THE CD STORY

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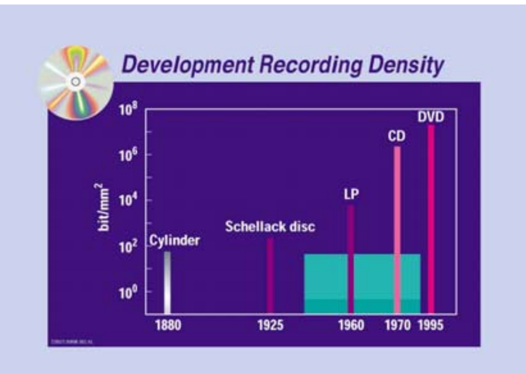
Kees Immink presents a research engineer's view of the years leading up to the launch of the CD, and the various crucial decisions that were made during the time, which could determine the technical success or failure of the medium. From a personal perspective he comments on the history of the first mass-market digital audio medium and delivers some predictions for the future of optical media in data storage.

A bit of history

I should say at the outset that I am not a historian but an engineer, and that what I will say comes from my personal recollections of the meetings that took place over 15 years ago between engineers at Philips and Sony. Even so, like the best historians, I shall give you a brief summary of the 100 years of disk recording that led up to the launch of the CD. The equivalent storage density of recording media in bits/mm2 grew gradually from that of the original Edison cylinder to the recent DVD.



We are now dealing with storage densities some one million times greater than those available at the end of the last century. One must remember that it was at least l0 years after Edison's cylinder, before Berliner and others came along with a method of disk recording - in fact I visited Edison Labs and was told that all recording devices up until about 1920 were effectively prototypes and that there was no way of replicating media, so to have a recording 'hit' at that time must have been quite an achievement. I think in the 50s, the stereo LP record delivered a major step in sound quality, but as far as optical recording is concerned everything before 1969 must be called prehistory.

Optics and Laservision

In 1969, Philips' researcher Klaas Compaan suggested that it might be worthwhile developing the use of optics for storing pictures. They threw around the idea of a spiral track with bits or pits, and from that time it took six years before Laservision videodisc was born. I started in 1973 working on servo systems and electronics, and we considered that if one could store video with audio information optically then one could also manage audio only. The research management at the time dismissed this idea saying that audio was far too simple, and not worth the effort, so we, at research, left it alone for the time being. And then came the launch of Laservision in 1975, which was a monumental flop. It flopped hugely, and of some 400 players that were sold some 200 were returned because buyers had been under the misapprehension that it would also record programmes - of course it could not. After two years the Philips management decided to throw in the towel, and withdraw it from the market.

Early digital audio

It is my view that digital audio was made possible at that point, and between 1970 and 1980 numerous meetings were held between Philips and Sony. In order to understand the technical choices concerning sample resolution and such at that time one must look to what was happening with studio equipment and with digital audio in broadcasting. The BBC in the UK was one of the first to adopt digital sound, and they were working with a 13-bit distribution system for the transmitter network, sampled at 32 kHz. Stockham's experiments in 1972-3 with the Soundstream system involved sample rates averaging around 40 kHz, and he used computer tape as the means of storage, which made it practical to store data at 16 bit resolution because of the byte-orientated nature of computer data storage. 8 bits would have been too few, and 14 bits would have meant inefficient use of the storage space, so 16 bits seemed logical. Computer tape was really the only way of storing perhaps one hour of sound at the time. Towards the end of the 70s, (PCM) adapters were developed which used ordinary analogue video recorders as a means of storing digital audio data, since these were the only widely available devices with sufficient bandwidth. This helps to explain the choice of sampling frequency for the CD, because the number of video lines, frame rate and bits per line end up dictating the sampling frequency one can achieve if wanting to store 2 channels of audio. The sampling frequencies of 44. I and 44.056 kHz were thus the result of a need for compatibility with the NTSC and PAL video formats used for audio storage at the time.

An optical audio disc

From 1973 to 1976 two Philips engineers were given a mandate to develop an audio disc based on optical videodisc technology, and they started by experimenting with an analogue approach using wide-band frequency modulation. The problem with this was that it was not really much more immune to dirt and scratches than an analogue LP, although there was a certain improvement in sound quality, so they decided to look for a digital solution. In 1977-8 Philips and Sony both demonstrated the first prototypes of a digital sound system using a laser videodisc, and, then, in 1979 a crucial high-level decision was made to join forces in the development of a world audio disc standard. Philips had lost the market for Laservision, but had considerable optical expertise, as well as expertise in servo systems and digital and analogue modulation systems. Sony's huge expertise digital techniques, such as error correction, PCM adapters and channel coding would complement this ideally. A reasonable summary would be that the contributions were complementary: the videodisc 'physics' was provided by Philips and the digital audio experience by Sony.

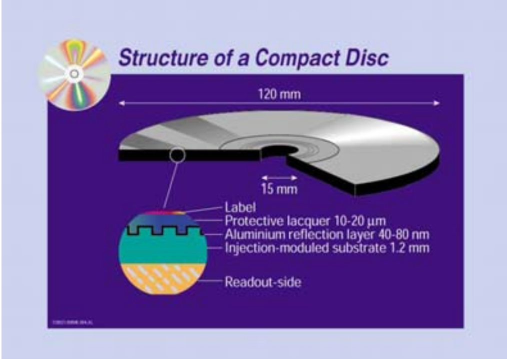
The Sony-Philips liaison

In 1979-80 a number of meetings were held in both Tokyo and Eindhoven. The first, in August 1979 in Eindhoven, and the second in October 79 in Tokyo, provided an opportunity for engineers to get to know about each other and to discover the main strengths of each team. There was a great deal to learn from each other. Both teams had working prototypes and decisions had to be made concerning modulation and error correction systems. Parallel experiments were conducted in both locations, and naturally there were numerous occasions on which each team felt it had the best or most practical solution - either theirs could correct the longest burst errors or give the longest playing time, and so on. The delicate prototype electronic equipment had to be transported with the engineers across the world, and consequently travelled first class in a separate seat booked especially for it. The airline KLM really loved us for that, because, as you know, boxes of electronics do not drink champagne or ask for more food! By May 1980 almost everything was in order. The modulation system was still a point of contention, with each party still claiming one was better than the other, and then there was a phone call from the current chairman of Sony, Mr Ohga, who told us that if we could not make a decision within a week then management would make it for us. I was tempted to say that if they were able to make a decision so easily then why did they not do so six months ago? but refrained in the interests of diplomacy. So we moved quickly and made all the decisions concerning the mechanical specification of the disk and so forth.

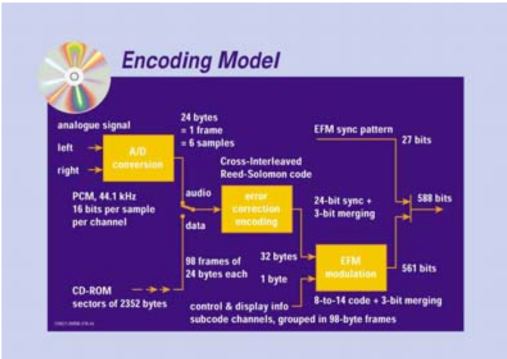
Deciding the parameters

The disk diameter is a very basic parameter, because it relates to playing time. All parameters then have to be traded off to optimise playing time and reliability. The decision was made by the top brass of Philips. 'Compact Cassette was a great success', they said, 'we don't think CD should be much larger'. As it was, we made CD 0.5 cm larger yielding 12 cm. (There were all sorts of stories about it having something to do with the length of Beethoven's 9th Symphony and so on, but you should not believe them. In the next section, playing time, we will give more details.)

The sampling frequency of 44. I kHz was decided. In fact it was the only choice we could make since there was, at that moment, no equipment available that offered a different sampling frequency but 44.056 kHz. After a long deliberation we decided 44.1 kHz as opposed to 44.056 simply for the reason that it was easier to remember - there was really no other reason. Sony made the excellent choice of 16 bit resolution, although Philips had developed a 14 bit D/A converter at the time, leading Philips to argue initially that it was impossible to redesign its converters for 16 bits in a short enough time. But my colleague Karel Dijkmans said 'no problem, I know a small trick to turn a 14 bit converter into a 16 bit converter - it's called oversampling', so we managed to solve that problem quite easily s it happened, and all the first Philips players had oversampling converters in them as a result. The Cross Interleaved Reed-Solomon code (CIRC) chosen was much better than that proposed by Philips, although extremely complicated at the time.



Sony was proposing using 16kbyte RAMS for interleaving which would have cost around $50 to us, and added significantly to the commercial cost of the players. 'Are they crazy, those Sony guys?' asked many at Philips, but in fact the price of RAM and its capacity have changed so fast that it is impossible to buy less than about 1 Mbyte RAMs today, and for less money than 16k then - so fast have we moved. So that turned out to be a good decision. The 8-14 bit channel code was agreed and all the specifications between them led to a playing time of 75 minutes. Geometry and the other physical parameters were decided, and a plastic layer covering the pits was added (a basic paradigm of all optical disks) to protect the data surface from damage and to ensure that dirt and scratches on the surface were well out of focus for the laser pickup . (I should note that the recent DVD has lost a small part of this paradigm, as the cover layer is only 0.6mm thick, and so the optical pickup will be more vulnerable to dirt and scratches.)



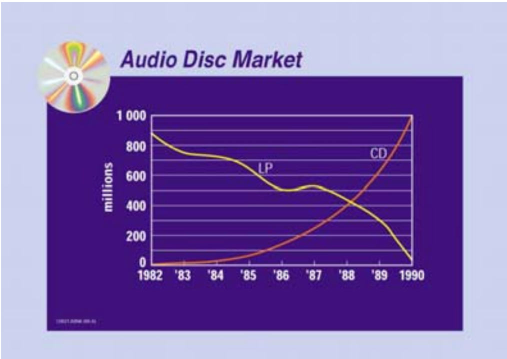
Playing Time and all that Stuff

Probably the most important parameters that had to be decided were the playing time and the disc diameter. Clearly, these two are related since the disc size has an immediate effect on the playing time: a

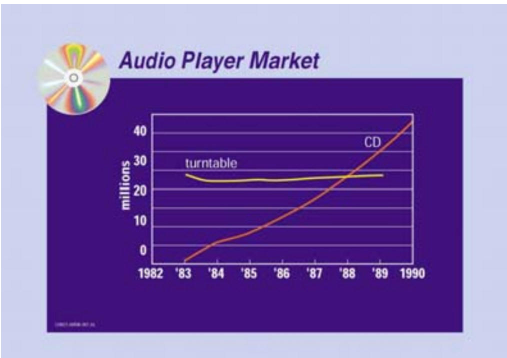
10% increase in disc diameter yields a playing time increase of 20%. During the first discussion, both partners wrote down their list of ideal characteristics of the audio disc.

The rise and rise of CD

So Compact Disc was born, and the audio disk market shows a gradually declining sale of LP and an exponential increase in sales of CD. The sale of players also climbed sharply.



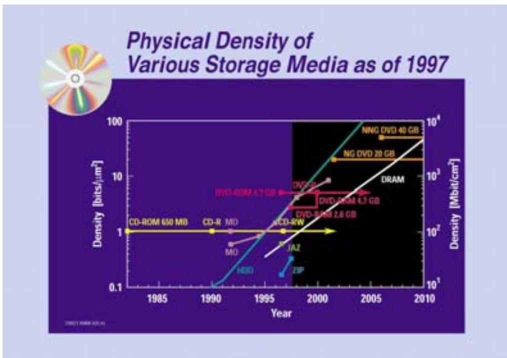
Personally, I was not at all sure that CD would succeed, as I had seen the problems that arose with Laservision, but I am happy to see that it is expected some 5 billion CDs will be sold in the in the world in 1997, which makes it a very successful market. (I saw also that 100 billion hamburgers would be sold in the US this year as we l, so perhaps it is not so big after all...)



Now we have numerous other 'books' in the CD standard, with CD-ROM players outselling CD Audio by about 70% to 30%, which is something I never expected.

Looking forward

As a researcher I like to look forward as well as back, and I should like to make some predictions for the future of optical disk media, based on DVD. This new disk has a capacity some 7 times larger than CD, and we need to look at this to see how the optical disk growth path will be defined. A number of different characteristics have led to the increase in capacity of the DVD compared with the CD. The wavelength of the laser and the numerical aperture (NA) of the objective lens have both been altered, and new research is making further advances possible in this area. The greater NA of the lens is only possible if the disk is made thinner, so future improvements here will only be possible if the disk is made thinner and thinner. Blue and green lasers are already possible. It will be appreciated that a large part of the potential increase in capacity is purely dependent on physics, not on recording specialists. Other advances in capacity have already been made for DVD. Some things can only be done once - for example removing the 3rd layer, CIRC and removing subcode. Reducing the track pitch and other physical margins has been possible because we now know how to manufacture and read optical discs well. The main parameters of the DVD compared with the CD can be seen in Table I. This leads me to make some predictions to the year 2010, concerning the physical density of various storage media. The recording density is compared with CD, which has a density of 1 bits per square micron compared with the 6-7 bits per square micron of DVD. High density forms of DVD will extend this further, so that in 2002 (probably in May!) we shall see a 20 Gbyte disk, and in 2006 (almost certainly in June...) we shall see a 40 Gbyte disk. Meantime the growth in DRAM and magnetic disk capacity continues to grow at an exponential rate, although the price of DRAM is currently very much higher than that of optics.



Whether companies will market these products is another matter entirely - this is just a prediction made by an engineer. So that is the end of my story, and of course it has been biased.

I have told the story from an engineer's point of view. Many of the decisions concerning the CD were made by very clever marketing people - for example the idea of using a 'jewel case' for storing the disk. Those decisions are not the responsibilities of engineers, for very good reasons.

THE AUTHOR

Dr. Kees A. Schouhamer Immink, a native of the Netherlands, was born in Rotterdam December 18, 1946. He received Masters and PhD degrees from the Eindhoven University of Technology in 1975 and 1984, respectively. He worked from 1968 to 1998 at Philips Research Labs, Eindhoven. Then, in 1998, he founded Turing Machines Inc, where he currently serves as its president. Since 1994, he has been an adjunct professor at the Institute for Experimental Mathematics, Essen University, Germany, and a distinguished visiting professor at the National University of Singapore and Data Storage Institute, Singapore.

Immink gained eminence through his numerous inventions and contributions to digital audio, video, and data recording devices. He and his colleagues at Philips' Research conducted pioneering experiments with optical videodisc recording, starting in the early 70s. In the late 70's, he was Philips' principal engineer in the joint efforts of Sony and Philips to develop the Compact Disc (CD). In the 80's and 90s, he was involved in the creation of a long list of digital audio and video recording products, for which he designed the coding techniques. The list includes CD-R, CD-Video (1982), the Digital Audio Tape recorder, DAT (1985), the Digital Compact Cassette system, DCC (1988), the DVD (1996), the Video Disc Recorder, VDR (1998), and the Blu-ray Disc (2002).

His research resulted more than 1000 international patents. The influence of his creative skill on everyday life can easily be summarized: It is virtually impossible to listen enjoy digital audio or video, played from any brand or type of recorder -optical, magnetic, or magneto optical-, -disc or tape- that does not use one of his basic inventions.

He received widespread recognition for his many contributions to the digital audio and video revolution. He was knighted by Beatrix, Queen of the Netherlands, and received an 'Emmy' award, the 2004 SMPTE Progress Medal, the 1998 IEEE Edison Medal, and the AES Gold Medal. He was named a fellow of the IEEE, AES, SMPTE, and IEE, was inducted into the Consumer Electronics Hall of Fame, and has been elected into the Royal Netherlands Academy of Sciences. He served the profession as President of the Audio Engineering Society, New York, in 2003.