure

◄ FIG. 4: The center hole in the CD: a Dutch 10 cents coin

▲ FIG. 5: The Philips and Sony teams at the final, decisive meeting (June 1980). The author is at the far left

promise is a promise. One also has to bear in mind that, after Hiroshima and Nagasaki, the 9th Symphony choral '*Alle Menschen werden Brüder*' had become an important musical symbol in Japan.

Polygram, the music company of Philips, was shocked by this new requirement. Contrary to Ohga, Polygram wanted a rather limited playing time. The argument was that no music group would be able to regularly produce albums with playing time much in excess of existing LP's 40 minute playing time. Eventually, a political compromise was reached at an actual playing time of 74 minutes on the disc, while the Red Book Standard defined a playing time of 60 minutes only. Not often a new format formally denied its higher storage performance!

An unfortunate consequence of the playing time requirement was the disc size: it grew from 11.5 cm to 12 cm diameter. This last-minute change caused real problems. With great difficulty, I had convinced our media engineers to accept the critical specification on disc flatness based on an 11.5 cm disc size. I had no choice, so I told them they had no choice. In hindsight, I think we were too conservative, we could have maintained the 11.5 cm disc size, whilst squeezing the data density on the disc a bit more. However, at the time, only one trial run of one thousand discs from one 'stamper' was available, so we had no real information on mass production quality of discs.

▼ FIG. 6: The first commercial Philips CD player

This history may sound as work only; in actual fact, we enjoyed the drinking parties in the evenings just as well. Yet, we worked very hard indeed: many times the target for next round of testing was felt as impossible to meet. And often, when proudly showing our hottest Philips data, it turned out that also Sony had met the impossible dead line, sometimes during the night before: it was a neck-and-neck race.

One of the last discussion points was the center-hole diameter. This time, we agreed within a few minutes. Our project leader, Joop Sinjou, put a tiny Dutch 10 cents coin on the table and said: why not? Indeed: why not, so we agreed on a center hole of a Dutch 10 cents coin, *i.e.*, 15 mm diameter (Fig 4).

In June 1980, the two development teams agreed on the specification of Compact Disc. Fig 5 shows the two teams at that decisive meeting.

The history of CD did not end by finalizing the format: actually that is where its history started. Therefore, I want to share also some of my memories on the product introduction of the CD.

A highlight for me was the Tokyo Audio Fair of 1982. Suddenly all Consumer Electronics companies presented their first CD players. During that Fair, I met many product engineers. They were all very proud to show the first CD player of their company. Their enthusiasm created a great feeling in all of us being part of a major innovation. And certainly, as a Philips engineer, I could be proud of our first CD player: the smallest one at the show! And with very simple and logical control and display. In one word: a beauty (Fig 6).

When I saw the first CD player in the shop at my own little home town I felt proud. I remember what I said, with some exaggeration, to my 11-year-old daughter: Look, this is what daddy invented! But she was not impressed, which taught me another lesson: There is more to life than the CD. ■

About the author

After earning his PhD in Physics from Leiden University in 1973, Jacques Heemskerk joined Philips Research in Eindhoven, where he worked on various optical problems. When, in 1979, a development laboratory was established for the Compact Disc, he joined as optical group leader. Later he became head of the laboratory, head of the optical predevelopment of Philips Consumer Electronics, and responsible for the physical part of the standardization of DVD and Blu-ray. He received the Japan Audio Society award for his contribution to CD development, the Nakajima award for CD-R, and he has been honored with a Knighthood in the 'Orde van de Nederlandse Leeuw' for his contributions to industry and optical disc technology. He holds more than 180 patents for over 50 inventions.