Origins and Successors of the Compact Disc

Philips Research

VOLUME 11

SCOPE TO THE '*PHILIPS RESEARCH BOOK SERIES*'

As one of the largest private sector research establishments in the world, Philips Research is shaping the future with innovative concepts that meet peoples' needs and desires. While the ultimate user benefits of these inventions end up on the high-street shelves, the often pioneering scientific and technological basis usually remains less visible.

This 'Philips Research Book Series' has been set up as a way for our researchers to contribute to the scientific community by publishing their comprehensive results and theories in a convenient book form.

Dr Peter Wierenga

Chief Executive Officer of Philips Research

For other titles published in this series, go to
www.springer.com/series/6437

Origins and Successors of the Compact Disc

Contributions of Philips to Optical Storage

By

Hans Peek
Fellow, IEEE;
formerly with Philips Research Laboratories, Eindhoven, The Netherlands

Jan Bergmans
Eindhoven University of Technology, Eindhoven, The Netherlands

Jos van Haaren
Philips Research Laboratories, Eindhoven, The Netherlands

Frank Toolenaar
Philips Research Laboratories, Eindhoven, The Netherlands

and

Sorin Stan
Philips Consumer Lifestyle, Eindhoven, The Netherlands

Springer

Authors
Hans Peek
Fellow, IEEE
formerly with Philips
Research Laboratories
Eindhoven
The Netherlands

Jan Bergmans
Eindhoven University of Technology
Eindhoven
The Netherlands
j.w.m.bergmans@tue.nl

Jos van Haaren
Philips Research Laboratories
Eindhoven
The Netherlands
j.a.m.m.van.haaren@philips.com

Frank Toolenaar
Philips Research Laboratories
Eindhoven
The Netherlands
frank.toolenaar@philips.com

Sorin Stan
Philips Consumer Lifestyle
Eindhoven
The Netherlands

ISBN: 978-1-4020-9552-8 e-ISBN: 978-1-4020-9553-5

DOI 10.1007/978-1-4020-9553-5

Library of Congress Control Number: 2008941734

Printed on acid-free paper

9 8 7 6 5 4 3 2 1

springer.com

Acknowledgements

The editors would like to thank the following persons for their help in providing historical information for Chapter 1 and Sections 2.1, 3.1 and 6.1: C.P.M. Baggen, H.F.M. Beckers, C. Buma, L.M.H. Driessen, T. Fujimoto, J.P.J. Heemskerk, H. Hoeve, R.J.van de Plassche, K. Schep, J.J.H.B. Schleipen, E.C. Schylander, J.P. Sinjou and G.J.J. Vos. They are further indebted to J.P.J. Heemskerk, V.P.J.M. Paulissen, R.J. van de Plassche, K. Schep, J.P. Sinjou, J. de Vries, F. Uittenbogaard and G.J.J. Vos for proofreading parts of the book. Thanks are also due to F.J.W. Schraven and J.C.M. de Valk-Roulaux for their typographic contributions.

Contents

Chapter 1

THE COMPACT DISC AS A HUMBLE MASTERPIECE

J.A.M.M. van Haaren

Philips Research Laboratories Eindhoven

Perhaps the simplest piece of art on display in the entire Museum of Modern Art in New York, is a 12 cm brightly reflecting, plastic disc with a small hole in its centre. This artefact, a Compact Disc with its rainbow-like colours, is exhibited in the museum's department of Architecture and Design. That department welcomes visitors with an explanation of the criteria the curators used for including contemporary design objects in their prestigious collection[1]. One of these criteria is *Innovation*. "Good designers transform the most momentous scientific and technological revolutions into objects that anybody can use." Other criteria, like *Cultural Impact*, are mentioned as well before arriving at the final criterion: Necessity. "Here is the ultimate litmus test: if this object had never been designed or produced, would the world miss it, even just a bit? As disarming as this question might seem, it really works. Try it at home."

The Compact Disc (CD) was inducted into the Museum of Modern Art (MoMA) in 2004 in an exhibition called *Humble Masterpieces*. At this exhibition, the CD occurred together with design highlights such as the paperclip and the tea bag. To be exhibited next to these common objects is an unexpected result and an honour for a development that started about 30 years earlier at Philips in Eindhoven, the Netherlands.

The seemingly simple disc represents a lot more than meets the eye. People may be intrigued by the rainbow interference colours from a Compact Disc. On a microscopic scale each CD contains millions of bits, coded and stored in a globally standardized form, and reproduced with unprecedented precision in millions of low-cost copies. The interference colours are a macroscopic manifestation of this.

This precious disc is useless without a player. The CD-player has evolved from a sophisticated laboratory set-up with state of the art contributions from many scientists and engineers with a wide variety of backgrounds, via advanced products that were costing a monthly salary, into a commodity product that sells for the price of two cinema tickets.

The CD stands for a new industry that created new formats for optical data storage and new applications in the decades that followed the launch of the CD. The CD arrived in a consumer electronics landscape of vinyl discs discs and magnetic tape that was dominated by analogue electronics. The CD-system was the first digital entertainment product brought to the consumer's home, and in this way it marks the change of a paradigm. The resulting benefit of robust, accurate, wearless play-back was clear from the onset.

The cultural impact of introducing digital technology for content storage, distribution and play-back proved to be even bigger than that. Digital content allows transfer to other media without loss of quality, even when the channel between the two is imperfect. This perfect-quality transfer leading to 'pure' sound was a technical ambition and inspiration to the experts in the seventies. By now it is a common notion for consumers, even for technical laymen. To some extent it has led to a separation of content (a song, a photo, a document) from medium (an optical disc, a memory card, a hard disk, or a file on a server). Even young children are aware that valuable content may be protected and preserved in its original form via digital copies, and in some cases it takes a considerable effort to explain that there was a time that this was not possible. In addition, the introduction of digital technology in mass markets for consumers has motivated an unprecedented, competitive race to more powerful and smarter devices at stunningly lower costs.

The CD was at the start of the digital entertainment era for consumers. The distribution of music turned out to be only a first step. Later, CD-ROM was standardized (1985) and also became popular. With the increasing popularity of personal computers (PCs), user-friendly and cost-effective ways of distribution of software and data became of crucial importance. This could initially only be done with magnetic media, the so-called floppies. In the early nineties, popular software releases encompassed typically a series of floppy discs. But then the software releases grew bigger: Windows 95, for example, was released on 13 floppy discs. This made the alternative offering of an even more complete CD-release of the same program very attractive. CD become a crucial enabler for the evolution of the PC industry in that period of time. In addition the CD also enabled the distribution of games. The extra storage space and the random access to content enabled games with increasing sophistication and with more appealing and realistic graphics.

Let's return to the show-case with the compact disc in the Museum of Modern Art in New York. Artifacts on display in the museum come with a small label that acknowledges the artists who created it. For the Compact Disc, the card-board label says: "Philips Research Laboratories, Dutch, est. 1891, and Sony Research Laboratories, Japanese, est. 1946". The label fails to specify the year of creation: it only says "1970s".

The reference to both Philips and Sony gives proper recognition of the excellent teamwork between these two established, global companies that was essential to the success of optical recording. There has been a much wider and crucial support of thousands of other companies that followed Philips and Sony. This wide industry support has led to globally accepted standards that have meant so much for consumers and for the industry.

The absence of a single creator, designer or inventor aligns well with the answer Philips consistently gives on a question often asked to them: Who invented the CD? Philips Research answers this question on its website[2] as follows. "The inventor of the CD does not exist. Nobody even invented one part of the technology alone. The CD was invented collectively by a large group of people working as a team. Emil Berliner, the founder of Deutsche Grammophon, might have been able to invent the gramophone record on his own in 1887, but the technology on which the CD is based is too complex for just one genius. "We needed all the skills that you would find in a large lab," says Piet Kramer, who at the time was head of the Optics group that made a significant contribution to the CD technology. "Electronics engineers, photographic experts, mechanical engineers, control engineers, you have to bring all of these experts together, and then look to see if it can be done." The pooling of creativity like this is typical of the way in which technological progress is made nowadays."

So what could be invented at the start of the CD, and what not?

When in the seventies, a skilled digital communication engineer or someone familiar with the recording of digital signals on magnetic tape or hard disk, looked at a track on Video Long Play (VLP) disc consisting of pits and lands, (s)he would have concluded that this new optical recording system was ideally suited to record and play back digital signals. In the worlds of patent and inventions, such a merging of two existing major technologies is called an evident step. And it cannot be patented. So there is not a single invention, nor are there inventors of the CD as such.

However, the successive digital signal processing operations and subsystems in the CD-system had to be adapted to the properties of the optical storage medium and the reading device. This required new ideas, with major inventive steps. Many of these inventions were done at Philips. The realization of each subsystem, taking into account the proper functioning of the other subsystems, required team work and this holds even stronger for the total CD system. When

Philips decided in the seventies to start the development of the CD player and the disc, they showed an exceptional vision. And when the CD system was unveiled to the public on March 8, 1979, it was the result of great team-work by experts and inventors from many different disciplines.

Scientists, engineers and business men and women have worked for years on making this happen. For some of them, this has been a single project. A step in their personal development and career. Others have built a life-long career in the optical disc industry. Some of the early contributors to the CD in the late 1970s had moved to senior positions in their companies around the year 2000. And the field of optical disc storage had grown into a global, mature industry. Trade fairs, supplier networks, specialized workshops, industrial roadmap committees and global conferences had become part of the routine in this industry.

Expertise fields had been introduced in the optical disc storage world as a topic of an individual scientist or engineer in Eindhoven or Tokyo, often with its roots in adjacent applications. Examples are lens design and manufacturing, solid state lasers and photodetectors, actuators and servo electronics, digital rights management, coding and signal processing for detection, materials for read-only, write once, and rewritable discs, disc mastering and replication. Around the year 2000, each of these fields had become specialisms with dedicated sessions at international optical-storage conferences, and in some cases dedicated supplier-companies of knowledge and tools.

Specialists of several companies and academia in Europe, Japan and the USA, but also in Korea, Taiwan, China and India met each other at these international events. They increased performance of their current products, for instance in the speed race for optical recording. At the same time they pushed down manufacturing costs. But they were also interested in inventive solutions for a next generation optical disc formats. In 1995 this resulted in the realization of a second generation optical disc standard for standard-definition video: the Digital Versatile Disc (DVD) with more than 7 times the storage capacity of CD. And while DVD was becoming a big market success, already at the turn of the century some of the people who started the Compact Disc worked intensively with younger generations to look even beyond DVD. They used their joint expertise for the creation of the new Blu-ray Disc (BD) format, boosting the storage capacity with another factor of 5 compared to DVD. This BD-format serves for the distribution of high-definition video content. Blu-ray Disc is now conquering the market as, perhaps, the ultimate optical disc format.

A lot of this has been facilitated by global standards. This has been started with CD-audio, but it was later followed by many more standards, on different modalities of optical storage (read-only, recordable, rewritable) and different applications (computers, audio, video). It may even be claimed that the worldwide recognition in the market has been a critical success factor that was enabled by the global standards. And this recognition could be identified both at consumer and supplier side. Consumers could be confident that CDs of different brands or different geographical origin would play in their appliances at home. And manufacturers could be confident that if they had met the specifications, their systems would find their place in the optical disc storage world.

The founders of CD have retired or are close to retirement now. It is appropriate to acknowledge and honour their contributions to this industry. Their heritage is a mass-market optical disc technology that has been pushed to its limits. Its specifications are far beyond the imagination of the original CD-workers in the 1970s. And its business impact and global proliferation have met only the most optimistic projections at its market introduction.

The optical data storage story has started with imagination and inventions in research laboratories. Its breakthrough success was, however, only possible because the ideas resonated in the business groups. People saw an opportunity and acted on that by creating appealing products. Right from the start, technical developers and business managers took a leading role in this process. This interplay of science, technology and business may be caught in a single term: Innovation.

In the end, the success of optical discs has been created in the markets. It is granted by our customers, and by our customers only. Since the invention of the compact disc, billions of discs have been sold and almost everybody on our planet uses them. They have enriched people's lives via the distribution and reproduction of music, and later also data, movies, software, and as a back-up medium of records ranging from digital pictures to tamper-free off-line back-up of mission-critical data.

This rich world may indeed be caught in a simple, shiny disc on display in an exhibition on contemporary design in a museum filled with masterpieces. The curators of the museum ask the *Necessity*-question as the litmus test for justification of its presence: "Would the world have missed it, if it had not been invented or produced?" We think the answer is yes.

About this book

The advent of the compact disc has been an important milestone for today's digital world. This book has been created at the occasion of the awarding of an IEEE Milestone in Electrical Engineering and Computing[3] to Philips to commemorate the first public announcement of the Compact Disc, at a press conference on March 8, 1979. The book provides a survey of the evolution of optical storage, with an emphasis on the contributions of Philips to this field. It covers 4 phases: (1) The work leading to the first prototype (Pinkeltje) and its public announcement, (2) The CD system as standardized by Philips and Sony, (3) the period following the market introduction of Compact Disc audio, with the proliferation of new formats, like CD-ROM, CD-I, and finally with DVD and its standards, and (4) the research leading to Blu-ray Disc, the highest capacity optical disc on the market today. For phases (1), (2) and (4) the book provides introductory historical perspectives, followed by reprints of seminal texts by Philips technical experts. For phase (3), it can be argued that the success of CD and DVD owes much to the development of worldwide standards for CD and DVD formats. For this reason the book covers phase (3) via a detailed account of these standards and formats.

While the editors have used their best efforts in preparing this book, they make no representation or warranties with respect to the accuracy of the contents.

References

[1] Paolo Antonelli and Christian Larsen, Department of Architecture and Design, New York Museum of Modern Art, New York, USA. See also www.moma.org.

[2] See www.research.philips.com.

[3] See http://www.ieee.org/web/aboutus/history_center/milestones_intro.html for a complete list of IEEE milestones.

Chapter 2

THE PHILIPS PROTOTYPE OF THE CD SYSTEM

2.1 Introduction to contributions on the Philips prototype of the Compact Disc digital audio system

J.B.H. Peek

On March 8, 1979, a prototype of the Compact Disc (CD) digital audio system was presented at Philips in Eindhoven, the Netherlands, to an audience of about 300 journalists. The system was presented and demonstrated by J.P. Sinjou, the head of the Compact Disc laboratory of Philips' main industry group Audio. The optical disc he showed had a diameter of 11.5 cm. The text of his presentation, together with the slides that he used, is reproduced in Sect. 2.2. Referring to this demonstration, R. Bernard noted in his paper ('Higher fi by digits', IEEE Spectrum, pp. 28-32, Dec. 1979) that "Demonstration systems have been impressive, and the total lack of background noise of any kind during pauses in musical passages is particularly dramatic". Since the prototype CD-player had such small dimensions, the engineers of the Compact Disc laboratory named it 'Pinkeltje' after a tiny dwarf who plays the central role in a Dutch fairy tale book. The text by J.P. Sinjou is followed by three papers that describe various subsystems used in the prototype player.

The demonstrated system was the conclusion of a successful merger of two major existing technologies. First, the optical read out, by using a laser, of information stored on a disc, and, second, the digital coding/decoding and digital processing of signals.

The optical playback of an analog color video signal by using a laser was introduced in 1973 by Philips with the VLP (Video Long Play) system. The development of the VLP system was the result of the combined effort of a team of specialists in very divergent fields. In 1974, the VLP player and the disc became available on the market. An introduction to the VLP system was presented by K. Compaan and P. Kramer in a paper (1973) that is reprinted here in Sect. 2.3. The experience that was obtained in developing the VLP system was crucial in the realization of the optical part of the CD prototype player. This is also true for the production, on a small scale, of CD discs for the prototype player.

In the VLP player there is no mechanical contact between the optical pick-up unit and the disc. The information on the VLP disc is present in the form of a spiral track that consists of a succession of pits and flat areas called lands. In the case of the VLP disc the length of a pit and also of a land is a continuous variable. This is in contrast to a CD disc where the length of a pit and a land is a discrete variable. The track is optically scanned by a laser beam that is focused by an objective lens on the information layer of the disc. Before the beam reaches the information layer it passes a transparent protective layer. When the spot of the beam falls on a land, the light is almost totally reflected. After that, the light is detected by a photodiode. However, when the spot falls on a pit, the depth of which is about a quarter of the wavelength of the laser light, interference and extinction occur which cause less light to be reflected and to reach the photo-diode. Hence, ideally the output signal of the photodiode is a fair representation of the originally recorded signal. Unfortunately, there are several sources of errors that can occur in or on an optical disc. First, small unwanted particles or air bubbles in the plastic material, or pit inaccuracies, may occur in the replication process. This can cause errors when the information is read out by a laser. Second, fingerprints or scratches may appear on the disc when handled. As a consequence of this, and of the small dimension of the pits, the errors mainly occur in bursts. A burst (dropout) implies that the signal pattern at the output of the photodiode differs for a long interval, encompassing many pits, from the originally recorded pattern.

There are two reasons why these errors do not seriously affect the picture quality in the VLP system. The first reason, generic to all optical storage systems, is that the diameter of the beam at the surface of the disc is much wider than the diameter of the spot at the information layer. As a result, local defects and imperfections at the disc surface effectively get blurred and de-emphasized in the readout signal. This effect is inherent in reading out a disc through a transparent substrate, and constitutes one of the key patents of the CD system (P. Kramer, ”Reflective optical record carrier”, U.S. patent 5,068,846). The second reason, specific to the VLP system, is that in a TV picture there is a high correlation between two successive lines. A dropout can be detected and rendered much less visible by replacing the affected line by the preceding line (U.S. patent 4,032,966). However, the correlation in a signal is not always present in a useful form to conceal errors. This was observed in 1975 with the failure of experiments made at Philips to play back high-fidelity analog audio signals recorded on an optical disc. In this case burst errors caused an unacceptable deterioration of the audio. It was at this time that it became clear to most people at Philips that the only solution to record high-fidelity audio signals was to go digital.

In the VLP player and also in the CD prototype player, three servo systems are used. The first servo system ensures that the light beam is kept on track. The second servo system keeps the spot focused on the information layer. The third servo system ensures that the beam scans the spiral track at a constant velocity. The function of the first servo system in the CD prototype can, if no precautions are taken, be disturbed by the digital recorded signal. To prevent this disturbance of the servo system in the CD prototype player, the digital signal is modulated before recording. By applying modulation prior to recording, the frequency spectrum of the recorded digital signal can be given a spectral null at zero frequency. As a consequence, the first servo system is only minimally disturbed. A modulation code called M3, invented by M.G. Carasso, W.J. Kleuters and J.J. Mons, was used in the CD prototype. Although this code was not described in a journal or conference paper, it is covered in a U.S. Patent (4,410,877) that was granted in 1983 to the three inventors.

When the stored signal is digital, a certain number of errors can be corrected by using error correcting codes. A high-fidelity analog audio signal can be digitized by using pulse code modulation (PCM). PCM was proposed by A. Reeves in 1937. An early, successful application of PCM was in the T1-carrier system developed by AT&T in 1962. In the DS1 version of the T1 system, 24 PCM speech signals (each with 8 bits) are transmitted over one twisted pair of copper wires. Each of the two audio signals(stereo) in the CD prototype system was PCM encoded using 14-bit uniform quantization.

A digital audio signal can be protected against errors by an error-correcting code that adds so-called parity bits before recording. The precise recipe for adding these parity bits depends on the mathematical properties of the applied error-correcting code. In 1950, R. Hamming gave a method for designing block codes that have a single error correction capability per block (R.W. Hamming, 'Error Detection and Error Correction Codes', Bell Syst. Techn. J., Vol. 29, pp. 147-160, 1950). With his work he started the discipline of error-correction coding that resulted in codes with greater error correcting capabilities per block.

Burst errors, which may exceed the capability of a given error-correcting code, may in general be corrected by an additional technique called interleaving. By using interleaving before recording, a burst of errors is, after de-interleaving, spread out in time. These dispersed errors can be corrected by a less powerful code that needs to correct only a few errors per block.

In the prototype CD system an interleaved convolutional error-correcting code was used. This code was chosen by L.B. Vries based on measured statistics of optical disc errors. His paper that describes the convolutional code is reprinted in Sect. 2.4. In the summary of his paper he wrote “Implementations made so far prove that a single-chip realization of a Philips Compact Disc Decoder is very well feasible”. This is an important point, essential for realizing a Compact Disc player at an attractive price for the consumer. During the sixties and seventies, digital system engineers assumed that in the course of time, complex digital systems could be realized on one chip and that consequently the price of digital systems would go down. This assumption was based on Moore’s law. In 1964 and 1975, G.E. Moore made predictions on the future growth of the transistor density in integrated circuits. He predicted in 1975 that the transistor density of integrated circuits would double every two years for the next decade. This prediction proved to be remarkably accurate and still holds after more than 40 years.

The presence of two monolithic 14-bit Digital-to-Analog (D/A) converters in the Philips prototype CD player shows the sophisticated and advanced level of IC technology at that time. The monolithic 14-bit D/A converter is described in a paper by R.J. van de Plassche and D. Goedhart that is reprinted in Sect. 2.5. In 1978, this D/A converter was the only one available on the market with that resolution. At that time more complex non-monolithic 12-bit D/A converters were priced between 250 and 500 US dollars. However, the availability of the Philips 14-bit D/A converter was an encouraging sign that in time all digital and mixed-signal subsystems needed in a CD player could be realized on just a few chips. A significant promise for future cost savings was also that the prototype CD player contained a solid state ‘Aluminum Gallium Arsenide’ laser.

Finally, it is important to note that the basic arrangement of the successive digital signal processing operations in the CD prototype system did not change when the CD system was standardized by Philips and Sony in June 1980. What changed, however, in the standardized CD system was that the successive digital signal processing operations became more effective and powerful.

2.2 Presentation of J.P. Sinjou on the public presentation of the Philips prototype of the CD system on March 8, 1979

J.P. Sinjou

Fig. 1. The presentation of the CD by J.P. Sinjou.

Ladies and gentlemen,

For the explanation of the technical specification of our new sound-reproduction system I like to describe:

- the disc and the player,
- the coding system,
- the optical read-out,
- track following,
- and the disc production.

After this you will hear classical music as well as popular music. The Compact Disc and its slip-case are shown in Fig. 2.

Fig. 2. From left to right: Compact Disc, prototype CD player and slip-case.

As you see it is a small disc, it is 115 mm in diameter, 1.1 mm thick and it is made of transparent plastic.
The recording takes the form of a helical track of etched pits commencing at the centre of the disc. A Compact Disc of this size can carry a stereo recording of 60 minutes. This is due to the track to track distance of 1.66 microns, as shown in Fig. 3.

Disc	
Diameter	: 115 mm
Thickness	: 1.1 mm
Track pitch	: 1.66 micron
Recording time	: 60 min. stereo 1 side recorded
Material	: Polyvinyl chloride

Fig. 3. Key physical parameters of the disc.

The disc is recorded on one side only and is covered by a metallic layer embedded beneath a transparent protective coating. It is light and in all respects more convenient than the conventional long play. The Compact Disc bears certain similarities to present day gramophone records, however, with regard to sound quality the similarity ceases to exist. This is due to the breakthrough achieved in storing the music information on the disc digitally and reading it out optically.

As a result of disc size, the Compact Disc player chassis need be no larger than a compact cassette tape-deck. The pick-up head is an optical device employing a miniature laser and a compact optical system. The light reflected back from the metallic layer in the disc contains all the signal information in digital form, with which to reproduce the original music information. The location of the optical pick-up unit determines the speed rotation of the disc and this changes inverse-linearly with the radius from 500 r.p.m. in the centre to 215 r.p.m. at the outer edge. Since there is no physical contact between the optical pick-up head and the disc, the optical pick-up unit generates signals, which indicate whether the disc is in focus and whether the spot is correctly following the track in the radial direction. The optical pick-up unit is mounted at the end of a moveable arm, which is driven by a linear motor.

The player can directly be connected to all existing Hifi-chains, e.g. amplifiers and loudspeakers. Operating the Compact Disc player amounts to no more than selecting play, stop, automatic or search modes. The player is shown in Fig. 2 and it will be demonstrated today. It is built for this reason only and has no commercial purpose.

The coding system

The main object of the encoding system is to obtain the required high quality properties in combination with a high information density on the disc.

As a digital encoding system is chosen Pulse Code Modulation (P.C.M.), offering the following advantages:

- It is an efficient encoding method requiring a low transmission bandwidth as compared e.g. with FM modulation.
- The noise in the transmission channel is not determined by the disc, but by the code chosen.
- The frequency response can be very flat and independent of the disc properties.
- Disc surface deteriorations, clearly audible on a conventional disc, can be made inaudible by applying an appropriate error correcting code.
- Besides music information, other data can be added in encoded form, such as text and programme information.

The text information like e.g. music titles, the name of the composer, conductor, etc. can be incorporated, and the potential exists for visual display of this information as well. Numerical data can be included during disc recording, which makes it possible to play the disc in programmed sequence.

To convert the analog signal into digital form the analog signal has to be sampled with a frequency which has to be at least two times the audio bandwidth, which is 20 kHz per channel, see Fig. 4. The sampling frequency chosen is 44.3 kHz and is derived from a 4.4 MHz crystal.

Player	
Number of channels	: P.C.M. 2 channels (more channels possible)
Frequency response	: 20 Hz - 20000 Hz
Dyn. range	: > 85 dB
S/N ratio	: > 85 dB
Harmonic distorsion	: less than 0.05 %
Wow/Flutter	: precision of Quartz - oscillator.
Quantisation	: 14 bits linear
Drop out compensation	: yes
Sampling rate	: 44.3 kHz

Fig. 4. Key characteristics of the prototype CD system.

The samples are uniformly quantized and converted into binary words. Each individual sample of sound information consists of 14 bits and so a 60 minute recording will total approximately 6 billion bits. The bits are laid out on the disc in the form of a helical track of microscopic pits and non pits. Digitally a pit represents 1 and the area between the pits nought. The 14 bits give a total of more than 16.000 levels and are required to achieve a signal to noise ratio of 85 dB. By the application of pre emphasis a signal to noise ratio of 92 dB is in fact obtained.

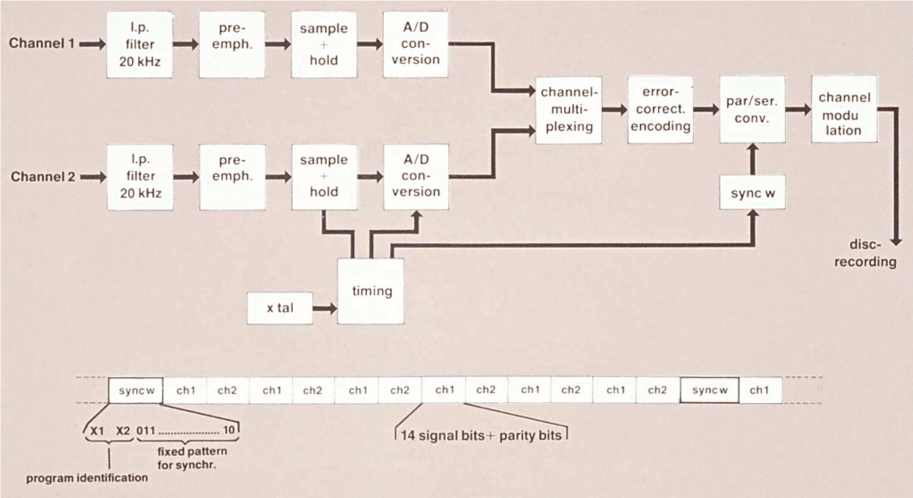

Fig. 5. Signal encoding system and frame format.

Fig. 5 shows the encoding system as applied to both channels. Following the functions of pre emphasis, sampling and conversion, time multiplexing of the two audio channels, in case of stereo, takes place. In the following stage error correcting parity bits are added to the 14 bit words to enable correction of bit errors. Word synchronization also occurs in this stage. The multiplexer has been so designed as to allow implementation of more than two channels in the future. Thereafter channel modulation occurs in which the bit stream is adapted to the properties of the read system and of the disc. The main requirements for the channel modulation are:

- D.C. free transmission, necessary for good tracking error signals.
- Good clock regeneration capability.
- No increase of transmission bandwidth.

The information (word) pattern is shown in the lower part of this figure. Each word per channel consists of 14 signal bits and the added parity bits. In the synchronization word (sync w) bits are reserved for text and programme information.

The optical read-out

Since the information has been deposited in the form of a helical track of pits and non pits in the disc, an efficient read out system had to be devised.

The information structure as it appears in the disc is shown in Fig. 6 at a magnification of 10.000 times. As the minimum length of the pits is less than 1 micron, the width a constant 0.6 micron and the depth a quarter of the wavelength, it will be obvious that a system of mechanical contact will fail to produce the required read out.

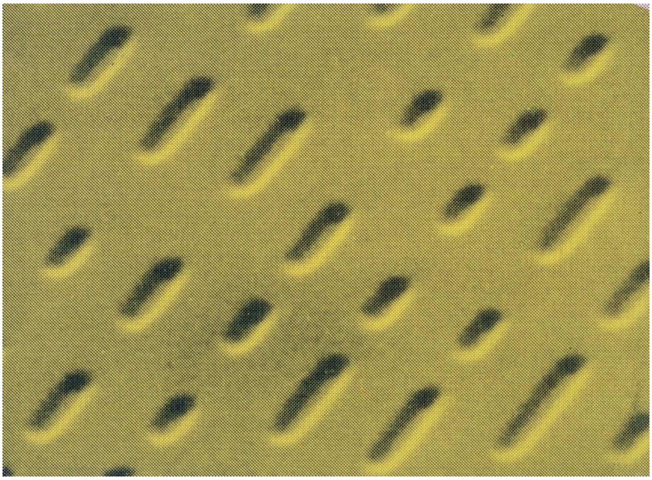

Fig. 6. Information structure as it appears in the disc.

Fig. 7 serves to illustrate this point and shows the comparison with the conventional gramophone record.

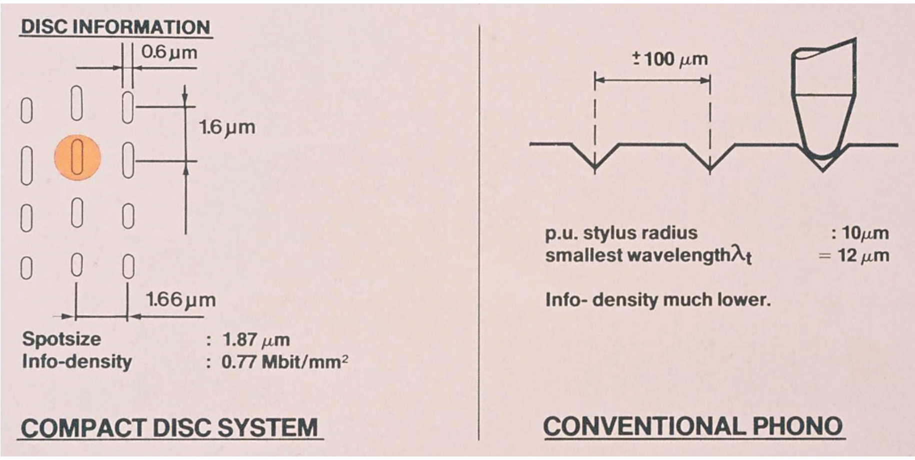

Fig. 7. Comparison of compact disc structure and structure of conventional gramophone.

The information layer is covered with a metallic reflective coating so that we can extract the information by means of reflected light. We achieve this by focussing the light from an Aluminum Gallium Arsenide (AlGaAs) laser onto the track. This diode laser is a light source of considerably less power than that

used for writing the master disc. The laser light, which is concentrated into a spot of 1.87 microns in diameter, follows the track thereby striking pits and non pits alternately. Due to this, light will be lost because it is diffracted over angles larger than the lens is capable of accepting. Thus the intensity of the reflected light is modulated by the physical structure of the disc and this is detected by a photodiode which, in turn, produces a modulated electrical signal.
The optical pick up unit is shown in Fig. 8.

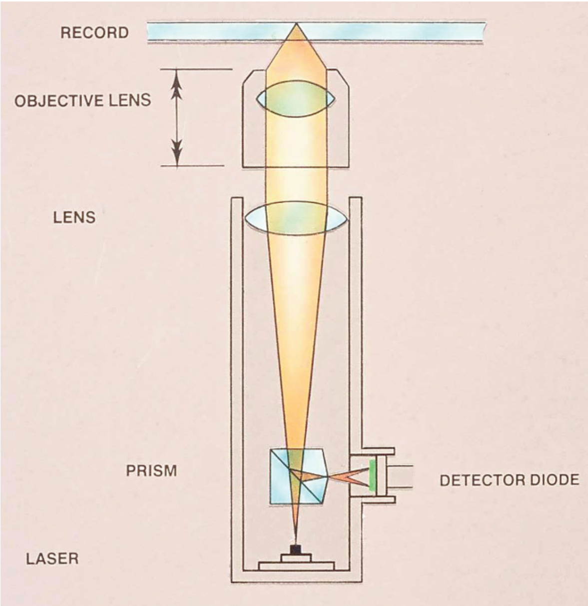

Fig. 8. Optical pick-up unit of the prototype CD system.

The divergent light beam emitted by the laser is converted into a parallel beam by means of a lens. The parallel beam is directed toward the objective lens. It is here that the beam is focussed onto the information track. The reflected, modulated light is directed at the detector diode by a prism, which serves as an output coupling mirror. A wedge is situated between this half mirror and the photo diode to split up the reflected beam into two parts, forming spots on different parts of the photo diode. The output currents of the diode parts contain the desired information signal as well as the error signals for radial tracking and focussing.
The optical pick up unit is only 45 mm in length, 12 mm in diameter and weighs 14 grams. It is mounted at the end of a moveable arm enabling it to follow the track in radial direction. The objective lens is mounted above the light-pen and with the help of a drive system of the principle of that of a loudspeaker it is possible to keep the spot focused on the information layer.

The modulated output signal of the photo detector diode in relation to the pits and non pits on the disc is shown in Fig. 9.

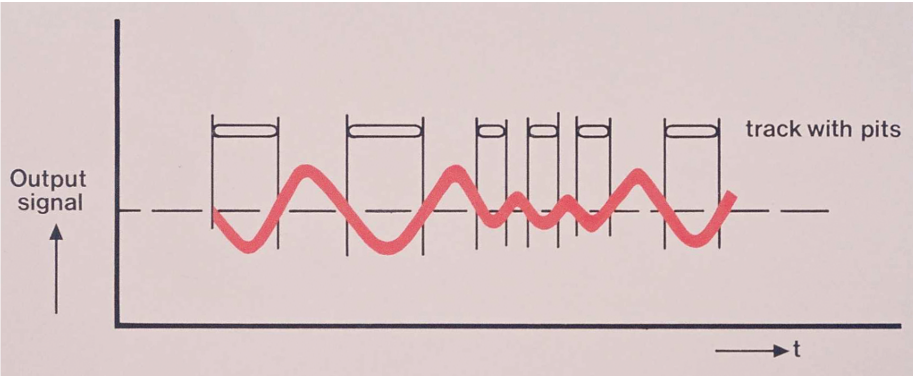

Fig. 9. Modulated output signal of the photo detector diode.

Fig. 10 shows that the point of information is found at a depth of 1.1 mm through the transparent disc material. The diameter of the light beam at the place it enters the disc surface is 1 mm, so 1.000 microns. Dust particles and small scratches will be out of focus and intercept relatively little of the beam.

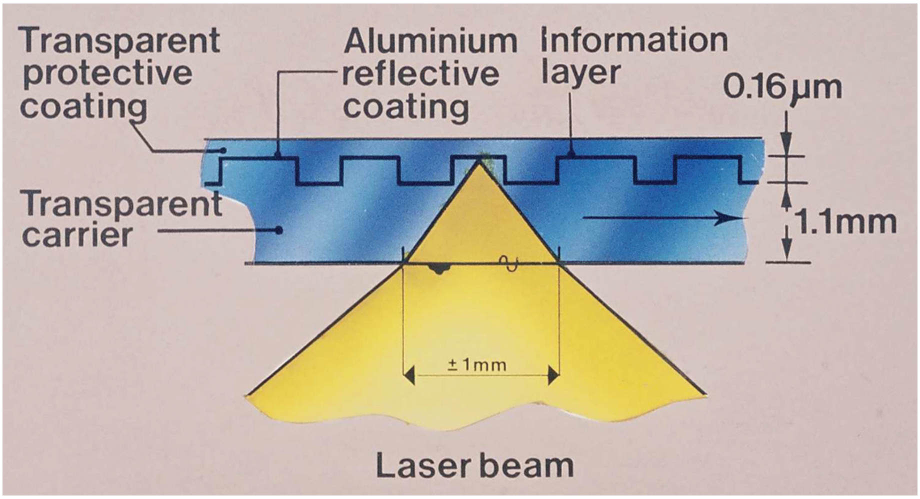

Fig. 10. Information read-out through a transparant coating.

The track following servo system

Track deviations from the circular and vertical unevenness of the rotating disc must be accounted for, since both the width of the track, 0.6 microns, and the depth of focus of the spot, 2 microns, are particularly critical. Because there is no mechanical contact with the track, these irregularities have to be controlled by servo systems, which receive their information from the optical pick up unit.

The focus error signal, as indicated in Fig. 11, results in a vertical movement of the objective lens. The track error signal derived from the disc, maintains the spot exactly on the track. The turntable speed varies with the detection radius to give a constant linear track velocity. In order to exactly reproduce the speed used during recording the motor servo, controls the turntable motor to make the detected digital coding signal equal to a standardized clock frequency. The track error signal and the arm position signal have a direct relation to each other as the random access facility enables the arm to be moved to a predetermined position. Therefore the tracking process is automatically cut out by a control logic system. This control logic system initiates also the correct function of user operated keys, such as start and stop.

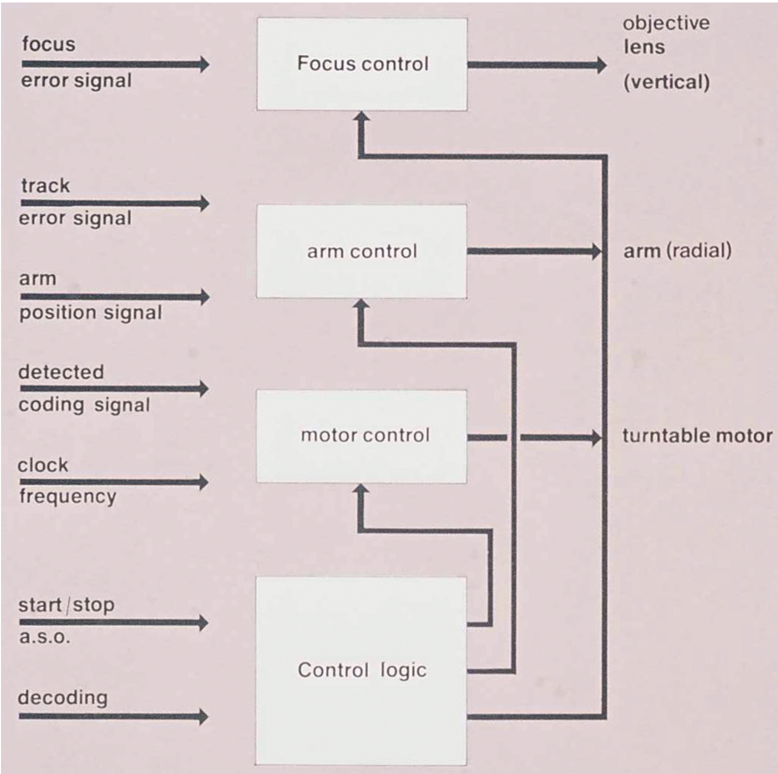

Fig. 11. Block diagram of the servo systems.

The block diagram, given in Fig. 12, shows the main functions of the player:

- The disc with the drive motor.
- The optical pick up unit giving the high frequency, focus and radial tracking signals.

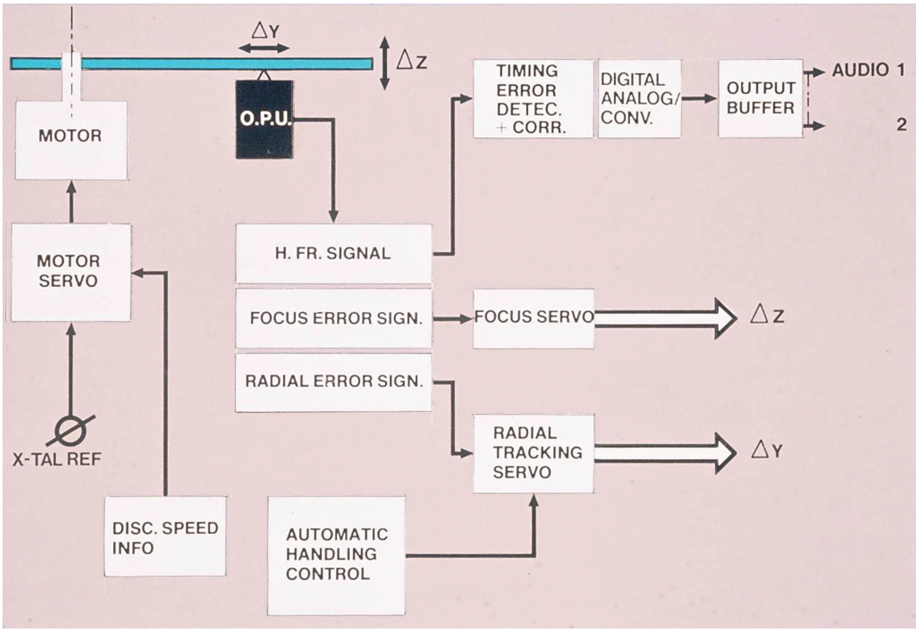

Fig. 12. Block diagram of the player.

Disc production

The Compact Disc production process differs in a number of ways from that of conventional gramophone records. The master recording, be it an analogue master tape or, in the future a digital master tape, is transferred into a coded signal before being put on the disc. The master disc is a glass plate with a photo sensitive layer deposited on one side.

The coded music signal modulates the beam of a laser, which writes the information in the photo sensitive layer in real time. A developing process follows, which leaves a pattern of pits in the glass plate exactly representing the original master recording. Via a galvanic process, stampers are then made which are used for disc production in a manner similar to that of pressing normal gramophone records. After pressing an extremely thin reflective metal coating is deposited on the information side of the disc, and further sealed with a transparent protective coating.

2.3 The Philips 'VLP' System

K. Compaan, P. Kramer

Drs K. Compaan is with the Philips Electro-Acoustics Division (ELA), Eindhoven;
Dr P. Kramer is with Philips Research Laboratories, Eindhoven.

Abstract
Television pictures are recorded on the Philips video long-playing ('VLP') record in a spiral track of pits in the surface. The pits have constant width and depth but the lengths and spacings are variable. The information is read out by a beam of light, which is reflected at the surface of the record. The reflected beam is modulated by deflection of the light through diffraction at the pits. To enable the 'VLP' playback unit to operate at the required accuracy, control systems have been developed for holding the speed of rotation of the record constant, focusing the read-out beam on the record surface and centring the beam on the spiral track without the assistance of mechanical guides. The player can be used to show the recorded pictures one at a time, and will also allow them to be shown in reverse motion, slow motion, or at faster speed.

Now that almost every home and many educational institutions have a television set it is natural to think of the possibility of using it, in combination with a playback unit, for reproducing programmes that have been permanently recorded in some way or another. This gives the user the freedom of being able to watch a programme he is interested in at a time convenient to himself - the same freedom he can enjoy with a shelf of books or a collection of gramophone records.

The 'VLP' system described here allows a colour-television programme of about 30 minutes duration to be reproduced from a recording on a 'gramophone record' 30 cm in diameter, the usual size for a long-playing record. The 'VLP' record can be produced simply and in quantity by the normal pressing techniques. The 'VLP' system is complementary to the video cassette recorder (VCR), which has been on the market for some time, but to some extent it offers an alternative to it. A programme can be recorded as desired with a cassette recorder, but it is more expensive to produce recorded tapes than it is to press 'VLP' records.

The development of the 'VLP' system is the result of the combined efforts of a team of specialists in very divergent fields. In this article we shall give a broad general survey of the system; the three short articles that follow will describe some of the components in more detail [1] [2] [3].

Reprinted with permission from Philips Tech. Rev. **33**, 178-180, 1973.

The diameter of the spot is of the same order of magnitude as the wavelength of the light used in the equipment, and it is therefore no longer possible to speak of a particular diameter. A diffraction pattern (an Airy disc) is formed at the focal plane of the lens; this pattern consists of a central maximum surrounded by successive dark and light rings. To produce a pattern in which the half-intensity diameter is 0.9 to 1.0 μm at the wavelength used, a lens with a numerical aperture of 0.4 is required.

The information is recorded on the record disc along a spiral track, which occupies the part of the disc between the 10 cm and 30 cm diameters. The speed at which the disc rotates has been made equal to the picture frequency, 25 s^{-1} for the European market and 30 s^{-1} for North America. As we shall see later, this offers some interesting possibilities. If the playing time is half an hour, these figures give a pitch of 2 μm for the track.

For following a track with such a small pitch an optical method is very suitable. In the 'VLP' player this scanning is done with a spot of light 1-2 μm in diameter, projected on to the track by a lens.

The information for the reproduction of a television picture is recorded as a succession of short grooves or pits of variable length and repetition frequency. The width of the pits is 0.8 μm, and the depth 0.16 μm (see Fig. 1). Since in pressing a gramophone record the surface roughness does not amount to more than 0.01 μm, it is clearly a practical possibility to make such a pattern in the surface of a pressed disc.

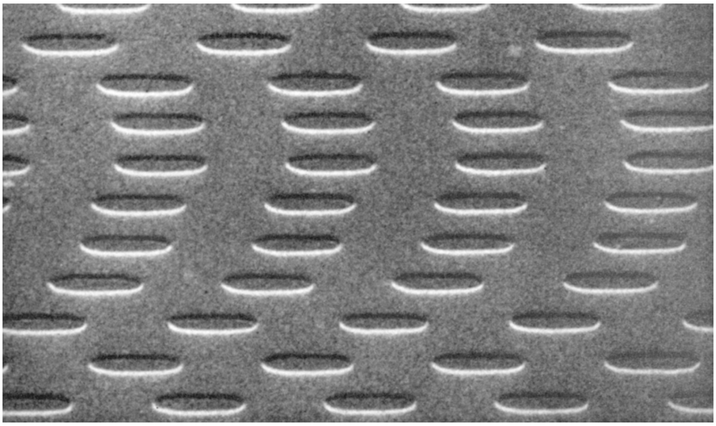

Fig. 1. Information layer of the 'VLP' disc.

If the spot of light falls on the surface of the disc between two of the pits, then most of the light will be reflected back into the objective lens. If on the other hand the spot falls on one of the pits, the light will be deflected by diffraction at the pit in such a way that most of it is not returned to the objective (Fig. 2). In this way the intensity of the light reflected through the aperture of the lens is modulated by the pattern of pits[1]. The intensity variations are converted into an electrical signal by a photodiode. The width and depth of the pits in the surface are arranged to give as large a modulation depth as possible.

To obtain a high signal-to-noise ratio in the detector signal, the reflected beam should have as high an intensity as possible. If the photocurrent is too low, the noise will no longer be mainly determined by the thermal noise in the detector, but by the shot noise in the photon current. We have therefore used an He-Ne laser as the light source. Also, to improve the reflectivity, the surface of the 'VLP' disc has been coated with a thin layer of evaporated metal.

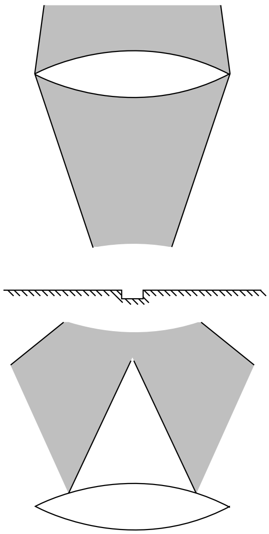

Fig. 2. Modulation of the light by a pit in the surface of a 'VLP' record. For clarity the system is drawn as if the record were transparent, with the beam incident from above and a second lens placed underneath the record to receive the light. The pit is also shown many times enlarged with respect to the rest of the figure. If the record surface is flat, all of the incident light is received by the lower lens. If there is a pit in the surface there will be diffraction, and some of the light will be deflected; when the pit is correctly dimensioned much of the incident light will be deflected away from the aperture of the lower lens. In practice the record surface is reflecting, and only one lens is required for concentrating the light on to the record and receiving the reflected light.

Some of the members of our team have developed a special technology that enables the He-Ne laser to be manufactured in quantity. This 1 mW laser has been built into the player in such a way that it can be of no possible danger to the user.

The information on the surface of the disc can be read out through a transparent protective layer. Any contamination or damage only affects the outer surface of this layer, and not the disc. The diameter of the beam at this outer surface is much larger than the spot, so that these imperfections have