Historical Development of Analog Disk Recording Technology and Artifacts Now in Existence

1

— Shift from Mechanical to Electrical Recording Methods for Longer Duration Recordings and Stereo Sound —

Takeaki Anazawa

■ Abstract

Chapter 2 of this study, titled “The Birth and Rise of the Phonograph,” touches on related developments . The history of analog recordings dates back to 1877 when American inventor Thomas Edison came up with a new phonograph that enabled users to record sound onto a recording cylinder and replay that audio. In 1887, just 10 years later, German inventor Emile Berliner created the gramophone. The era from that time up until the end of World War I was one where the cylinder-based recording medium competed with the disk-based medium. Later, the disk medium, which was more conducive to mass replication, went on to dominate in the realm of analog recordings.

Chapter 3 of this study, titled The Birth of Acoustic (Mechanical) Disk Recording and Playback, describes developments in Japan with respect to audio recordings . Toward the end of the nineteenth century, Japan began importing wax cylinder audio devices. At the beginning of the twentieth century, Western record companies began making recordings in Japan, and then reproduced those recordings back home for export to Japan. In 1909, a Japanese company began manufacturing disk-shaped records (single sided 78-rpm records, 10-inches in diameter), which were released under the “Nipponophone” label. One year later, in 1910, Japan’s first domestically produced gramophone player was released.

Chapter 4 of this study, titled The Advent of Electrical Recording, describes circumstances ensuing after the end of the World War I. This era marked the advent of broadcasting, the success of which hinged on numerous developments, such as with respect to vacuum tube and microphone technologies. Such efforts ushered in an era in analog recording, beginning in 1924, where electrical recording offering superior audio quality came to replace earlier mechanical recording techniques that did not use electricity. Initially, users of gramophones would have to make their own recordings for playback sometime later. However, it became easier to mass-reproduce analog recordings with the advent of electronic recording, where records could be produced using conductive analog record masters with pre-cut grooves. Whereas this enabled distribution of analog recordings of music, it also gave rise to issues with respect to the piracy of music recordings.

Meanwhile, up until the introduction of magnetic recording devices in 1950, broadcasters would create program content using disk-based recording equipment, one prime example of this being coverage of the Berlin Olympics in 1936. Japan also embarked on development of disk-based recording equipment offering performance and audio quality exceeding that of equipment from overseas, with the intent of using it in what were to have been the 1940 Tokyo Olympic Games. However, whereas the eventual cancellation of those games meant that those devices were ultimately not used for that purpose, they would later be used in broadcasting the imperial edict that brought World War II to an end. During the immediate pre-war to post-war era, many Japanese engineers engaged in original development efforts, which yielded breakthrough technologies, such as Filmon sound belt devices, which offered up to 36-minute recordings, the disk recording equipment mentioned previously, broadcast microphones, and magnetic recording devices. These technologies would go on to form the foundations of consumer devices developed in Japan after the war.

Chapter 5 of this study, titled The Shift to Longer-Playing and Stereo Disk Records, traces such developments. First, the chapter overviews developments with respect to methods for picking up sound with microphones and sound field reproduction. It then goes on to trace changes in sound pick-up and recording technology from the recording stage to that of editing, mix down, and cutting (disk mastering), both analog and digital. The chapter then touches on the topic of integrating recording and playback equalizers, and that of test recordings that draw on recording disk calibration methods and monitoring of recording devices. Explanations are also given with respect to development of technologies for correcting recording disk playback distortion and those for cutting grooves on recording media with up to four channels of audio. The latter half of Chapter 5 touches on technologies for manufacturing read-only

records and looks at improvements in materials used in making records. More specifically, this section provides details on developments with respect to conductive properties of master recordings, the use of electroplating techniques with lacquer masters, manufacturing processes for master plates, mother plates and stampers, and record manufacturing processes. It also touches on changes with respect to base materials used in making records, and adds details about the flexi disc format (flexible records) and other special types of records. The chapter later introduces the subject of developments in record player technology, providing details about pick-up cartridges, tone arm and phono motors, throughout the respective gramophone, tuner equipped player and stereo set.

Chapter 6 and later chapters delve into background details necessary in understanding technological developments. Chapter 6 goes into changes in the record and record player industries, and trends with respect to factory shipments. Chapter 7 looks at various standards, such as international, Japanese and industry standards related to recordings. Chapter 8 delves into numbering schemes of the International Standard Recording Code and respective means of copyright protection. Chapter 9 conveys details about artifacts still in existence.

As this study suggests, American companies played a large role in the early days of analog audio recordings. On a more limited scale, Japanese engineers, fueled by a passion for such technology, also developed superior technologies on par with those coming from the U.S. Some prime examples of this include the likes of Koichi Tsubota, who developed a superior cutter head, Naotake Hayashi, who developed a world-leading condenser pick-up and condenser "ear speakers," and Masaru Ibuka, who developed magnetic recording devices for consumer use. Many other world class consumer devices were later conceived of in Japan, including noteworthy developments with respect to the introduction of practical digital recording applications in the 1970s and the development and market launch of compact disc technology 10 years later. Meanwhile, some have asserted that digital technology is unlikely to surpass levels achieved using analog means in areas with a close connection to the arts. Going forward, it is hoped that audio engineers from Japan and other countries will mobilize their collective talents and knowledge in order to overcome such hurdles.

■ Profile

Takeaki Anazawa
Chief Researcher, Center of the History of Japanese Industrial Technology, National Museum of Nature and Science

March 1967	Graduated from Waseda University's Faculty of Science and Engineering
March 1969	Completed a master's degree in acoustics at Waseda University's Graduate School of Science and Engineering
April 1970	Entered Nippon Columbia Co., Ltd. and joined the Recording Department, where he was involved in music content digitization and the development and production of 4-channel audio and karaoke.
April 1972	Commercialized a digital PCM audio recording device.
1974–1985	Engaged in digital audio recording and production of classical music, etc., in Europe and the U.S.
March 1992	Awarded the AES Silver Medal for Outstanding Achievements in Digital Audio Technology
June 1995	Assumed the position of board member of Nippon Columbia Co., Ltd.
October 2001	Retired and assumed the position of board member of Nippon Columbia Co., Ltd. and Denon, Ltd.
March 2002	Retired as COO of both companies
May 2002	Appointed President of DRM & Solutions Inc.
March 2009	Retired as President of DRM & Solutions Inc.
April 2013	Appointed Chief Researcher at the Center of the History of Japanese Industrial Technology, National Museum of Nature and Science Director of the Japan Audio Society

Fellow of the AES (Audio Engineering Society)
Member of the Acoustical Society of Japan

■Contents

1 Introduction

Acoustics is a branch of the natural sciences that has been studied since the time of the ancient Egyptians and Greeks and is not merely concerned with making and testing physical and mathematical theories, but also the designing of churches, temples, and musical instruments. When the phonograph record was invented in the latter half of the nineteenth century, and freed from the limitations of hard classical craftsmanship in the twentieth, it gave a powerful impetus to the yet-unanticipated content industry, and heralded a time of growth and prosperity for the same.

The content industry is tied into a wide range of technologies and disciplines, such as mechanical engineering, electrical engineering, acoustics, and chemistry. Acoustics, which underlies the content industry itself, is a fundamental interdisciplinary study that lies on the boundary of physics and engineering. This, accordingly, not only includes engineering, but many other fields besides. A notable characteristic of this industry is the fact that it encompasses not only technology that falls within the domain of engineered machinery, but also art outside of the domain of engineering.

The history of the technical innovation surrounding phonograph records is actually full of great artists. SP (standard play) records appeared during the peak of the career of the famous Italian tenor Enrico Caruso, enabling people to enjoy his voice through SP records and record players, and the marches composed by John Philip Sousa that Edison loved gave enjoyment to Americans through records and broadcasts. SP records have captured the renowned performances of the Spanish artist Pablo Casals, cellist, opponent of fascism, and artist of the same caliber as Picasso; and they have also captured the profound inner world of Albert Schweitzer, the organist, philosopher, and researcher of Johann Sebastian Bach.

The era of LP (long play) and stereo LP records saw the first Japanese LP records (see 5.5.5), which captured the performances of Bruno Walter and other musicians who escaped the oppression of the Third Reich. The recordings of famous musicians who fled to Western Europe from Hungary in the upheaval after WWII cannot be overlooked either. Péter Bartók, son of the well-known Hungarian composer Béla Bartók, became a successful recording and sound engineer in New York, and made a recording of the celebrated cellist János Starker (also from Hungary) playing Kodály’s sonata for solo cello – which was said to have the sound of “flying rosin” – and which eclipsed all previous records to became the most famous LP record of its time. Fritz Reiner, who was a conductor for the first Japanese stereo LP records, was also Hungarian. EP (extended play) records are relevant to iconic singers like Hibari Misora, Elvis Presley, and the Beatles. Japan’s PCM (Pulse Code Modulation) digital audio recording efforts propelled Maria João Pires, a talented but obscure Portuguese pianist, into the spotlight with Mozart’s complete piano sonatas. Also world-renowned were the complete collection of Beethoven’s string quartets played by the Smetana Quartet (who were the pride of Czechoslovakia), and Mahler’s collected symphonies conducted by Eliahu Inbal. Whenever successful records have seen technical improvement, there have always been first-class artists supporting them.

The history of phonograph records has seen the development of technologies such as recording and playback media manufacturing technology, content data recording technology, long-term storage technology, mass-production technology, distribution systems, and copyright protection technology. This expertise and these accomplishments will undoubtedly continue to be applied to the mass duplication-free distribution of digital content in the new fully-networked society.

2 The Birth and Rise of the Phonograph

In 1877, 137 years ago, Thomas Edison invented the phonograph record. Some of the changes surrounding them that have happened since that time are shown in Fig. 2.1, such as recording media, recording techniques and other methods of production, the diameters of disk records, their rotational speed, groove type, base material, playback time, frequency response and dynamic range.

Also included in Fig. 2.1 along with SP records, LP records, EP records and CDs are phonograph cylinders, the Filmon Sound Belt, which was invented in Japan in the 1930s and which boasted over 30 minutes of recording and playback, compact cassettes, which became established as a medium for audio in their own right, and MDs, SACDs, DVDs, etc. The bottom row shows changes in broadcast technology, as well as the devices used to record programs, such as disk recorders, prototype PCM digital recorders, and MH microphones, all of which will be examined in this paper.

As can be seen below, disk records have undergone drastic changes every quarter-century. Their history now spans 137 years, from the era of mechanically-recorded cylinders and SP records beginning in the late nineteenth century, through the era of electrically-recorded SP records, and the era of LP records and 45-RPM 17-cm (7-inch) EP records, to the era of 12-cm and 8-cm CDs.

First came the early days of records, when cylinder and disk-type records competed for dominance, then came the era of 78-rpm mechanically-recorded disk records that lasted for a quarter century until the end of WWI. During the next quarter-century period from the beginning of the Great Depression to the end of WWII, electrical recording and transmission systems were developed for broadcasting, and these developments were also applied to records, leading them in to the era of electrical recording. This era saw the introduction of disk recorders into broadcasting stations as recording machines for use in the production of radio programs. Attempts were made to perfect stereophonic records, and records with increased recording and playback time were also attempted. In the 1950s, after mono LP records had run their course, the real era of LP, EP, and stereo records began. The late 1960s were the golden age of stereo LP records, but technology was already being developed that would underpin the next generation of records, and recording sites began to use digital PCM recording when it was practically implemented for the first time in 1972.

More than 400 digitally-recorded albums were made during the next ten years, and the first digitally-recorded music recordings reached homes in 1982 in the form of CDs, a quarter-century after the era of stereo LPs had begun in earnest.

Though Japan pioneered some of the popular technologies shown in Fig. 2.1, there were some, such as the Filmon Sound Belt and the CD-4 (a 4-channel record), that failed to gain popularity. Much of early Japanese recording technology was an imitation of foreign technology developed by AT&T Bell Laboratories and other companies. Some Japanese technologies of particular note are pressure microphones (see 5.1.1) and CDs, which were jointly developed by Japanese and European companies, and PCM/digital recording machines/editing machines/mixing consoles (see 5.1.3 and 5.1.4), all of which became successful on an international scale after they were developed with the active support of musicians and others in the music business.

It is impossible to mention CDs without mentioning the fact that although more than 30 years have passed since their introduction, the quarter-century cycle of technical innovation in records has not continued, raising ever-increasing concerns about the lack of new developments.

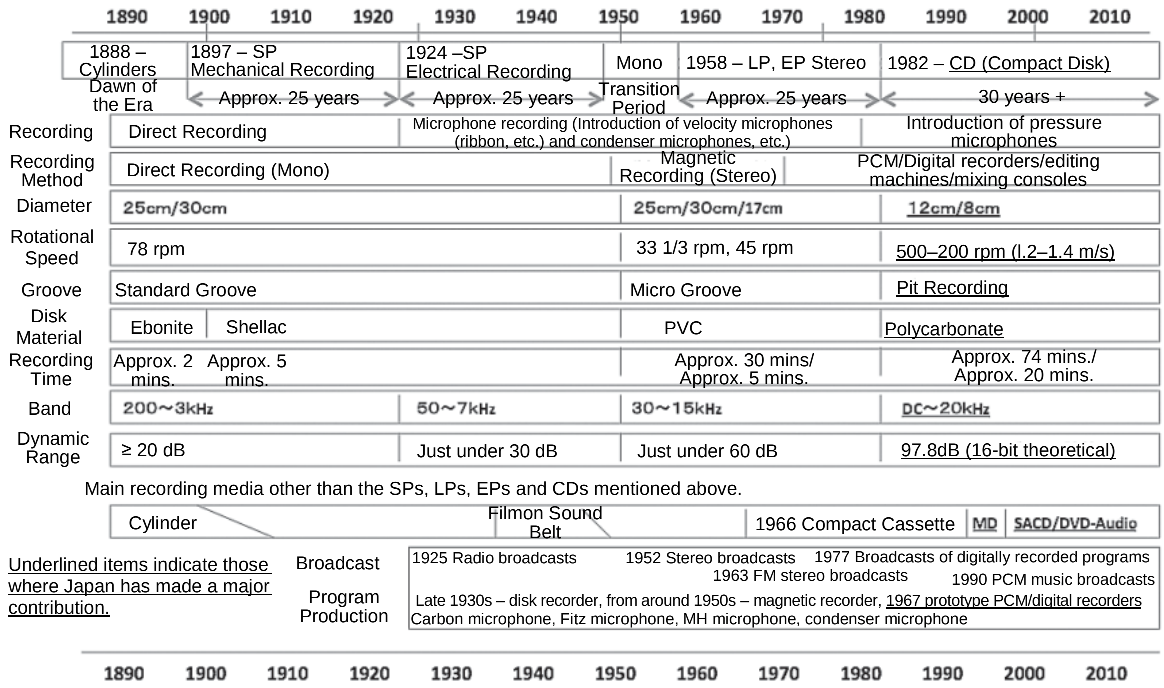


Fig. 2.1. Changes over the 137 year history of disk records

Although early records were invented and developed with the aim of making acoustic equipment that could record and reproduce sound on the same machine, with the diffusion of records via the new music distribution business, they came to be widely used in the early twentieth century as a means of distributing audio content.

The history of this content distribution medium has been the history of man's efforts to realize the efficient reproduction of high quality recordings, the history of acoustic improvements in playback quality, and the history of the trend toward increased playback times and three-dimensional (stereo) sound reproduction.

The first records faced difficulties due to pirated copies being made, as high-quality copies could be efficiently and easily duplicated. Piracy began quite early in Japan, where in 1912, in the last days of the Meiji period, pirated records were made and sold by buying and electroplating records to make stampers.

The twentieth century could be called the "century of recording" for the remarkable growth of its record industry, but it was also a century full of the fight against piracy. Additionally, it was a century full of want for the development of technology to prevent large-scale illegal distribution such as record piracy and overpressing, where extra records would be produced without permission. This paper will continue to report on the systematization of record technology, which underwent a revolution every quarter-century.

Bibliography

[1] *Fifty Years of Audio History*, Japan Audio Society, 1; The curtain rises on audio, 2; Toward the era of electrical gramophones, 4; The state of audio in the '30s (December 1986)

[2] *The History of Phonographs and Records* by Kei Ikeda, Recording Industry Association of Japan (October 1959)

3 The Birth of Acoustic (Mechanical) Disk Recording and Playback

3.1 Competition Between Disk and Cylinder Records

In the U.S. on December 6, 1877, Thomas Edison invented the cylinder phonograph, the first talking machine that could record and reproduce sound.

This experiment in recording used the nursery rhyme “Mary had a little lamb,” recited by Edison himself. The original recording has unfortunately been lost, but another recording of Edison reciting “Mary had a little lamb” from the 10th anniversary event of the phonograph has survived, and is available for people to listen to (Japan Audio Society 60th anniversary commemorative CD). This phonograph recorded and reproduced sound by pressing a needle attached to a diaphragm from a telephone transmitter onto a sheet of tin foil that was wrapped around a helically-grooved metal cylinder, with the initial intent of recording and reproducing sound in a self-contained unit.

In 1888, prompted by the increasing need for pre-recorded cylinder records for reproducing music, Edison released an improved version that recorded onto wax cylinders, and the Columbia Phonograph Company also began selling molded cylinder records in the following year. Edison continued to make improvements, releasing the Triumph Model A for household use in 1896 and the Standard Model B wax cylinder phonograph in 1901. Figure 3.1 shows a wax cylinder phonograph.

Fig. 3.1 Edison Standard Model B wax cylinder phonograph. Made in the U.S.A. in 1901 (Kanazawa Phonograph Museum).

On September 26, 1887, 10 years after Edison invented the phonograph, Emile Berliner invented the gramophone, which was first talking machine to use flat disks. He sang the children’s song “Twinkle, twinkle, little star” for its first recording test. One may still listen to this recording (Japan Audio Society 60th anniversary commemorative CD).

Figure 3.2 shows cylinder and disk records.

Fig. 3.2 Cylinder and disk records (SP type).

The gramophone recorded sound waves as lateral vibrations on wax-coated zinc disks, which were then etched with acid to make grooves. In this method, the master disk was electroplated to make stampers, which were then used to press appropriate materials, and it had the advantage of being able to produce large quantities of records. However, the grooves of disk records (which were usually laterally recorded) had a lower amplitude than those of cylinder records (which were usually vertically recorded), the etched sound grooves had a rougher surface, and additionally, the ebonite or vulcanized rubber substrate made a very disagreeable scratching noise, so disk records did not equal cylinder records in audio quality until the first half of the 1890s.

In 1897, Berliner improved the methods and material used to cut the wax master disks in order to obtain better sound quality.

The competition between cylinders and disks intensified as they entered the twentieth century. In 1902, the Columbia Gramophone Company (previously known as the Columbia Phonograph Company), which had been producing wax cylinder phonographs, began selling disk records, and in France in 1907, Pathé Records, which had been selling cylinders, began selling disk records employing the same vertically-cut recording method as cylinders.

In 1912, Edison released the "Diamond Disc" record, a high quality vertically-cut disk record that could record vertical high-amplitude signals by virtue of its thickness.

Figure 3.3 shows a Diamond Disc record.

Fig. 3.3 Edison's Diamond Disc record (Kanazawa Phonograph Museum)

Even Edison began to sell disk records, and when Decca portable gramophones came to be widely used by British soldiers after WWI broke out in 1914 to help them to pass the time at the bogged down front, making portable gramophones and disk records almost military supplies, the ease with which disk records were mass produced indicated the eventual triumph of disk records over cylinders.

Over in Japan, Edison wax cylinder phonographs were reportedly being imported and sold by Waichi Araki (owner of Araki Shoten) in Osaka in 1896.

Various accounts exist of Japan's first disk recordings, but it is generally accepted that Japanese music began to be recorded after recording equipment was transported by the Gramophone Company in England to Japan in 1901 so that they could record Japanese music. They worked with A. Cameron & Co in Kobe City and recorded 170 7-inch records and 110 10-inch records over the period of a month at the Hotel Metropole in Tsukiji, Tokyo. Recordings were made of *gagaku*, *tokiwazu*, *kiyomoto*, *nagauta*, and other forms of traditional Japanese music. The master disks were taken to England, where they were used to produce records that were then exported back to Japan. One such record is shown in Fig. 3.4.

Fig. 3.4 The first disk record recorded in Japan (Kanazawa Phonograph Museum).

Various American and European companies went to Japan to make recordings in the wake of the Gramophone Company in 1901. Columbia Phonograph recorded 900 single-sided disks with performances by the master musicians of the Meiji period in Japan during 1905 and 1906. Wega from Germany also made recordings in Japan in 1906, followed by the Victor Talking Machine Company in the U.S. in 1907. Wega is said to have produced over 3,000 SP records.

3.2 Japan's First Gramophones and Disk Records

Japan's first gramophones and disk records appeared in less than a decade after the turn of the twentieth century. The Japan-American Phonograph Manufacturing Company pressed the first Japanese-made disk records (10-inch single-sided records) in 1909, which were then sold through Nippon Chikuonki Shokai.

Figure 3.5 shows a single-sided SP record of the *nagauta* "Kuramayama" performed by Ijuro Yoshimura, which is a typical example of a Japanese-made record sold by Nippon Chikuonki Shokai at the end of the Meiji period (1912) under various labels such as Symphony and Nipponophone.

At the end of the Meiji period, shortly after Japanese-made disk records became available for sale, pirated records containing the same song as the ordinary record shown in Fig. 3.5 appeared on the market for lower prices. Figure 3.6 shows two such records.

It could be argued that these SP records are not pirate copies as they were not illegal under contemporary legislation, but the fact remains that the performers were never paid. This kind of piracy remained rampant until laws were enacted during the Taisho (1912–1926) period. Until then, expensive records that paid royalties to performers were targeted. Pirates would buy two single-sided records containing hit songs, then electroplate them to make molds, manufacture copies, glue on attractive authentic-looking labels, and sell them as double-sided records without paying any royalties.

Fig. 3.5 An SP disk record of the *nagauta* "Kuramayama" performed by Ijuro Yoshimura (Kanazawa Phonograph Museum).

Fig. 3.6 Am example of a pirated record from the Taisho period (a pirated version of the record shown in Fig. 3.5) (Kanazawa Phonograph Museum).

In 1910, shortly after disk records became available [in Japan], Japan Phonograph Trading (previously named The Japan-American Phonograph Manufacturing Co., Ltd., now Nippon Columbia Co., Ltd.) released the Nipponophone Model 25 (numbered after the retail price of 25 yen), the Nipponophone Model 32 *han* (32.5 yen), the Nipponophone Model 35 (35 yen), and the Nipponophone Model 50 (50 yen), which were the first record players to be made in Japan. Although they were called various names at the time, they eventually came to be known as *chiku'on-ki* (which translates as "sound-storing machines").

Fig. 3.7 The first record players to be made in Japan. The Nipponophone Model 35 with morning glory-shaped horn. (Kanazawa Phonograph Museum)

A Nipponophone Model 35 and Model 50 are shown in Fig. 3.7 and Fig. 3.8 respectively.

In 1911, Nippon Chikuonki Shokai released two models of record player that had an internal horn instead of a morning glory-shaped external horn. One of these, the Eufon, is known to have been favored by the famous author Kenji Miyazawa.

Fig. 3.8 The first record players to be made in Japan. The Nipponophone Model 50 with morning glory-shaped horn. (Kanazawa Phonograph Museum)

The exterior is shown in Fig. 3.9.

Fig. 3.9 A 1911 Eufon record player with internal horn as loved by author Kenji Miyazawa. The horn in located internally in the right front of the unit. (Kanazawa Phonograph Museum)

3.3 The Birth of Legendary Record-Playing Masterpieces

In the early twentieth century, cylinder and disk record players had exposed mechanisms and large horns that were frowned upon by housewives. Then in the U.S. in 1906, the Victor Talking Machine Company released the Victrola, which featured an internal horn concealed inside a wooden cabinet. This improvement in external appearance was accompanied by the introduction of acoustic improvements such as horns with longer equivalent lengths and the adoption of duralumin diaphragms in soundboxes (the section of a record player that turns vibrations from the needle into sound). These acoustic improvements continued into the late 1920s, and led to the advent of magnificent machines that were known as "grand gramophones" such as the HMV Model 194 (England, 1927–1930) and the Orthophonic Victrola Credenza (USA, 1925–1928), and other outstanding tabletop record players, portable record players, and record players with horns.

Technical masterpieces were made that were said to cost as much as a house. One such machine, the Victrola Credenza, is shown in Fig. 3.10.

Fig. 3.10 The famous Victrola Credenza VV8-30. Made in the U.S. during 1926 and 1927. (Kanazawa Phonograph Museum)

Bibliography

[1] *The History of Cylinder and Disk Record Players*, Kei Ikeda, published by the Music Disc Association of Japan, October 1934.
[2] *The Gift of Nostalgic Sound*, published by Kanazawa Phonograph Museum.
[3] Japan Audio Society 60th anniversary commemorative CD *Tracing the Path of Audio Century using Sound* and guide.
（JAS Journal 2013 Vol.53 No.2）

4 The Advent of Electrical Recording

4.1 The Age of Disk Records and their Rivalry with Radio

The early 1920s rode on a wave of prosperity following the end of World War I, and although the American record industry reached a peak in 1921, production volumes gradually began to decline. This was caused by the commencement of regular radio broadcasts, which began to captivate the average consumer.

Until 1924, all records had been recorded acoustically (and without electricity) since the invention of the phonograph in 1877. Artists performed in front of horns, setting the diaphragms at the end of the horns vibrating, which caused a cutting stylus to cut a wax disk. With this method of recording, the overall reproducible frequency range was limited to about 300–1,500 Hz, as lower-pitched sounds were limited by the cutoff frequency of the horn and higher-pitched sounds were limited by the resonant frequency of the diaphragm. Most records from this era are voice recordings, perhaps because this frequency band corresponds with the spectrum of the human voice, or because it was easy to pick up vocal music. Radio, on the other hand, had the advantage of high-quality sound, and was free to boot. In May 1924, H. C. Harrison, who was an engineer for AT&T’s primary supplier, the Western Electric Company, filed a patent for electrical recording. This widened the reproducible frequency range to 100–5,000 Hz, and also enabled the use of multiple microphones.

4.2 The Electric Gramophone Arrives

The range of reproducible frequencies widened with electrical recording, but electrical playback was desired, because electrically-recorded records had an unusual sound quality that emphasized scraping sounds when they were played back using soundboxes. Bell Laboratories researched electrical sound reproduction at the same time they were researching electrical recording. The first electric gramophone went on sale in 1926, and although this improved declining sales for a while, sales plummeted with the Wall Street crash in the fall of 1929. Then, to add insult to injury, the advent of talkies around 1930 caused sales to plummet even further. Figure 4.1 shows a Victrola RE-45, an early electric gramophone. This electric gramophone featured electrical sound reproduction and a radio receiver.

Fig. 4.1 Victrola RE-45 gramophone with integrated radio. This model was imported and sold by RCA from November 1929 for ¥1,075. (Kanazawa Phonograph Museum)

4.3 Broadcasting Stations Adopt Electric Disk Recorders

Edison had envisioned a self-contained machine to record and reproduce sound when he invented the phonograph, but as disk records became commonplace, he changed his standpoint and began developing technologies to mass-produce records for content distribution.

Broadcasters, who do not need mass-production technology, rapidly adopted machines that recorded and played back disks until magnetic disk recorders were introduced. The history of disk recorders in Japan up to that point is described in detail in *The Story of Disk Recorders* by Yoshiharu Abe [3].

In 1936, German broadcasting stations used many disk recorders made by *Telefunken Gesellschaft für drahtlose*

Telegraphie mbH in Germany in broadcasting events at the Berlin Olympics. This encouraged NHK to import the same machines in preparation for the 1940 Tokyo Olympics, but equipment gradually became more difficult to import, prompting the domestication of disk recorders. At the time, although there were steel tape and steel wire recorders, as well as optical sound-on-film recorders, only with disk recorders was it possible to play back sound onsite immediately after recording it, and sound quality was also of an acceptable level. Disk recorders were the mainstay of the broadcasting industry until they were displaced by magnetic tape recorders, beginning in Germany in 1942, then in the U.S. in 1947, and later in Japan about 1950.

In 1934, Koichi Tsubota (formerly a managing director of Nippon Columbia Co., Ltd.) established the Nippon Denki Onkyo Research Institute and began researching and developing electroacoustic devices. After five years of work, he completed a compact record cutter head that was compatible with German Telefunken recorders. The prototype cutter heads were installed on Telefunken disk recorders and tested repeatedly at NHK, and finally in 1938 a disk recorder was completed that surpassed the performance of the Telefunken machines. Then, Katsuma Tani (who later founded TEAC and acted as a representative director) became involved in efforts to improve its recording characteristic, and after improving both recording and noise characteristics, and reducing manufacturing costs, the first improved unit was completed in September 1939. This disk recorder was equipped with Tsubota's cutter head. This cutter head was later improved, and although it was small and lightweight for a general-purpose head, its frequency response was second to none at the time. Figure 4.2 shows this cutter head.

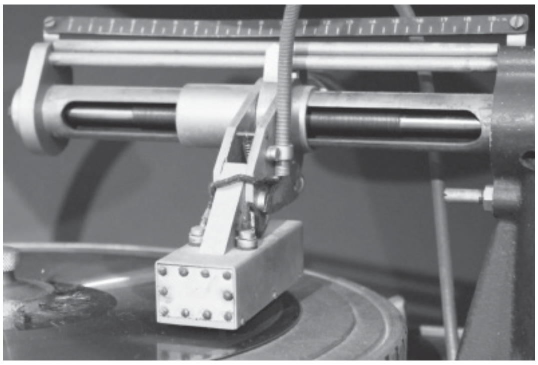


Fig. 4.2 Tsubota's general-purpose cutter head.

The characteristic of the cutter head is shown in Fig. 4.3.

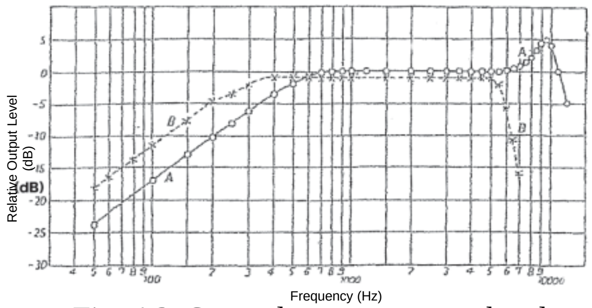


Fig. 4.3 General-purpose cutter head characteristic.
A. Nippon Denki Onkyo Research Institute cutter head characteristic.
B: Western Electric cutter head characteristic.

Tsubota's cutter head (Fig. 4.3 A) is comparable with the Western Electric cutter head, which was considered to be the best cutter head of its time (Fig. 4.3 B). As Fig. 4.3 shows, Tsubota's cutter head had a lighter oscillatory system, which raised its upper frequency limit from 5 kHz to 12 kHz – a dramatic increase. This high-performance cutter head was used to cut the Filmon Sound Belt (described below) and records containing the imperial edict at the end of the World War II.

The disks for this disk recorder used a long-lasting flammable cellulose with excellent recording characteristics, and were developed with the experienced assistance of Yutaka Tate (former chief engineer of JVC). On June 4, 1938, the Tokyo Nichi Nichi Shimbun (Tokyo Daily News) published an article covering Tsubota and Take's invention, titled "A Triumph for Recorded Broadcasts – Outstanding Japanese Invention – Completed by Two Students," reporting that the broadcasting stations who were panicking over the lack or foreign-made disk recorder were now set at ease. Unfortunately, the 1940 Tokyo Olympic Games were canceled due to the war.

4.3.1 The First Japanese Disk Recorders

The first Japanese disk recorder (the Denon TPR-14-C) is shown in Fig. 4.4, and its mechanism is shown in Fig. 4.5.

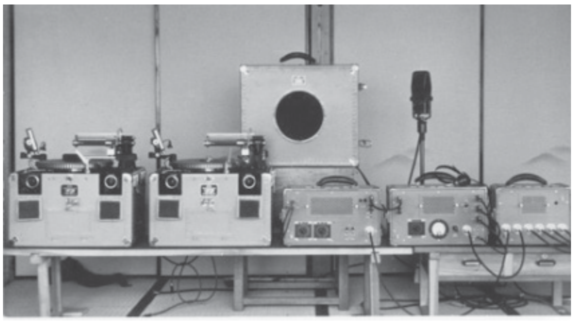


Fig. 4.4 Japan's first disk recorder, the Denon TPR-14-C.

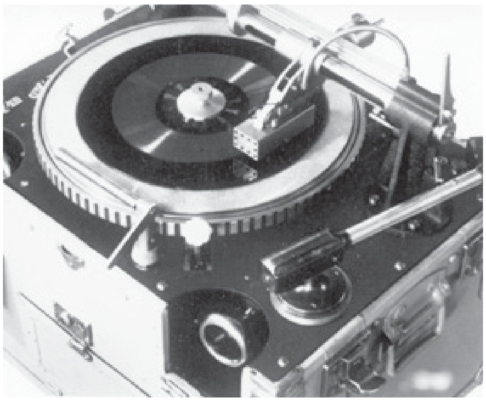


Fig. 4.5 Denon TPR-14-C disk recorder mechanism.

Although the disk recorder shown in Fig. 4.4 was described as "portable," the 94 kg of recording and playback equipment was combined with over 40 kg of recording amplifiers, playback amplifiers, speakers and power supplies, reaching a massive 135 kg.

The recording and playback mechanism shown in Fig. 4.5 had a 34-cm turntable driven by a 78 rpm low-speed synchronous motor, and could record 25-cm disks with 3 minutes of audio, but could alternate between two recording/playback mechanisms if longer recording was needed. Unlike analog records, the groove spiraled from the center to the outside edge, so that the swarf would not entangle the cutter head. A feed screw moved the cutter head like an engineering lathe to cut 90 grooves per inch. The cutter head used oil damping as an efficient mechanical filter, enabling it to cut the standard reference tone (1 kHz, 75 mm/sec) with 0.5 W. Constant-amplitude recording was used for frequencies under 800 Hz, and constant-velocity recording was used for frequencies over 800 Hz. The recording frequency characteristic was such that it could capture frequencies from 50 Hz to over 10,000 Hz. This meant that it had an extremely wide-band recording characteristic for its time. The steel stylus had very high mechanical impedance, enabling the recorder to cut wax or acetate disks without the recording characteristic changing due to the difference in hardness.

Records for this machine were made from high-purity aluminum disks with a diameter of 25 cm and a thickness of 1 mm, which were coated with a 0.3 mm-thick layer of nitrocellulose lacquer on both sites. Such records are usually called acetate disks or lacquer disks. Acetate disks could reportedly be played back a few dozen times if light tracking force was used; noise increased as wear accumulated, and after about 30 plays they had the same level of noise as a new (shellac) SP record.

Further improvements were made to the first Japanese disk recorder, resulting in a succession of models; the DS-15-A stationary recorder, the DS-14-B (installed at NHK's various main broadcasting stations), the DP-16-B (portable), the DP-16-C (stationary), the C-16-E (cutter), and the slim DP-16-K. These were used not only for broadcasting but also by the army and navy for various military applications.

One can image the difficulties experienced by the staff who had to carry two heavy DP-16-K recorders into the imperial court without attracting the attention of the military for the imperial edict on the termination of the war on August 15, 1945. These two recorders were used to make two records, which were taken to the broadcasting center in Uchisaiwai-cho (while still avoiding the scrutiny of the military) where the edict was broadcast. The same model of disk recorder and disk record can be viewed at the

NHK Museum of Broadcasting. The recording and playback machine is shown along with a microphone in Fig. 4.6, and the record used for the broadcast is shown in Fig. 4.7.

Fig. 4.6 A recording/playback machine of the same type as that used in the broadcasting of the imperial edict on the termination of the war on August 15, 1945 is shown along with a Tokyo Denki Type A microphone. (NHK Museum of Broadcasting)

Fig. 4.7 The record used to broadcast the imperial edict on the termination of the war on August 15, 1945.

Disk recorder continued to be in demand after the war, with the R-23-A portable disk recorder being adopted by NHK in 1948. The development of disk recorders with increased disk diameter (16 inches for longer recording/playback time), decreased rate of rotation and increased groove spacing (pitch) continued, and in 1950 the R-24-B stationary disk recorder was introduced, followed in 1952 by the first (and last) experimental Japanese LP disk recorder for broadcasting use was unveiled. Support was added to this recorder for variable pitch (adjusting the spacing between grooves according to a signal) in 1957, and it was used to cut LP and EP master disks at a number of Japanese record companies.

One notable disk recorder was a portable household model (the Denon RC-1), which was released in 1949. This disk recorder (shown in Fig. 4.8) was the subject of much discussion, but interest waned as cheap magnetic recorders became widespread, and it disappeared without becoming popular.

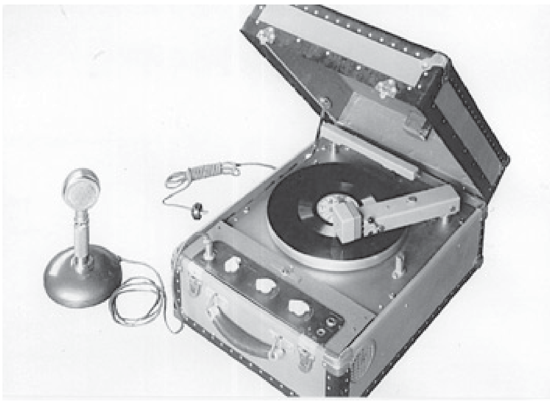


Fig. 4.8 The portable Denon RC-1 consumer model.

The ubiquity or EP and LP records meant that they were even used in radio programs, so disk recorders were popular with broadcasting stations even after the transition from disk recorders to magnetic recorders

4.3.2 The Downfall of Disk Recorders for Broadcasting and the Rise of Record Players

Japanese disk recorders, which did not see much progress during the war, remained in the world of 10- or 12-inch, 78-rpm SP records until the end of the war when occupying forces brought 16-inch, 33 1/3-rpm long playing disks to use in their broadcasts. Japanese disk recorder improved following this development, but the rise of magnetic recording was more prominent. Magnetic recorders using steel wire or steel tape already existed but were rare. Disk recorders remained unchallenged until magnetic tape recorders were developed by Masaru Ibuka and others.

Compared with magnetic tape recorders, the disk recorders of that period had the advantages of being easy to record and play back, and easy to cue, etc., but they were also extremely sensitive to external vibration, restricted to certain situations (use on level surfaces, etc.), not suited to making multi-channel parallel recordings with, restricted to a certain number of plays, difficult to erase, impossible to re-record, and, above all, heavy and expensive. At the time, although they were both similar in terms of size, weight, audio quality and reproducible frequency range, and play back directly after recording was not possible, the extreme sensitivity of disk recorders to external vibration during recording and playback, and their need for a level surface made them less convenient for broadcasters than magnetic recorders.

Record companies had to isolate their cutting machines (cutting lathes for disk records) from vibration caused by machinery such as air-conditioning equipment. They would also avoid external vibrations by installing their cutters on anti-vibration mounts. Recording would be stopped during even the smallest of earthquakes.

The susceptibility of disk recorders to vibration was one reason for broadcasting stations to replace them with magnetic recorders, which they began to do in the 1950s. Broadcasting stations eventually ceased to install disk recorders, but adoption of record players proceeded rapidly with the spread of LP and stereo records and the growth of commercial radio broadcasting.

The only exception was the magnetic disk recorder developed by NHK Science and Technology Research Laboratories in 1959, which combined the strengths of disk recorders and magnetic tape recorders but was unsuccessful because of shortcomings such as deteriorating sound quality towards the center of the disk. Even in this digital age, one cannot say that it is extremely easy to make recording machines that combine the advantages of disk recorders and magnetic recorders by using optical or magnetic disks.

The most important components of a disk recording and playback machine for broadcasting use are the turntable, the cartridge, and the pickup on the tonearm, but development languished in postwar Japan, and churning out replicas of products from the U.S. and other countries became the cornerstone of the postwar Japanese audio industry. Some turntables developed and sold by Tokyo Television Acoustic Company (a subsidiary of Yamaha Corporation) were adopted by broadcasting stations (Tokyo Television Acoustic Company later merged with Tokyo Electro Acoustic Company (TEAC). Tonearms were mostly imported from the U.S. and included models made by Clarkstan Corporation that were supported on steel balls, oil-damped tonearms made by Gray Manufacturing Company that rested on a single pivot filled with silicone oil (Fig. 4.9, Fig. 4.10), and tonearms made by Pickering and Company with articulated cartridge mounts. Broadcasters used Japanese-made copies of such tonearms.

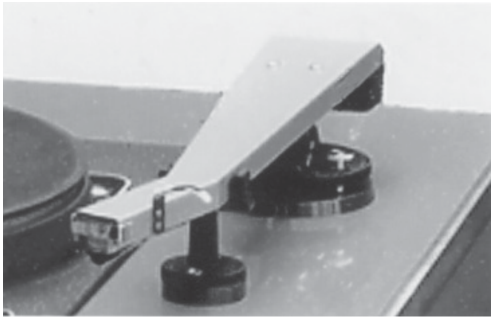


Fig. 4.9 Gray tonearm (made by Denon).

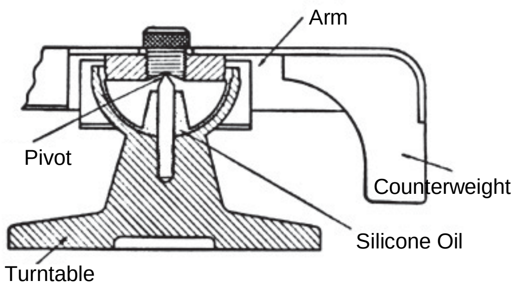


Fig. 4.10 Gray tonearm construction.

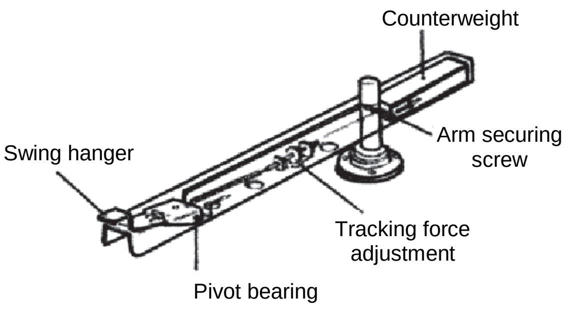


Fig. 4.11 Pickering tonearm

Clarkstan tonearms were eventually displaced by oil-damped tonearms for SP playback; Pickering tonearms were used for LP playback. Famous American cartridges, such as GE variable reluctance (VR) cartridges, Pickering balanced armature (BA) cartridges and Fairchild moving coil (MC) cartridges, were widely copied or improved. One such cartridge was the Denon PUC-3, which had an excellent characteristic but was so similar to the Fairchild product that some called it the *mane-child* (imitation-child). Only after this period of copying overseas products had passed did technology unique to Japan appear.

An outstanding example of that technology is the Denon DL-103 moving-coil stereo cartridge (Fig. 4.12 and Fig. 4.13), which was developed by Takeo Yamamoto (former vice president of Pioneer) together with Nitadori and others from NHK Science and Technology Research Laboratories (who introduced FM broadcasting in 1965) and Masuda and others at DENON.

Fig. 4.12 Japanese moving coil type stereo cartridge (Denon DL-103) used for domestic broadcasting.

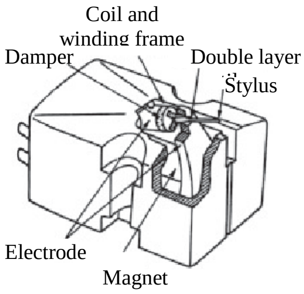


Fig. 4.13 Construction of a Denon DL-103 moving coil type stereo cartridge for domestic broadcasting.

Moving coil cartridges have essentially the same construction as high-performance cutter heads, and their moving parts are lighter than those of moving magnet cartridges, meaning that it is easy to obtain a flat frequency characteristic close to the input obtained using a cutter head. However, they had their disadvantages as well: for example, their complicated construction (the way the coils were wound and so on) prevented their needles from being changed easily.

Although the DL-103 cartridge was rated as having sound quality nearly as good as cutter head input (i.e. the output from the master tape), users could not replace the needle. This cartridge was put on the market for consumer use in 1969, and it is still in production. Though it has contributed to the expansion of the Japanese audio industry for half a century, its amazing sound quality continues to captivate audiophiles even today.

4.3.3 A Long-Playing Medium Born in Japan: the Filmon Sound Belt

When records were first beginning to be recognized as a medium for distributing recorded music and other audio, many of the people involved wished to be able to extend the playback time of SP records somehow. In 1937, the Filmon sound belt was introduced, invented by Shozo Konishi in response to this demand. The Filmon was a long-playing recording system unique to Japan with an extraordinarily long playback time of 36 minutes – unheard of in a household record.

Filmon – a contraction of “film” and “phone” – was a system for obtaining long playback time by attaching multiple grooves from disk records to an endless tape . The sound belt was a 13 m long endless loop of celluloid tape 35 mm wide and 0.3 mm thick, wrapped around 23 times, on which audio signals were recorded at a pitch of 80 grooves per inch and a linear velocity of 610 millimeters per second, to provide over 1,000 m of grooves on the tape. It recorded and reproduced audio signals using the same principles as disk records. This sound belt had up to 35 minutes of playback time. Filmon sound belts were manufactured in much the same was as disk records, and were cut with the same small wide-band cutter head developed by Tsubota for disk records (exterior shown in Fig. 4.2, characteristic shown in Fig. 4.3). Because the sound belts were longer with more surface area than disk records, they needed a collection of mass-production stages such as electroplating vats exceeding 3 meters in diameter and stages for making and pressing the enormous masters and attaching the sound belts.

Figure 4.14 shows a Filmon sound belt, and Fig. 4.15 shows the interior of a large Filmon sound belt press.

Fig. 4.14 Filmon sound belt, endless film (13 m long), case and instruction manual. (Kanazawa Phonograph Museum)

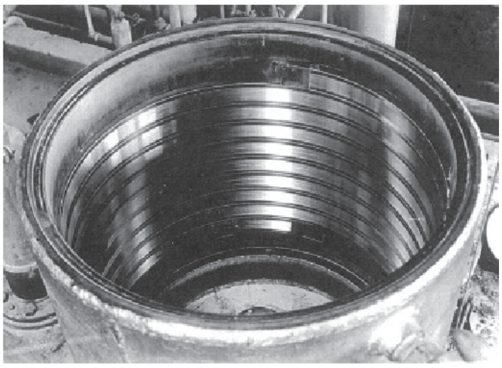


Fig. 4.15 Interior of a large Filmon sound belt press.

Tens of thousands of Filmon players were manufactured and sold to spread Japan's ambitious and unique long-playing sound recording and reproduction system. Meanwhile, musical content (mainly consisting of *rokyoku*, *nagauta*, and *kodan* performances by master artists) was being eagerly recorded in dedicated studios, with the number of recorded playback titles reportedly reaching 300. This would have equated to approximately 2,000 SP record titles at the time.

One cannot help but admire the passion of Tsubota and the others who worked as a company to develop a new sound reproduction system and to record titles for their new playback medium, all to realize long-playing records (thought to be only a dream at the time), and during the extremely difficult time as Japan teetered on the brink of WWII.

Figure 4.16 shows the Filmon player (Filmon FA100) than went on sale in 1937. This Filmon player could also be used to play 78 rpm records. It had an electric motor-driven turntable for disk records on the upper left-hand side, a mechanism for playing Filmon belts directly beneath it, and a small horn on the right, which was driven by a soundbox in the same way as phonograph horns were.

Fig. 4.16 Filmon FA100 tabletop Filmon/record player made by Nippon Filmon Co., Ltd. In 1937, it had a 13-meter-long film, and a maximum playing time of 36 minutes. (An identical model is in the Kanazawa Phonograph Museum)

The Filmon was an ambitious, new, uniquely Japanese medium for music. Not only were recorders and players made for it, but new content was developed and produced as well. Although this made the problems that the engineers faced all the more difficult, and although success was hard to come by, it ultimately fostered many of the brilliant engineers that supported the Japanese audio industry after the war.

Filmon grooves were cut using a universal cutter head developed by Koichi Tsubota (shown in Fig. 4.2; characteristic shown in Fig. 4.3) in a similar way to the disk recorders for broadcasting that were described in greater detail in 4.3.

Unfortunately, the Filmon factory was demolished in 1940 as the war intensified, only a few years after it was built, and the Filmon disappeared with it.

Katsuma Tani, who was Koichi Tsubota's foremost apprentice, penned a moving essay on the Filmon for the *JAS Journal* in 1980 titled “Reminiscences of the Filmon.” In it, he wrote: “Though the Japanese audio industry has without a doubt reached the highest standard in the world, behind the creation of this environment are the labors and hardships of those who went before us. For this, they deserve to be held in the highest esteem.”

4.3.4 Japanese Audio and Record Technology Pioneers

Let us now turn our attention to the pioneering engineers who contributed to the expansion of Japan’s audio and record industries after the war. It is widely known that Koichi Tsubota, founder of Denon in 1939, graduated from the same Department of Electrical Engineering (class of 1933) as Masaru Ibuka, founder of Tokyo Tsushin Kogyo (Tokyo Telecommunications Engineering Corporation, later Sony) and Shigeru Shima, former head of NHK Science and Technology Research Laboratories. The academic support of Takeshi Itow, who was a professor at the Faculty of Science and Engineering at their alma mater (Waseda University) should also not be overlooked. Ibuka developed a magnetic tape recorder in 1950, and being an engineer with a great interest with preschool education, he began music education projects, etc., for young children together with his good friend Soichiro Honda, Gen’ichi Kawakami (former representative director of Yamaha Corporation) and the composer Kuranosuke Hamaguchi. Ibuka was named a Person of Cultural Merit in 1989, and in 1992 he became the first industrialist to be awarded the Order of Culture. The first Japanese tape recorder (the Sony G Type), which was developed by Ibuka at Tokyo Telecommunications Engineering Corporation (now Sony), is shown in Fig. 4.17.

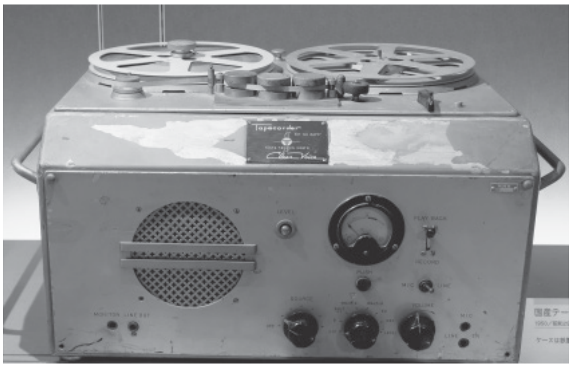


Fig. 4.17 The Sony G Type tape recorder, Japan’s first magnetic recorder – developed by Masaru Ibuka. (NHK Museum of Broadcasting)

One of the first buyers of this tape recorder was Toriro Miki, the father of broadcast writing in Japan, who was born a hundred years ago in 2014. Miki studied the violin under Anna Ono and the piano under Sealey Watanabe while studying at the Faculty of Law of Tokyo Imperial University (now known as the University of Tokyo). After graduating, he learned composition from Saburo Moroi, who was the father of composition in Japan. Miki began working in the radio industry in 1946, and took charge of the *Jodan Ongaku* (Joke Music) show in 1947 for the *Nichiyo Gorakuban* (Sunday entertainment program), which was said to have emptied the streets when it was being broadcast. He is widely known in Japan as the producer of that famous radio show, full of dry humor, in which he viciously satirized society, which even Shigeru Yoshida (then the Prime Minister of Japan) found to be greatly amusing. This show used Miki’s own personal tape recorders during production and recording, and thanks to this, we are still able to listen to his radio programs.

Naotake Hayashi, of the same generation as Tsubota, Ibuka, and Shima, who also studied at the University of Tokyo, should also not be overlooked. Hayashi, an innovative and persistent engineer who developed electroacoustic transducers, founded Showa Ko’on Kogyo Kabushiki Kaisha (Showa Photo-Acoustic Industries KK.) in 1938, and then went on to release a condenser microphone under the STAX brand in 1950. In 1952 he displayed the CP-20 condenser pickup system at the first Japanese Audio Fair, after which he then worked to develop electrostatic headphones and speakers, commercializing the world's first electrostatic headphones in 1960. A pair is shown in Fig. 4.18.

Fig. 4.18 STAX SR-1 electrostatic ear speakers (still in normal working order, but the frail delicate ear pads have been replaced).

In 1963, Showa Ko'on Kogyo Kabushiki Kaisha was renamed STAX Industries Ltd. STAX headphones were called "ear speakers," and even now, over 50 year later, the successors of the original SR-1 remain unassailable as some of the highest-quality headphones on the market. While these ear speakers have the advantage of having light diaphragms, they also require special amplifiers, which made them expensive and limited their popularity.

Tsubota, who developed the record cutter head that compared with American models, was a violinist and once was the concertmaster for his school orchestra, received the Medal of Honor with Purple Ribbon for "Achievements in contributing to the development of disk recording and reproduction technology" in 1967.

Takeshi Itow was a pupil of Saburo Moroi, father of Japanese composition (and teacher of Toriro Miki), and in addition to composing, wrote the two-volume classic *Onkyo Kogaku Genron* (*Acoustic Engineering Theory*) (Corona Publishing Co., Ltd.). Ibuka, Ito and literary critic Kenzo Nakajima were deeply involved in establishing the Japan Audio Society, which recently celebrated its 60th anniversary. They were also key members of the Japan section of the US-based Audio Engineering Society (AES) at the time of its establishment. Ito worked together with the Acoustical Society of Japan and the Institute of Electronics and Communication Engineers to encourage apprentices to participate in research activities at academic societies such as the Electro-Acoustic Research Society, freely providing guidance and support.

Tsubota's pupils included the aforementioned Katsuma Tani (founder of TEAC), and also Yasunori Mochida (former senior managing director of Nippon Gakki Co., Ltd, now Yamaha), Yoshiharu Abe (former director of TEAC), and many other talented individuals in the Japanese audio industry who appeared after the war. Takeo Yamamoto (former vice president of Pioneer Corporation), who developed cartridges at NHK Science and Technology Research Laboratories (STRL) for use in broadcasting, went to work at Pioneer where he played a central role in developing LaserDiscs. Heitaro Nakajima (former president of AIWA), who later supervised the CD development program at Sony, was Yamamoto's boss at NHK STRL.

Although the contributions of AT&T Bell Laboratories and other American companies to the popularization of audio have been significant (as this paper shows), the contributions of NTT Telecommunication Laboratories (called "Japan's Bell Labs" by some) should not be forgotten. One such contribution was from Tanetoshi Miura, former president of the Acoustical Society of Japan. After working at NTT Telecommunication Laboratories, Miura went to the Hitachi Central Research Laboratory, and then on to Tokyo Denki University where he conducted comprehensive research into orthostereophonic sound. In the late 1960s, Miura called attention to matters such as dummy head pickup and surround stereo, the importance of measuring head-related transfer function in Japanese people and the problem of unnatural lateralization in headphones, and the importance of digital recording as a future technology.

In 1943, the Recording Industry Association of Japan was established. Shozaburo Wada (former Imperial Japanese Navy Commander and former director of King Record Co., Ltd.) provided technical support for the association from the beginning, and was later made an advisor. Supporting the Recording Industry Association along with Wada were Kenjiro Takayanagi (former vice president of Victor Company of Japan, Ltd. (JVC)), a man known as the father of TV in Japan, Toshiya Inoue (former executive managing director of JVC), the aforementioned Koichi Tsubota (founder of Denon), Takeo Shiga (former managing director of Nippon Columbia Co., Ltd.) (who devised methods for cutting piezoelectric elements and invented the “cigar cartridge” which could produce a stereo signal from a pair of piezoelectric elements), and other distinguished Japanese engineers.

Kenjiro Takayanagi, who dreamed of *musen-enshi* (television), became an assistant professor at Hamamatsu Industrial High School (now the Faculty of Engineering at Shizuoka University) in 1924. He immersed himself in his beloved television development and in 1926 successfully scanned an image of the Japanese character “イ” with a Nipkow disk, transmitted it, and received it using a cathode ray tube. Figure 4.19 shows a reconstruction of the “イ” character on a display at the NHK Museum of Broadcasting.

Fig. 4.19 Kenjiro Takayanagi’s image transmission experiment. (NHK Museum of Broadcasting)

In 1937, Takayanagi moved to NHK STRL, where he perfected a TV that could display 441 scan lines at 30 frames per second, and in 1939 he successfully performed Japan’s first experimental television broadcast. He continued development with the aim of broadcasting the 1940 Tokyo Olympic Games, but they were canceled. After World War II, he moved to Victor Company of Japan Co., Ltd. (now JVC Kenwood Corporation), where he worked to improve televisions and train technicians. He was named a Person of Cultural Merit in 1980, and was awarded the Order of Culture in 1981.

Kenjiro Takayanagi taught Toshiya Inoue, who oversaw the development of audio technology. In 1958, Japan’s first 45/45 stereo records were unveiled and demonstrated at Victor Studio in Tsukiji, Tokyo, and they provided a cheerful topic of conversation for the Japanese people as they recovered from the war. This demonstration is said to have triggered the rapid expansion of the Japanese audio industry. Japan’s first stereo LP (Tchaikovsky's Piano Concerto No. 1, conducted by Fritz Reiner and featuring Emil Gilels on the piano with the Chicago Symphony Orchestra) (Victor Company of Japan SLS-2001) was released in August of the same year. In November, JVC’s second stereo LP and Nippon Columbia’s first were released.

Toshiya Inoue’s efforts were spectacular. He was involved in the development of VHS, which took the world by storm with VCRs and video cassettes; VHD disks, which competed with LaserDiscs; and the CD-4, which was a discrete 4-channel record. In 1979 he supervised the editing of the famous Japanese book *Records and Record Players.*

Shiga Takeo, who received an AES Silver Medal Award for his achievements (including the development of the “cigar cartridge”) (an award later awarded to Toshiya Inoue as well), was a pupil of Hideo Itokawa (formerly of Systems Research Institute), a man known as the father of Japanese space and rocket development, when the latter was conducting research into acoustics. Another pupil of Itokawa at the same time was Masahiko Morizono (former vice president of Sony). Itokawa graduated from the Department of Aeronautics at Tokyo Imperial University’s Faculty of Engineering in 1935 and joined Nakajima Aircraft Company, where he worked to design fighter aircraft such as the *Hayabusa.* In 1941, he became an assistant professor at Tokyo Imperial University’s Second Faculty of

Engineering in Chiba City, where the influence of the military was relatively weaker. In 1949, he obtained a degree for his thesis *Research concerning Methods of Measuring Minute Displacements due to Acoustic Impedance*. In 1954, Itokawa formed the Avionics and Supersonic Aerodynamics research group at the Institute of Industrial Science at the University of Tokyo. After the Pencil Rockets, the Baby Rockets, and the Kappa rockets were developed and test launched, he was involved with the Lambda rockets, the Mu rockets, and Japan's first satellite "Osumi."

Itokawa was a member of his high school music club, where he was deeply involved in music with cello performances and ballet etc.

Masahiko Morizono joined Tokyo Tsushin Kogyo (now Sony) in 1953, where he later was involved in developing systems for capturing TV programs. In 1991, he received an Emmy Award for Lifetime Achievement in Broadcast Technology.

Bibliography

[1] *Echoes of Bygone Times*, Kanazawa Phonograph Museum

[2] *A Century of Sound*, Japan Audio Society 60th Anniversary Commemorative CD and Pamphlet (JAS Journal 2013 Vol. 53, No. 2)

[3] *The Story of Disk Recorders* by Yoshiharu Abe, JAS Journal (Eight-part serial lasting from 2003 to 2004)

[4] *Fifty Years of Audio History*, Japan Audio Society, IX Broadcasting, 3.1 Recording machines for broadcasting (December 1986)

[5] *Prototype Stereo Amplifiers for Broadcasting Use* by Yamamoto and Nitori, NHK STRL News, Volume 8, No. 5 pp. 49–55 (May 1965)

[6] *Filmon Recording and Playback Machines*, Koichi Tsubota, *Musen to Jikken* (Radio and Experiments) magazine (December 1939)

[7] *Fifty Years of Audio History*, Japan Audio Society, II An Account of The Filmon from Disk Records (December 1986)

[8] *Reminiscences of the Filmon* by Katsuma Tani, JAS Journal (July 1980)

[9] Property of at Tsubouchi Memorial Theatre Museum, Waseda University

[10] Property of NHK Museum of Broadcasting

5 The Shift to Longer-Playing and Stereo Disk Records

5.1 Changes in Sound Pickup Technology Prior to the Advent of Digital Recording

Before electrical recording was developed in 1925, recordings were made mechanically without using electrical signals, a process known as “*rappa fukikomi*” (horn recording) in Japan.

With this acoustic recording method, performers would take turns to go and play in front of the horn that collected the sound.

In 1924, Western Electric developed a method of electrical recording, which Victor Talking Machine Company and American Columbia adopted in 1925, calling them “Orthophonic” and “Viva-tonal” respectively. In 1933, Victor Talking Machine Company changed the name “Orthophonic” to the familiar “High-fidelity Recording.” Victor Company of Japan began using this name in 1936. Nineteen twenty-five was the year that Japan first began radio broadcasts, and it was also the year that silent films really gave way to “talkies,” thanks to Western Electric’s development of the Movietone sound system. Western Electric also developed a speaker system for movie theaters that combined their legendary 555-W wideband field-coil compression driver with a large 1.5 m 15 A horn. This marvelous historic cinema sound system was even widely used throughout Japan in cinemas and public halls, etc., after the end of WWII.

The transition from acoustic recording (mechanical recording) to electrical recording came with an astounding improvement in the range of reproducible frequencies; although acoustic recording could capture from 300 Hz to 3 kHz (three octaves), electrical recording could capture from 100 Hz to 5 kHz (over five octaves). In 1944, during the war, full frequency range recording (ffrr) was announced. Developed by British Decca mainly for military use, it could capture from 30 Hz to 12 kHz.

Besides the attempts beginning in 1925 at high-fidelity sound reproduction, there was a desire to make audio recordings for movies and play them back in sync with the silent films. Although they wanted to record approximately ten minutes of audio on one record for one silent film, 12-inch (30 cm) 78-rpm SP records could not satisfy this requirement. Three options were reducing their rotational speed, taking time to increase their recording density, or increasing their diameter, but increasing their recording density would require reconsidering materials and manufacturing techniques, so the quickest and easiest option was chosen: 16-inch record with a rotational speed slow enough to record 10 minutes of audio. This meant selecting a rotational speed of from 33 to 40 rpm. To match the playback speed of the records with the movie projector, synchronous motors (which are synchronized with the frequency of the power supply) with simple gear ratios were needed. A rotational rate of 33 1/3 rpm can be obtained by using an 1,800-rpm synchronous motor running on American 60 Hz mains with a reduction ratio of 1:54, or by using a reduction ratio of 1:45 with a 50 Hz, 1,500-rpm synchronous motor. The 45-rpm disks released in 1949 could be played back with a 60 Hz, 1,800-rpm synchronous motor with a reduction ratio of 1:40; but not with a 50 Hz, 1,500-rpm synchronous motor with a reduction ratio of 1:45, as there was a small difference in speed.

Incidentally, Columbia Records worked on realizing microgroove recording (higher density with narrower grooves and closer groove spacing) to compete with RCA Victor. The combination of reducing rotational speed and using microgrooves eventually led to the LP, but improved materials, etc., were needed to reduce noise, delaying the LP’s commercialization until after WWII.

Three-dimensional sound also has a long history. In 1845, the German physiologist Ernst Heinrich Weber demonstrated the “binaural effect,” where people could determine the distance and direction of sound sources by using both ears. In 1928, a W. Bartlett Jones of Chicago filed a patent for a

"Method and Apparatus for Audition" that described a binaural recording system involving a dummy head. Dummy heads are still used today to solve sound lateralization problems with headphones. The basic patent for three dimensional sound reproduction from disk records is British Patent No. 394,325 "Improvements in and relating to Sound-transmission, Sound-recording and Sound-reproducing Systems," filed by EMI's Alan Blumlein in 1931, but it was not until 1957 that this 45/45 system was applied commercially by Westrex Corporation, a division of Litton Industries which acquired it from Western Electric. Although Decca soon followed with stereo records cut with a vertical-lateral technique, ultimately it was the 45/45 system that became the most widely used.

On April 27, 1933, Bell Laboratories, who had been researching high-fidelity sound reproduction and three-dimensional sound since the beginning of 1920, conducted a three-dimensional sound reproduction experiment over telephone connections between Washington and Philadelphia. The Philadelphia Orchestra was conducted by Alexander Smallens while Dr. Leopold Stokowski in Washington manipulated the controls. This experiment was overseen by Dr. Harvey Fletcher, Bell Laboratories' Director of Acoustical Research, who later laid out the conditions for high-fidelity reproduction (Table 5.1).

Table 5.1 Conditions for high-fidelity reproduction by Bell Lab's Dr. Fletcher from the 1933 experiment.

(1)	Transmitted noise is quieter than the noise pollution in the room where the audio is reproduced;
(2)	Peak dynamic range of 100 dB SPL is required to reproduce symphonies;
(3)	Distortion caused by nonlinear transmission characteristics is too small to distinguish;
(4)	Frequency range must exceed the range of human hearing;
(5)	Positioning is well defined.

True stereo (orthostereophonic) was the result of these experiments 80 years ago. If Dr. Fletcher might appear before us, then we should worry that he might urge us forward by telling us what little progress we have since made.

Individual recording technologies will be discussed in more detail below.

5.1.1 Microphones

Microphones are transducers that convert sound into electricity. First applied to practical use in telephones, they were later developed for broadcasting. One of the earliest was a carbon button microphone in the mouthpiece of the 323 W telephone, introduced by Western Electric in 1920. One of these was used in Japan's March 1, 1925 experimental radio broadcast. A regular broadcast on March 22 used a Western Electric Model 373 double button microphone. As these microphones did not have a sealed construction, they had a defect where noise increased as moisture entered through gaps and deteriorated the mobility of the carbon granules. Various measures were taken to ensure the mobility of the granules to solve this. Initially, the carbon granules would solidify during use, and they would be periodically taken out and mixed to loosen them. To solve this, the balanced armature, which is popular in modern earphones, was introduced. This method increased the mobility of the carbon granules by setting up a barrier inside the microphone, and also improved microphone bass characteristics.

Later, in the 1930s, Japan began importing high-power transmitters from Marconi's Wireless Telegraph Company in Britain and then Telefunken in Germany to increase the power of Japanese radio broadcasting stations. Included with these transmitters were Reisz microphones, which had a sealed construction using carbon granules and marble. Some Reisz microphones were later developed in Japan; notably the MH microphone, which was developed by and named after Noboru Marumo and Kichibe Hoshi at NHK Science and Technology Research Laboratories in 1932. The MH microphone (Fig. 5.1) used a hollowed marble block filled with carbon granules, and had a mica diaphragm and a carbon electrode attached to the front, with a filling port for the carbon granules on the side.

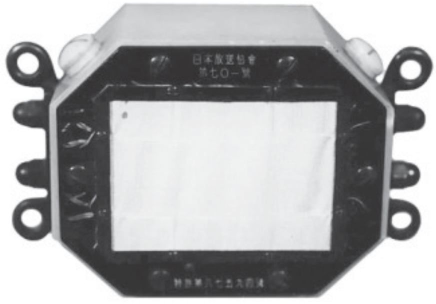


Fig. 5.1 The MH microphone, a Japanese-made Reisz microphone. (NHK Museum of Broadcasting)

Information regarding this is scarce, probably because know-how regarding the carbon granules was kept secret at the time. When this microphone was left for extended periods (around 10 hours), the carbon granules would gradually settle, and excessive current would flow because of the decreased internal resistance, causing sensitivity to drop. For this reason, before use it would be held upside down and gently tapped to loosen the carbon granules, and only used after the current had returned to the correct level.

Reisz microphones used marble, but microphones using *Seto-yaki* ceramic instead of marble appeared after WWII, which were used with great success in megaphones used in the general elections for the Upper and Lower House under the new constitution. Their development was handled by Shiro Kato (former auditor for Aiphone Co. Ltd.), and they were commercialized under the guidance of Yoshiro Tomita (who formerly worked at NHK STRL and JVC).

Ribbon microphones and other velocity microphones appeared in 1933, with microphones such as the Altec 639B, the RCA 44-BX and the RCA 77-DX being the main units used in recording studios right through until after the war.

The Altec 639B, called the “iron mask” for its appearance, is shown in Fig. 5.2. This microphone was not a simple ribbon microphone but a hybrid that including both moving-coil and ribbon elements.

Fig. 5.2 Altec 639B microphone. (Nippon Columbia Co., Ltd.)

The RCA 44-BX, which became famous as versatile multi-purpose ribbon microphone, is shown in Fig. 5.3.

Fig. 5.3 RCA 44-BX microphone. (Nippon Columbia Co., Ltd.)

When ribbon microphones came into frequent use in Japan, the demand for their loose ribbons to be repaired in Japan soon appeared. This state of affairs prompted Tokyo Denki (Tokyo Electric Company, now Toshiba) to produce the “Type A,” which in 1937 was the first Japanese ribbon velocity microphone. This microphone, which was also used to record the imperial edict at the end of the war and can be seen to the right of the disk recorder in Fig. 4.6, is very similar in appearance to the RCA 44-BX shown in Fig. 5.3. During the period of reconstruction after the war, Tokyo Denki developed a series of ribbon velocity microphones such as the Type B, the Type E, the Type F, etc., mostly with Masao Shimabara (formerly of Tokyo Shibaura Electric Co., Ltd.).

As these velocity microphones happened to have a tone suited to *enka* (Japanese ballads) singers and traditional Japanese musical instruments, they were widely used to record many of Japan's post-war hit songs. Another velocity microphone, the famous RCA 77-DX, was used to record hit songs by Hibari Misora and others who graced the period immediately after the war, and it is sometimes used in recording even to this day.

The RCA 77-DX is shown from the front in Fig. 5.4, and from the back in Fig. 5.5. As can be seen in Fig. 5.5, the microphone had a directional pattern selector switch on the back. A label stating that it is "exclusively for traditional Japanese music" is attached, indicating that it was used to record many famous Japanese recordings.

Fig. 5.4 RCA 77-DX, front. (Nippon Columbia Co., Ltd.)

Fig. 5.5 RCA 77-DX, back. (Nippon Columbia Co., Ltd.)

With regard to moving-coil microphones and headphones, the foundations of which were laid by Bell Laboratories, the Western Electric No. 618A was released in the early 1940s, and then introduced to Japan by their business partner NEC.

Despite their good characteristics, prior to the war it was known that condenser microphones had problems with unstable operation caused by electrical discharges, etc., and it was not until after the war that these problems were solved. It was then that condenser microphones such as the Telefunken M49 (Fig. 5.6) appeared.

Fig. 5.6 Telefunken M49 condenser microphone. (Nippon Columbia Co., Ltd.)

With regard to Japanese condenser microphones for broadcasting stations, in 1953 the CU-1 unidirectional microphone (Fig. 5.7) was developed after being devised by NHK STRL.

Fig. 5.7 CU-1 condenser microphone for broadcasting stations.

The development of this microphone was said to have been fraught with difficulties, including the fact that studios at that time were brightly lit by incandescent lights and the radiant heat caused the diaphragms of microphones to lose their tension, while a lack of insulation caused noise.

In 1955, Tokyo Tsushin Kogyo (now Sony) produced the C-37A microphone, which was modelled after the CU-1. The C-37A had four small openings at the back of the single diaphragm of the capsule, enabling omnidirectional or unidirectional modes to be selected by opening and closing a shutter (internal screw).

The sound of this microphone was criticized by some for its lack of brilliance in picking up remote voices, but it had an established reputation for picking up stringed instruments such as the *koto* and the *shamisen*, so it made a place for itself in Japanese broadcasting stations. The C-37A later came to be widely used not only in Japan but also overseas in the studios of private broadcasting stations and recording companies.

Many new microphones appeared during the 1960s and 70s, such as multidirectional microphones, which can clearly pick up multiple sound sources; close-talking microphones, which are indispensable for television broadcasting; mid-side (MS) stereo microphones, which can pick up stereo sound with a single microphone; dummy head microphones, which do not produce the lateralization that can be heard with headphones that normal recording produces; and other kinds of microphones for various purposes.

Outstanding examples include the following:

The Neumann SM 69 stereo condenser microphone (Fig. 5.8), which could pick up stereo audio on its own, was widely used in concert halls, etc.

Fig. 5.8 Neumann (Germany) SM 69 stereo condenser microphone. (Nippon Columbia Co., Ltd.)

Neumann also developed the KU100 dummy head microphone (Fig. 5.9).

Fig. 5.9 Neumann KU 100 dummy head microphone. (Nippon Columbia Co., Ltd.)

Dr. Karl Schoeps, who developed many products at Schoeps GmbH, designed microphones with excellent acoustic qualities, and introduced innovations such as microphones with low optical reflectivity that would not appear conspicuous in television programs (Fig. 5.10).

Fig. 5.10 Two Schoeps (Germany) condenser microphones with different reflectivity (Nippon Columbia Co., Ltd.).

In 1924, Mototaro Eguchi (formerly of the Technical Research Institute of the Japanese Navy) discovered the electret, which is a phenomenon where an electric charge remains after polymer materials are cooled and solidified under a strong electric field. The researchers at the Technical Research Institute of the Japanese Navy are now thought of as pioneers in the realm of electronics, having conducted groundbreaking research in fields such as materials for crystal microphones. Some are now connected with Rion Co., Ltd. Although the patents concerning Eguchi’s electret phenomena covered nearly all applications regarding electroacoustic transducers, nearly 40 years passed since its discovery before the electric microphone was invented at Western Electric in 1962. In 1968, Sony developed an electric microphone as small as the end of a person's little finger. They then built it into their TC-1160 cassette player, which they released on December 1 of the same year, blazing a trail for multi-purpose microphones in devices other than telephones.

Microphones must pick up sound from very low pressures to high pressures across the entire range of audible frequencies without distortion and with a sufficiently low residual noise level. This means working to improve their sound qualities and characteristics, but in spite of the efforts of many pioneers, an ideal microphone still does not exist that can evenly pick up sound waves from any direction and from any position in the sound field. Even omnidirectional microphones (which are considered nearly ideal) may have a far-from-ideal characteristic at the back and the sides, though they may have a relatively flat frontal characteristic. Directional microphones (which have more problems) have a relatively flat characteristic in one direction but usually have a poor base response. It is desirable for directional microphone to have a warm, flat frequency response even with lower levels, but in reality they usually sound thin from any angle other than the diaphragm axis.

Making omnidirectional microphones pick up sound properly from all angles is also difficult. Although microphones that can evenly collect both direct sound (arriving directly from musical instruments) and reflected sound (arriving after undergoing reflection) are desirable, and although many microphones can evenly collect direct sound, most microphones can only collect reflected sound and other indirect sound as garbled noise.

In 1970, Nippon Columbia joined forces with the Danish company Brüel & Kjær Sound and Vibration Measurement A/S (B&K) to re-evaluate microphones with great recording characteristics. Takeaki Anazawa (former director of Nippon Columbia Co., Ltd.; now director of the Japan Audio Society) participated as a representative of Nippon Columbia. The famous Danish recording engineer Peter Willemoës acted as an intermediary for the two companies.

At the time, microphones for measurement and microphones for recording belonged to completely different worlds. There was hardly any communication between engineers, both parties used different connectors and cables, and they even had completely different ways of powering their microphones. Measurement microphones needed to always have a flat frequency characteristic over a wide range of temperatures, but recording microphones needed to be easy to use, have a distinctive sound quality, and have low noise.

The purpose of Anazawa *et al.*'s review was to cultivate the strengths of both types of microphone, and they attempted to take advantage of the flat characteristic of measurement microphones, the low noise of recording microphones, easy-to-use connectors and cables, and power supplies.

As the 1970s drew to a close, B&K trial manufactured field-type recording microphones that could evenly capture direct sound, and pressure microphones for recording that could evenly record indirect sound in the recording field, and Nippon Columbia's European experiments in digital recording began. The characteristics of these trial microphones are shown in Fig. 5.11.

Although both types of microphone are omnidirectional, they both have different characteristics. The field-type microphone only has a flat frequency characteristic on the diaphragm axis, with reduced treble at other angles. On the other hand, with the pressure microphone, treble is increased on the diaphragm axis, with a flat frequency characteristic being obtained at an 80-degree angle, and although the characteristic changes at angles off the diaphragm axis, a flat characteristic is obtained as a whole. A flat characteristic can be obtained for both direct and indirect sound with a pressure microphone if the diaphragm axis is angled at 80 degrees to the music.

This joint investigation and trial manufacture with the Danish company B&K was carried out with the coming era of digital recording media such as the CD in mind, and many recordings were introduced that were captured by these trial microphones in 1982 when the CD was introduced. A large number of these microphones were used in February 1985 in relay broadcasting the performance at the reopening of the Semperoper in Dresden (on the 40th anniversary of its bombing) to not only West Germany, but also the whole world. Opera is a rather plain genre, but this did not stop the relay broadcast from gaining an extraordinary rating of 19% in West Germany. The successors of these microphones are still being manufactured today, over 30 years since the adoption of the first prototypes, and they are still indispensable where sound quality is important.

Direct sound from musical instruments on a stage is not difficult to capture with a flat frequency characteristic. By comparison, indirect sound reflected by the surrounding walls is difficult to capture with a flat frequency characteristic, and in many cases it sounds distant and lacks focus. Direct sound microphones had always been placed closer to instruments to avoid this problem, but this creates a vicious circle where indirect sound sounds even further away (relatively) as a result. This vicious circle was solved by the introduction of pressure microphones, which can capture indirect sound with a flat frequency characteristic.

5.1.2 Sound Capture and Sound Field Reproduction

Sound capture is called pickup, and in mechanical sound capture (acoustic recording), singers and musicians would stand in front of the horn and play in quick succession. Later, with the introduction of electrical recording, multiple microphones came to be used.

Three-channel stereo, which placed the solo singer (who required adjustment) in the center and the accompanying band in the left and right speakers, became common in the American pop music recording scene in the 1950s, where it was sarcastically called “three-channel monaural.” Three-track recorders were introduced for this, and the number of tracks increased continuously until it reached 16 in the latter half of the 1960s. Later, 24- and 32-track recorders appeared, and some recordings even used multiple 24- or 32- track recorders. The number of microphones used increased with the number of tracks. When reproducing sound in stereo, the locations of the left and right speakers are the actual sound sources where the actual speakers are, making localization especially precise. The center, where the sound image is located between the left and right speakers, is not as precisely localized as it would be with a real sound source, but it is located especially precisely among virtual sound sources. As this precise positioning is desirable for solo singers in pop music and announcers in radio and TV programs, the tendency to emphasize the center was widespread from the early days of stereo, and three-channel stereo appeared for the same reason.

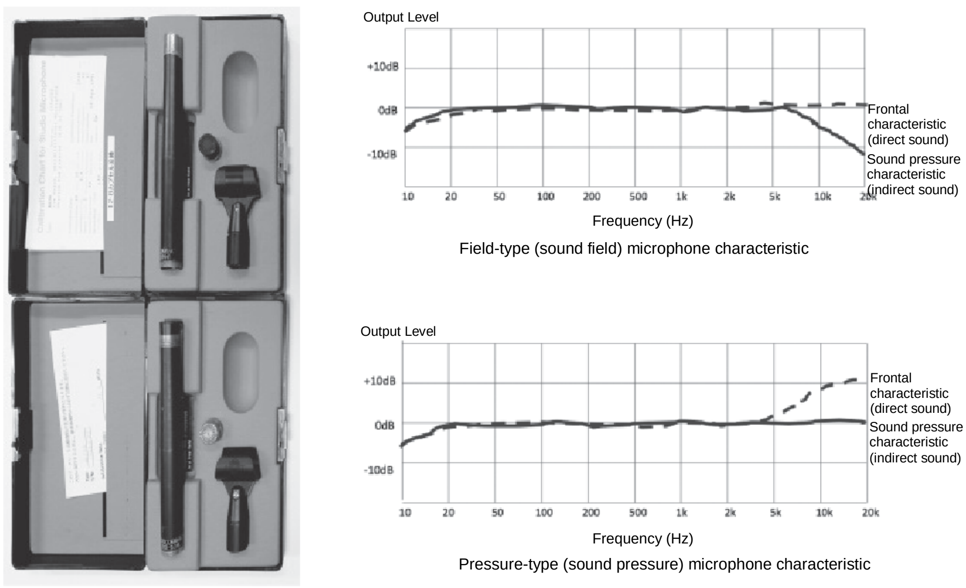


Fig. 5.11 B&K (Denmark) prototype field-type and pressure-type microphones and associated frequency characteristics. (Nippon Columbia Co., Ltd.)

On the other hand, with classical music and traditional Japanese music, etc., even when several microphones are used to pick up sound in concert halls and other spaces full of relative reverberation, there is a great deal of sound leakage between the microphones, making results similar to those obtainable with multiple microphones in pop music recording difficult to achieve. Moreover, volume balance often had to be maintained between all the instruments in the hall by repeated practice. Care was needed in such cases to reproduce the atmosphere of the hall. Recording engineers disliked making any particular location more distinct than any other, desiring positioning unlike the three-channel mono used for pop music, and captured sound with the aim of recording stereo, but not three-channel stereo.

The methods of using the actual microphones in the pickup methods described above can be broadly classified into multi-microphone pickup (which uses a large number of microphones) and one-point pickup (which uses a small number of microphones). Overall, multi-microphone pickup is good when recording in a sound space such as a studio that lacks sound volume balance, and usually microphones are placed in close proximity to each instrument to make later adjustment possible. Then the output of each microphone is collected at a mixing console, and the sound is balanced in post-production. On the other hand, one-point pickup is carried out on the premise that the sound among the instruments is already balanced, so the microphones are not placed nearer to the musical instruments than is necessary. In cases where the sound is balanced in the studio or hall where the performances are held, it suffices to place a microphone that can capture direct and indirect sound in the best location.

Generally, if multiple microphones are placed near a sound source and their output mixed electrically, a comb filter is created, making the sound remarkably muddy. To avoid this muddiness, it is important to take care to ensure that the same sound does not spill over to other microphones. Multi-microphone pickup therefore uses microphones placed near the musical instruments to prevent spill. As microphones are placed in close proximity to instruments in such cases, they need to be able to handle large inputs without distorting.

The transition from mono reproduction to stereo reproduction brought many changes and captivated many people. The orthostereophonic system appeared, which, aiming to achieve true stereo, opened up possibilities for reproducing the spread of sound sources using sound field data on the playback side. In the early days of stereo, various attempts were made to convey the atmosphere of the original sound field (including the sound fields of concert halls or music clubs, or sound fields synthesized in studios during production). Later referred to as sound field reproduction, these attempts can be broadly classified in the three categories shown below.

(1) Sound Field Reproduction by Processing on the Playback Side

This is a method where recording is carried out in the same way as for normal 2-channel stereo, and the recording is processed at the time of playback to recreate a sound field. In one form of early stereo called ensemble stereo, there was a spread control knob called a DSC that adjusted the spread of the sound image to the left and the right. This calculated the sum and the difference of the left and right signals, adjusted the levels of the sum and the difference, and returned the signals to the left and right channels. Emphasizing the sum causes the left-right spread to narrow, and emphasizing the difference causes the spread to increase. Listeners rotated this knob to adjust the spread to an optimal setting for the acoustic properties of the room, the positioning of the ensemble stereo, and the listener's personal preference, before sitting back and listening to the reproduced sound. Generally, the spread of the sound image varies due to the correlation between the sound arriving at the listener's left and right ears, and it is possible to quantitatively measure it by the cross-correlation function between the ears. This method of evaluation is also used to evaluate architectural acoustics.

In 1961, a stereo with a spring reverberation unit was released. By using this stereo, reverberation (reverb) could be added at home. The second half of 1970s saw the introduction of digital signal processors (DSPs) in sound reproduction systems with reverb functions, making it possible to add electronic reverb (which was called "sound field generation" at the time).

This kind of reverb function was limited by the fact that the reverb that was added that was different from the optimal reverb selected and introduced for the program source that was used as the subject of pickup and recording. It also had the drawback of being unable to decrease the original reverb, only increase it.

In 2010, revolutionary sound field reproduction technologies that broke down the above limitations appeared, and the continued development of the old yet new topic of sound field reproduction is anticipated. This reverb control technology was invented by Kinoshita and Nakatani *et al.* of NTT Communication Science Laboratories . This invention is based on the fact that reverberations are repetitions of sound that have already arrived, and it analyses the audio input and decomposes the sound into direct sound and reverberant sound. If they can be separated, then the proportion of each can be adjusted and used to construct a signal for playback. This method makes it possible to reduce the amount of direct sound or reverberant sound added to the sound in the original program source, and it also makes reducing the amount of reverb contained in the original possible.

(2) Sound Field Reproduction Using Special Pickup Methods

Methods such as dummy head recording fall into this category and although 2-channel stereo is used, pickup is carried out with the aim of reproducing the sound in a specific reproduction environment, so these methods are for sound field reproduction in specific reproduction environments. Although dummy head recording has been used for a long time as a method of achieving sound field reproduction, its spread was hindered by its lack of compatibility with speaker reproduction and the difficulty of adapting existing production techniques for music program sources that were developed with speaker reproduction in mind. These problems have persisted since the beginning, and they remain as yet unsolved, even today.

On the other hand, the spread of portable audio has caused the number of people (especially young people) who enjoy audio through headphones or earphones to increase. Ironically, because music recorded on dummy heads is nearly nonexistent on the market, these headphone and earphone users are still listening to recordings made for speaker reproduction, and they are enjoying music without being able to localize sound images in front of them (called lateralization).

(3) Sound Field Reproduction Using More Than Two Channels

This category covers methods for reproducing sound fields using two or more channels, such as 4-channel and 5.1-channel transmission systems.

In the latter half of the 1960s, the entire audio world was fascinated with 4-channel audio, but the key users were indifferent. It was amidst this state of affairs that in 1969 Tanetoshi Miura of Hitachi Central Research Laboratory (formerly president of the Acoustical Society of Japan) conducted psychological evaluation experiments into 4-channel audio in cooperation with Nippon Columbia (which was just about to go under the umbrella of the Hitachi Group) using a diverse assortment of bands. Although some variation was found to be caused by speaker placement, pickup methods, and music genre, the results were extremely disappointing: regardless of how much effort was spent to make 2-channel stereo into 4-channel, the effect was less then half of that obtained by making mono into 2-channel stereo, and substituting 4-channel for 6-channel or 8-channel resulted in only quarter of the improvement obtained by going from mono to stereo. The results showed that even with four channels, it was better to place the speakers to the sides rather than to the back. There are two types of sound field reproduction: passive sound field reproduction that can recreate the atmosphere of a hall as described in 1) above, and surround sound, a more active method of sound field reproduction which places the sound image on all sides.

In early the early 1970s, 4-channel records that could make surround sound practical became a popular topic, beginning with a matrix format 4-channel record announced by Sansui Electric Co., Ltd. in June 1970. This matrix format 4-channel record used a normal band music signal created by a matrix encoder before cutting, which was then used to cut the disk. Because the signals were passed through a matrix decoder during playback, despite the fact that the cutting itself had a large vertical component in the groove, the grooves were not very different from those found on ordinary records.

In September 1970, JVC unveiled a discrete 4-channel record called the CD-4, which is described in more detail in section 5.4. Then on June 25 of the following year, JVC released “Wonderful CD-4 Sound” (CD4B-5001), the world’s first discrete 4-channel record (Fig. 5.12).

Fig. 5.12 The label of “Wonderful CD-4 Sound,” the world’s first discrete 4-channel record.

Although many interesting technical endeavors were attempted with the CD-4, it unfortunately failed to gain popularity. The biggest reason for this failure is thought to have been the quality of the content itself. Few great pieces of music have been composed for surround sound that can localize in all directions. One was “Requiem,” composed by the French composer Hector Berlioz, which premiered at the Hôtel des Invalides in Paris, but no other great pieces followed, and there were very few pop masterpieces.

In cinema on the other hand, there are works which take the location and movement of the sound image into consideration during production and playing these using 5.1 channel or 7.1 channel surround sound is effective in movie theaters or in the home.

5.1.3 Methods of Recording

Around the time of the Second World War, audio from performances in studios and halls would be input directly into record cutting machines without modification – a method called direct cutting (also referred to as direct-to-disk recording). However, as this method made editing or re-recording (cutting another master disk) to correct the performance and adding various other effects difficult, after the end of the war, from the 1950s onward, magnetic recorders came to be introduced. Magnetic recorders only had enough tracks for monaural recording at first, and two tracks later became popular as they entered the era of stereo, but 3-track recorders quickly appeared on the market with the arrival of the era of American pop music to facilitate the adjustment of songs placed in the center. Later, as “British sound” became came into fashion in the latter half of the 1960s, the number of tracks gradually increased.

The number of tracks for magnetic recorders during that period could be broadly classified into two categories: 2-track/4-track recording and 8-track/16-track/24-track/32-track multi-track recording. The former mainly used a small number of microphones for pickup, and the latter mainly used multi-microphone pickup. An analogue 2-track recorder is shown in Fig. 5.13.

Fig. 5.13 Studer (Switzerland) A820 2-track analog recorder. (Nippon Columbia Co., Ltd.)

A similar analog 2-track recorder for cutting that could produce advanced signals to control groove pitch and depth is shown in Fig. 5.14.

Fig. 5.14 Studer A80 2-track reproducer for cutting. (Nippon Columbia Co., Ltd.)

This reproducer was equipped with bypass and extension rollers and an additional playback head to obtain the advanced signals necessary for controlling groove depth and pitch, and it selected an optimal advance signal depending on the speed of the tape and the rotational rate of the disk, which it then used to regulate the cutting machine.

Figure 5.15 shows a Studer A827 24-track analog recorder from Switzerland.

Fig. 5.15 Studer A827 24-track analog recorder. (Nippon Columbia Co., Ltd.)

At the end of the 1960s, disk records reached a plateau in terms of the technology developed up to that point, sales stabilized and there was a desire for records with added value. From this state of affairs came the desire for a new breakthrough. During this period, record companies attempted to make various improvements in recording and in the record manufacturing process, and these were actually put on the market and reviewed by audiophiles. Some examples of these improvements are shown in Table 5.16.

Table 5.16 compares the production and manufacturing process for normal records shown in the top row with the improvements (A) to (G), and assesses what methods were actually accepted. These improvements captured the interest of audio fans, and as they demanded that they be able to judge the improvements with their own playback systems and their own ears, and as far as possible the various improvements were elucidated when the records were put on sale.

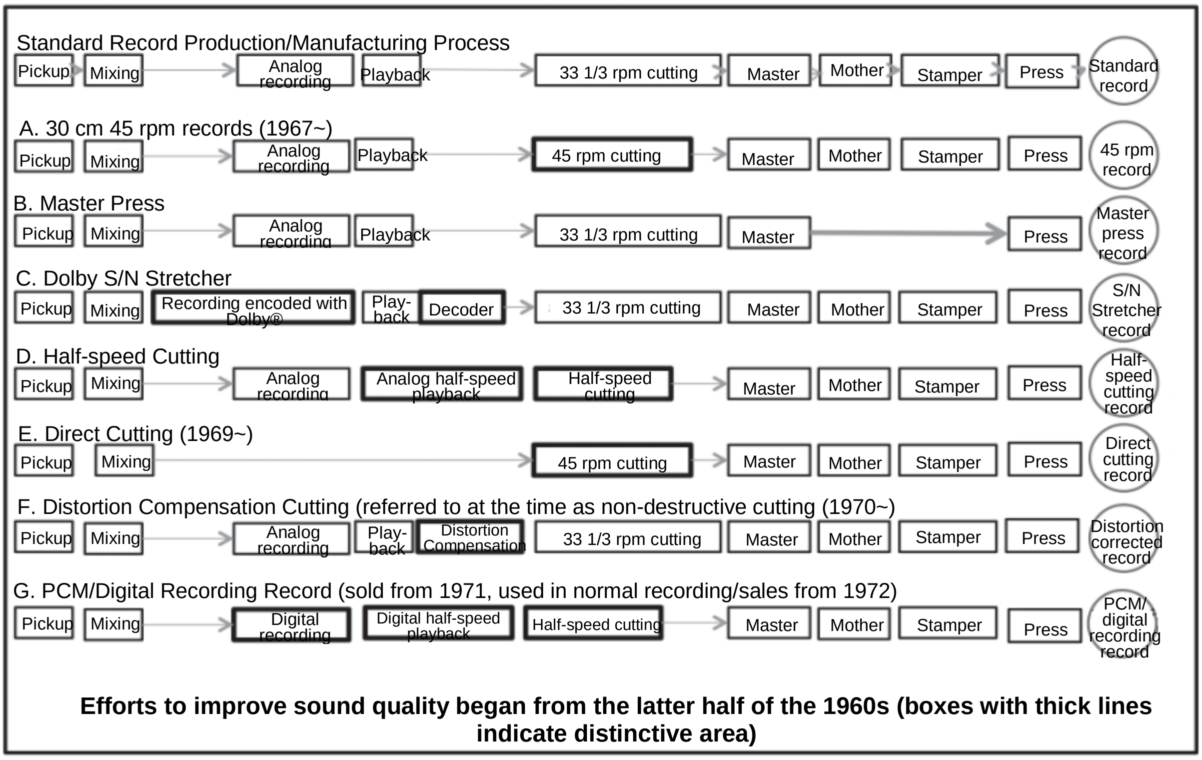


Fig. 5.16 Examples of attempts made to improve the record production/manufacturing process.

Table 5.16 compares the production and manufacturing process for normal records shown in the top row with the improvements (A) to (G), and assesses what methods were actually accepted. These improvements captured the interest of audio fans, and as they demanded that they be able to judge the improvements with their own playback systems and their own ears, and as far as possible the various improvements were elucidated when the records were put on sale.

(A) These were 30 cm, 33 1/3-rpm LP records that had their rotational rate increased to 45 rpm. These records were released into the market in 1967, and although they had the drawback of being limited to certain kinds of music by their short recording time, they gained support from audiophiles.

(B) Master Press records were records that were pressed directly from master disks without having made a mother and stampers, and as they omitted the process of making a mother and stampers, they were unsuitable for mass production. Priceless high-value classic editions which would only be available in limited runs of approximately 1,000 copies were sold and were received well.

(C) Dolby S/N Stretcher was a system developed by Dolby Laboratories in England (who later transferred their headquarters to the U.S.) to reduce noise created by magnetic tapes during playback. This system reduced noise by increasing the low-level signals that contained undesirable noise above the actual levels during recording, and decreasing them again during playback. S/N Stretcher was effective in analog multitrack recordings of pop music in particular, because even if parts with many instruments playing were fine, when only a few instruments were playing, the signal from other instruments was, of course, not added, but the noise from each of the tracks was. Dolby Laboratories released a form of S/N Stretcher for professional use called Type A, and later developed and released S/N Stretcher for cassette tape as Type B and Type C.

(D) Half-speed cutting is a technique that aims to improve the cutting characteristics and sound quality of a cutter head at high frequencies, and involves sending the signal to the cutting machine at half speed and reducing the cutting speed by half. Cutting systems are generally designed to cover the entire range of human hearing from low to high pitch. Accordingly, half-speed cutting with music that contains bass increases the risk of decreased levels of bass or distortion. To avoid these risks, the introduction of units that could reproduce and deliver the signal with a stable characteristic even at low frequencies of around 10 Hz (such as PCM/digital recording and replaying machines) was necessary. Even with analog recording, the effectiveness of half-speed cutting for music that does not contain much bass, such as *shamisen* music, was well known.

(E) Direct cutting bypassed the magnetic recorder, making it possible to improve the noise, harmonic distortion, modulation distortion, and wow and flutter associated with the use of such units.

(F) Playback distortion compensated cutting records were made with a technique that carried out correction during cutting to reduce the distortion caused by differences in the shapes of the cutting styluses and playback styluses introduced in 1970 (see Section 5.4, Fig. 5.54 to 5.58).

(G) These records are manufactured with a process that substituted PCM/digital recorders for analog magnetic recorders. Records manufactured as a trial were released in 1970 (Fig. 5.21, Fig. 5.22), with sales continuing in the form of LPs and CDs from 1972 up to the present (Fig. 5.24).

The method of improvement that was commended as having the greatest improvement among methods (A) to (F) described above in terms of sound quality was direct cutting, which eliminated the noise, harmonic distortion, and modulation distortion created by magnetic recorders.

One of the first experiments in direct cutting in the era of LP records was at Nippon Columbia's Studio No. 2 in Akasaka, Tokyo in 1969, where the output signal from a live performance was sent to three cutting rooms downstairs in the same building. This differed from ordinary cutting as it was impossible to know the groove pitch and groove depth in advance, so three cutting machines were each set with different cutting levels, groove pitch, and groove depth to provide levels that varied from a wide safety margin to nearly no safety margin. Recording was then carried out with the expectation of success. Flamenco, jazz, and Argentine tango were selected as they had improvisation and mistakes were not very likely to occur, The records were recorded at 45 rpm, which took sound quality and the frequency of musical and technical mistakes into consideration, and gave a little over 15 minutes of playback per side. These were released as 45-rpm doubles with a total of just over an hour of playing time.

Some direct cutting disks released at the time are shown in Fig. 5.17, 5.18, and 5.19.

Fig. 5.17 Direct cutting disk released in June 1969 containing Argentine tango. (Nippon Columbia Co., Ltd.)

Fig. 5.18 Direct cutting disk released in September 1969 containing Flamenco. (Nippon Columbia Co., Ltd.)

Fig. 5.19 Direct cutting disk released in November 1969 containing Jazz. (Nippon Columbia Co., Ltd.)

After direct cutting, in second place with good reviews came half-speed cutting, which could cut high pitches cleanly by reducing the cutting speed by half.

The other methods (Master Press, Dolby S/N Stretcher recording, playback distortion compensated cutting, etc.) were introduced, and although they were well received to a certain degree, they did not gain much recognition.

On the basis of the above, it was concluded that simultaneous direct cutting and half-speed cutting would be ideal, although it was thought to be theoretically impossible.

Around the same time in broadcasting, the good sound quality of live broadcasts without intermediate magnetic recorders was recognized. Between 1967 and 1969, Kenji Hayashi and others at NHK STRL worked to improve the modulation distortion created by magnetic recorders, developing the world’s first PCM/digital recorder (first in mono, later in stereo), using an industrial helical scanning VTR as a recording machine. Although this recorder did not meet the specifications for being installed at production sites because it could not do editing, nonetheless it was more than adequate as an experimental machine, and took the world by surprise. Despite that, however, it was not very well received at NHK production sites, and the developers of this PCM recorder sought opportunities to participate in evaluation experiments elsewhere.

This PCM/digital recorder from NHK STRL was used in the assessment experiments conducted by Hitachi Group described in Section 5.1.2 (3), producing valuable evaluation results for participants.

In two channels, the PCM/digital so was overwhelmingly superior to the conventional recorders that all of the people involved in the experiment were led to wonder if it would be better to practically implement PCM/digital recording as a priority over 4-channel sound, and focus on 4-channel sound later.

Four-channel sound did, in fact, die an early death, and a few years later PCM/digital recording was made a practical reality, and approximately 10 years later, digitally recorded music reached homes in the form of CDs.

Takeaki Anazawa, who facilitated these evaluation experiments, wasted no time in borrowing the PCM/digital recorder shown in Fig. 5.20 from NHK STRL, and began conducting full-scale tests of PCM/digital recording at studios and concert halls with the help of Nippon Columbia’s recording staff and production staff.

Fig. 5.20 NHK STRL’s PCM/digital recorder.

During recording tests with NHK’s PCM/digital recorder, the two analog disks shown in Fig. 5.21 and 5.22 were born. The record in Fig. 5.21 was released by Nippon Columbia in January 1971, and the recorder developed by NHK STRL was used to record it. Still, as it was unable to edit the audio, its operational efficiency and the amount of audio yielded were only slightly better than with direct cutting.

Fig. 5.21 *Something* by Steve Marcus + Jiro Inagaki & Soul Media, recorded with an early PCM/digital recorder. (Nippon Columbia Co., Ltd.)

Figure 5.22 shows a live recording released in April 1971 made on a recorder (without editing capabilities) developed by NHK STRL.

Fig. 5.22 *The World of Stomu Yamashita* by Tsutomu Yamashita, a live concert recording made at Tokyo Bunka Kaikan Recital Hall with an early PCM/digital recorder. (Nippon Columbia Co., Ltd.)

The specifications shown in Table 5.2 were established at the same time as the recording experiments described above were conducted with the help of people such as Kenji Hayashi (former head of the Consumer Products Research Center, Hitachi Ltd.) who oversaw development at NHK.

Table 5.2Required specifications for PCM/digital recorders (1969) and the performance, configuration and format of the Denon DN-023R (1972)

<table>
<tr><th>1. Required specifications as determined in evaluation tests (1969)</th><th>2. Specifications achieved in 1972</th></tr>
<tr><td>(1) Wide dynamic range.
(2) Low distortion rate.
(3) No wow or flutter.
(4) No crosstalk between channels.
(5) Flat frequency characteristic across a wide range of frequencies.
(6) 4 channels of multi-channel recording/reproduction of more.
(7) Ability to copy data from a single channel.
(8) Capable of half-speed cutting.
(9) No loss of sound quality during storage.
(10) No ghosting, etc.
(11) Equipped with advanced head for cutting.
(12) Capable of editing</td><td>(1) Dynamic range: ≥76 dB.
(2) Distortion rate: ≤0.1% (with active levels).
(3) Wow/flutter: undetectable.
(4) Crosstalk between channels: −80 dB or lower.
(5) 0 (DC) −20 kHz (deviation of +0.5dB or lower).
(6) Eight channels of recording possible.
(7) Possible to copy all of the data with 2 recorders, individual data copy possible with two systems.
(8) Possible: 0 (DC) −20 kHz (deviation of +0.5dB or lower).
(9) Data errors observed to increase after storage, but without a detectable decrease in sound quality.
(10) Ghosting level: −80dB or lower.
(11) Approx. 1 second (1/2 a revolution of a 33 1/3-rpm record) advanced stereo signal output possible.
(12) Capable of tape cutting/editing.</td></tr>
<tr><td colspan="2">3. Configuration and format of the Denon DN-023R PCM/digital recording system</td></tr>
<tr><td colspan="2">(1) PCM/digital audio converter
(2) 4-head, low-band VTR (modified)
(3) VTR activity monitor
(4) Format
Modulation method: Pulse code modulation (PCM)
PCM signal format: 13-bit natural binary code
Transmission clock frequency: 7.1825 MHz
Voice sampling rate: 47.25 kHz
Transmission waveform: Standard NTSC TV signal (excluding vertical synchronizing signal)
No. of voice channels: 8/4/2 switchable
Advance signal recording method: Direct recording of analog signal
No. of advanced signal channels: 2
Magnetic tape device: Modified 4-head low-band VTR
Tape speed: Recording: 38 cm/sec.; playback: 38 cm/sec./19 cm/sec. (switchable)</td></tr>
</table>

Later in 1970, with the approval of the new management of Nippon Columbia, a joint development project between NHK STRL and Nippon Columbia was commenced. Development was carried out by Hayashi, Miyashita, Todoroki, Oshinden and Anazawa, who were Koichi Tsubota's junior colleagues at the Nippon Columbia factory in Mitaka City where he worked before and after WWII. In 1972, exactly 10 years before digital recordings reached consumers in the form of CDs in 1982, Nippon Colombia released the Denon DN-023R, the world's first PCM/digital recorder for record mastering (Fig. 5.23) was completed, and it began to be installed in recording and record production sites from April of that year.

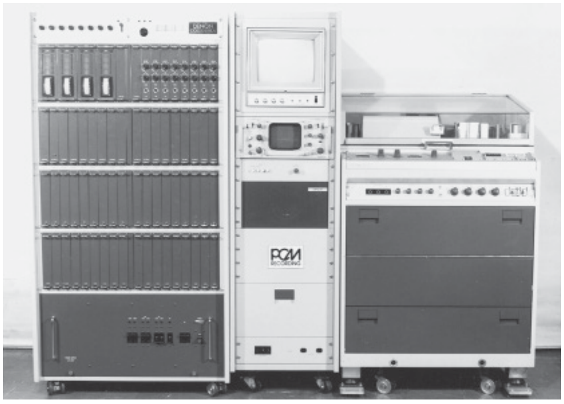


Fig. 5.23 The Denon DN-023R, the world's first PCM/digital recorder for record mastering (1972). (Nippon Columbia Co., Ltd.)

Digital recorders such as this require data recorders that can record and reproduce digital data in a stable manner.

NHK's PCM/digital recorder shown in Fig. 5.20 used a one-inch industrial VTR as a digital data recorder. Recording tests with this recorder at recording sites revealed a problem with its stability during operation as a data recorder. Other issues such at its lack of editing capabilities emerged, and the importance of drastically improving it was recognized. If eight channels of audio data with a 48 kHz sampling rate and a 16-bit bit depth are to be recorded and reproduced simultaneously, then the machine must be able to record and reproduce digital data at a rate of at least six megabits per second. Moreover, there were no data recorders at the time that could cut and edit recorded data, produce advanced signals (signals advanced by approximately one second) to control groove pitch and depth during cutting, and replay the tape at half speed for half-speed cutting.

After searching for a data recorder while considering factors such as operational stability and ease of modification, a four-head VTR for broadcasting use was settled upon. By coincidence, Shiba Electric Co., Ltd., who were manufacturing four-head VTRs for broadcasting stations, became part of Hitachi Denshi Co., Ltd. (now Hitachi Kokusai Electric, Inc.) at nearly the same time as Nippon Columbia became a member of Hitachi Group. So the four-head VTRs began to be manufactured within the Hitachi Group. The man who took charge of modifying the VTR at Hitachi Denshi was Toshiaki Kawamura, who supervised the writing of *History of the Video-Tape Recorder in Japan and the Preservation of (Early) Examples* as a systematization report for the National Museum of Nature and Science in March 2001.

The recorder portion of the PCM/digital recording equipment shown in Fig. 5.23 (on the right of the picture) used a 4-head low-band black-and-white VTR for broadcasting use. This VTR had lost its place in broadcasting stations with the transition to color for the 1964 Tokyo Olympics, so it was used to record digital audio in the form of white dots. As this recorder was developed during the era of 4-channel sound, it had the capacity to record eight channels, and it was configured so that reducing the number of channels would increase the accuracy of the recording. Editing, which is necessary in record production, could be done in the form of cutting and splicing the tape by hand. It also had the ability to produce advanced signals to control groove pitch and depth during cutting, and deliver audio data at half speed to enable high-fidelity cutting at high frequencies.

The first recording made on the recorder shown in Fig. 5.23 was made in April 1972 at Aoyama Tower Hall in Tokyo, where the Smetana Quartet, pride of Czechoslovakia, played Mozart's String Quartet No. 17 "The Hunt" and other pieces.

At the time, string quartets were a kind of music that traditionally demanded the most precise of ensembles (unlike jazz, flamenco, Argentine tango, and percussion ensembles), and getting consent from the performers to release the record without editing was impossible.

Figure 5.24 shows the recording made in April 1972 being edited.

Fig. 5.24 Editing scene from 1972.

During editing, the analog track of the 2-inch tape recording is played and the cutting point is found by listening to the reproduced sound. By doing this as described above, these analog signals are also used to change the groove pitch and depth of the disk during cutting. Then a method was used where the recording side of the 2-inch magnetic tape near the editing equipment was coated with magnetic powder dissolved in a volatile liquid, the recording tracks were located under a microscope, the tape was cut on both sides of the splice where the recording tracks joined, the magnetic powder was cleaned up, and then the tape was taped with thin aluminum splicing tape. Tens of thousands of splices were made using this editing method over the course of approximately eight years, continuing until the appearance of the random access editing system shown in Fig. 5.36. Now, 40 years later, editing can be done on laptop computers that have miniature high-capacity memory media and signal processing capabilities.

The first product to be recorded using the world's first proper PCM/digital recorder with editing capabilities, and then recorded as an analog record was released in October 1972. This record is shown in Fig. 5.25.

Fig. 5.25 The first analog record in the world to be recorded on a proper PCM/digital recorder with editing capabilities: Mozart's String Quartets No. 17 "The Hunt" and No. 15, recorded on April 24–26 at Aoyama Tower Hall, Tokyo. (Nippon Columbia Co., Ltd.)

A small and robust recorder was made two years later in 1974, and in the same year, digital recording was commenced in Western Europe. The first digital recording in Eastern Europe was made in 1975, and the first digital recording in the U.S. was made in 1977. French president Charles de Gaulle had ridiculed visiting Japanese Prime Minister Hayato Ikeda in 1962 by referring to him as "that transistor radio salesman," but Japan's PCM/digital recording work in Europe and America put an end to that and views toward Japan changed, and not only France but also other countries began to present Japan art-related awards and technology-related awards. Some of these awards are listed in Table 5.3.

Table 5.3 Awards presented by various countries for Japan’s PCM/digital recording work.

1976	France	Grand Prix du Disque ADF, Paris (Nippon Columbia, 1974 Maria João Pires, W.A. Mozart, Complete Piano Sonatas)
1976	Hungary	International "Ferenc Liszt" Record Grand Prix (1975 Dezső Ránki Plays Franz Liszt)
1977	Netherlands	Edison Music Award (Nippon Columbia, 1974 Maria João Pires, W.A. Mozart, Complete Piano Sonatas)
1978	USA	Billboard Trendsetter Award (Nippon Columbia, World’s first PCM/digital recording process)
1980	Switzerland	MONTREUX International Record Award, Prix d'Honneur Technique (Nippon Colombia, World’s first PCM/digital recording process)
1985	France	ACC Disk Award (Nippon Colombia, Huguette Dreyfus, Bach and Scarlatti Collections)
1986	Japan	Japan Audio Society Award (Software, PCM/digital recording process success)
1987	Japan	2nd Agency for Cultural Affairs Art Award (Nippon Colombia, 1985–87 Gustav Mahler, The Complete Symphonies with Eliahu Inbal)
1988	France	1st Diapason d’Or (Nippon Colombia, 1985–87 Gustav Mahler, The Complete Symphonies with Eliahu Inbal))
1988	Germany	German Record Award (Nippon Colombia, 1985–87 Gustav Mahler, The Complete Symphonies with Eliahu Inbal)
1992	USA	Audio Engineering Society (New York) Silver Medal (Individual, PCM/digital recording process success)

In this way, the dream of the Japanese people to see great works of art perfected was achieved with the help of technology. Figure 5.26 shows the exterior of the Alte Oper in Frankfurt, where the celebrated Eliahu Inbal conducted the complete Mahler symphonies, and Fig. 5.27 shows a scene from the recording session.

Fig. 5.26 Alte Oper, Frankfurt.

In 1985, after much discussion and practice over the space of ten years, the recording of the complete collection of Beethoven’s string quartets with the Smetana Quartet was completed. Soon after the project was completed, the quartet disbanded. Recording of Hibari Misora’s album, the complete collection of Beethoven symphonies conducted by Otmar Suitner, and jazz music in the U.S. were also completed, and by the time CD releases began in 1982, there were nearly 400 titles of digital content.

To find the theoretical dynamic range of a given bit depth, the bit depth is multiplied by 6 dB and 1.8 dB is added: therefore the dynamic range of 12-bit audio is 73.8 dB, and the dynamic range of 16-bit audio is 97.8 dB. Although the bit depth can easily be increased by increasing the number of comparators, achieving precision is a completely different problem. Sixteen-bit numbers are easy to represent, but actually achieving 16-bits of accuracy over the entire target frequency band with enough absolute accuracy and relative accuracy is extremely difficult.

Fig. 5.27 Mahler’s complete symphonies conducted by Eliahu Inbal with the hr-Sinfonieorchester being recorded at the Alte Oper, Frankfurt (using the Danish B&K microphone shown in Fig. 5.11).

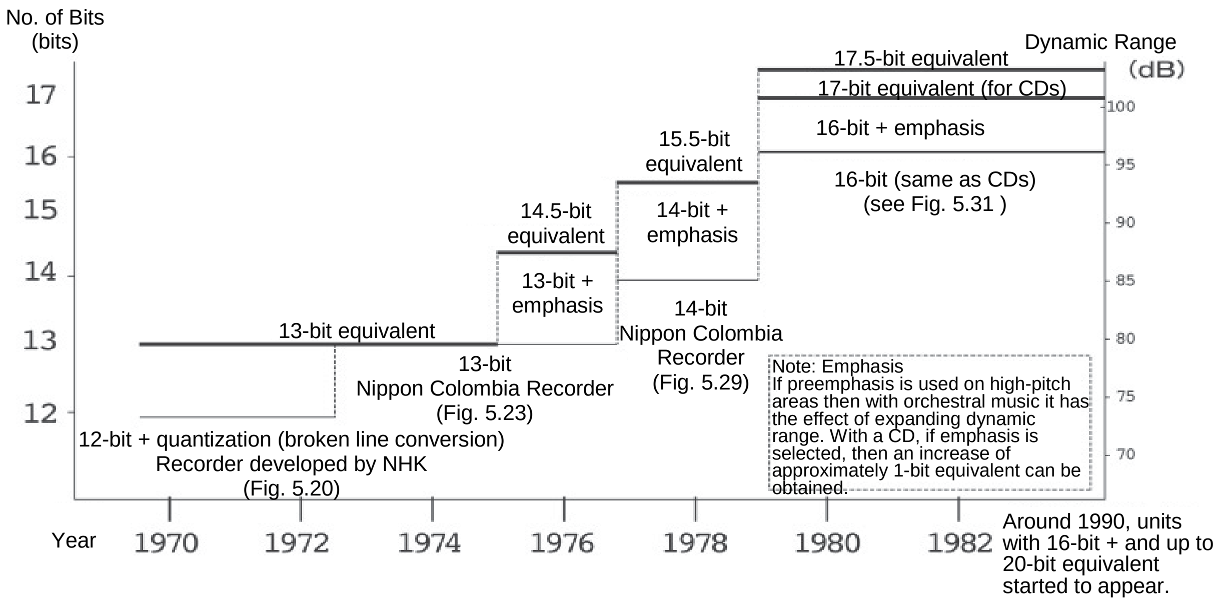


Fig. 5.28 Early PCM/digital recorder bit depth and dynamic range trends.

The bit depth and dynamic range of recorders increased from the end of the 1960s, arriving at the 16 bits per channel specification of the CD in the latter half of the 1970s. This progress is shown in Fig. 5.28.

The recorder with a 15.5-bit equivalent characteristic indicated in Fig. 5.28 is the Denon DN-034R, which is shown in Fig. 5.29. This recorder was transported to New York in the latter half of the 1970s and was used to make 8-track multitrack jazz recordings. The recordings received Billboard’s Trendsetter Award in 1978 for being America’s first commercial digital recording.

Fig. 5.29 Denon DN-034R 8-channel PCM/digital recorder, used for multitrack recording in New York and other places in the latter half of the 1970s. (Nippon Columbia Co., Ltd.)

The upper part of this particular recorder was a Hitachi Denshi SV-7400, which was famous in the era of 4-head VTRs, and installed underneath was a time base corrector unit in place of the processor shown on the bottom in Fig. 5.29. This VTR was registered as one of the Essential Historical Materials for Science and Technology by the National Museum of Nature and Science and is on display at the NHK Museum of Broadcasting.

Digital audio processors (Sony PCM-1600, PCM-1630) that used a semi-professional U-matic VTR as a recorder appeared at the end of the 1970s, a few years before the introduction of the CD, and the Denon DN-035RmkII, a 4-channel, 16-bit digital recorder that used the same U-matic tapes and U-matic VTRs appeared at the same time. Figure 5.30 shows a Sony PCM-1630 and a U-matic VTR, while Fig. 5.31 shows a Denon DN-035RmkII.

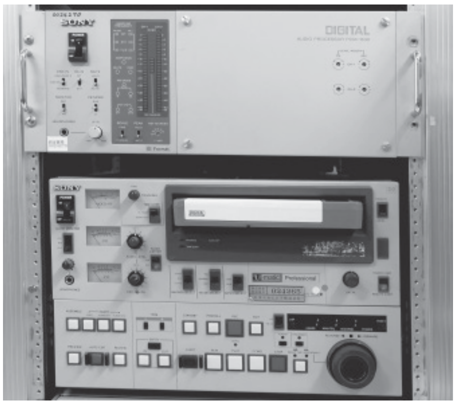


Fig. 5.30 Sony Digital Audio Processor PCM-1630 (top) and U-matic VTR (bottom). (Nippon Columbia Co., Ltd.)

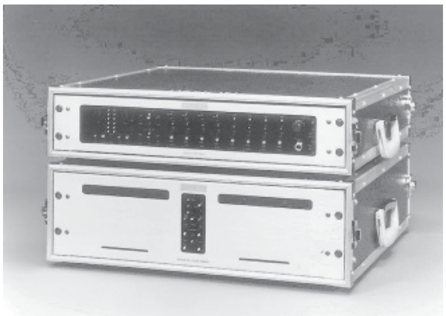


Fig. 5.31 Denon DN-035RmkII 4-channel PCM/digital recorder, which used a U-matic VTR (only the processor is shown). (Nippon Columbia Co., Ltd.)

Sony and Mitsubishi Electric also sold fixed-head digital recorders that did not use VTRs for recording. Figure 5.32 shows a Sony 2-track fixed-head digital recorder.

Fig. 5.32 Sony PCM-3402 2-track fixed-head digital recorder. (Nippon Columbia Co., Ltd.)

Figure 5.33 shows a Mitsubishi Electric 2-track fixed-head digital recorder.

Fig. 5.33 Mitsubishi Electric 2-track fixed-head digital recorder. (Nippon Columbia Co., Ltd.)

Later, multitrack recorders also appeared. Figure 5.34 shows a Sony PCM-3348 48-track digital recorder, and Fig. 5.35 shows a Mitsubishi Electric X-850 32-track digital recorder.

Both were fixed-head recorders.

Fig. 5.34 Sony PCM-3348 48-track digital recorder. (Nippon Columbia Co., Ltd.)

Fig. 5.35 Mitsubishi Electric X-850 32-track digital recorder. (Nippon Columbia Co., Ltd.)

This type or recording system was in use around the time when CDs began to be sold in 1982.

Pickup and recording work requires a mixing console containing microphone amplifiers, tone control circuits, and mixing circuits, etc. Incidentally, with regard to mixing consoles in general, many mixing console manufacturers appeared after WWII in the UK, where demand for loudspeakers for the many giant halls that exist there was particularly great, and they have retained a large share of the market even to this day.

If real-time processing can be carried out digitally using high-speed multipliers with control programs and amplifiers, tone control circuits, mixing circuits from analog mixers, then digital mixers can be realized. The development of digital mixing consoles began at various companies during the mid-1970s. At the time, semiconductor technology was making similar progress to that of digital media like the CD, reaching a practical level by the early 1980s; but issues such as the delay of convenient and cheap high-speed multipliers in reaching the market, the need for research to solve sound quality degradation caused by the occurrence of conversion errors and arithmetic errors, and delays in developing a machine interface for the mixing console itself held them back until the mid-1980s, after CDs were introduced.

5.1.4 Editing and Mixing Down

Editing involves finishing a work and correcting any mistakes made during the performance.

During editing, the items shown in Fig. 5.4 are important.

Table 5.4 Important conditions for editing.

(1)	The ability to search for the place to be edited while listening to the piece or looking at the waveform.
(2)	The ability to join two edits together.
(3)	No discontinuities (click sound) at splices.

Prior to World War II, editing was restricted to setting up several disk record players and disk recorders, synchronizing them, and sending the output to a recorder. In the 1950s, when magnetic recorders that used magnetic tape were introduced, tape splicing became widespread. When cutting and splicing, the technician slowly moves tape by hand, listening to the sound to find the edit point, which is then marked. Then the marked tape is cut diagonally to avoid a clicking sound, and splicing tape is used to reconnect it. Although narrow recording tape with a small number of tracks was cut and spliced, multitrack recordings on wide tape were not. Such tapes were corrected by re-recording over the parts of the tracks that contained mistakes.

These multitrack recordings are combined into a small number of tracks in a process called mixing down or tracking down to make the stereo sound fields, etc., of the completed recording.

In the early days of digital recording, recordings from fixed head recorders with a small number of tracks or from four-head VTRs were edited by cutting and splicing, and recordings from helical scanning VTRs, such as the U-matic, were edited by copying.

Although this kind of editing was done by splicing or copying, a random access editor that used a mainframe (IBM plug-compatible machine) hard disk unit (controlled by a TI 9900 microprocessor) for use in content editing environments was introduced in 1981, just before the introduction of the CD.

This enormous editor is shown in Fig. 5.36.

This editor increased editing efficiency significantly, and contributed toward improving the quality of sound sources for CDs and increasing the efficiency of production. Today, random access editing can be done at home with simple software, thanks to the existence of cheap personal computers with plenty of storage capacity. With classical music, where the same music is recorded several times with different musicians, there is a limit to the ability of people to achieve recording better that the one before them, so more edits are necessary.

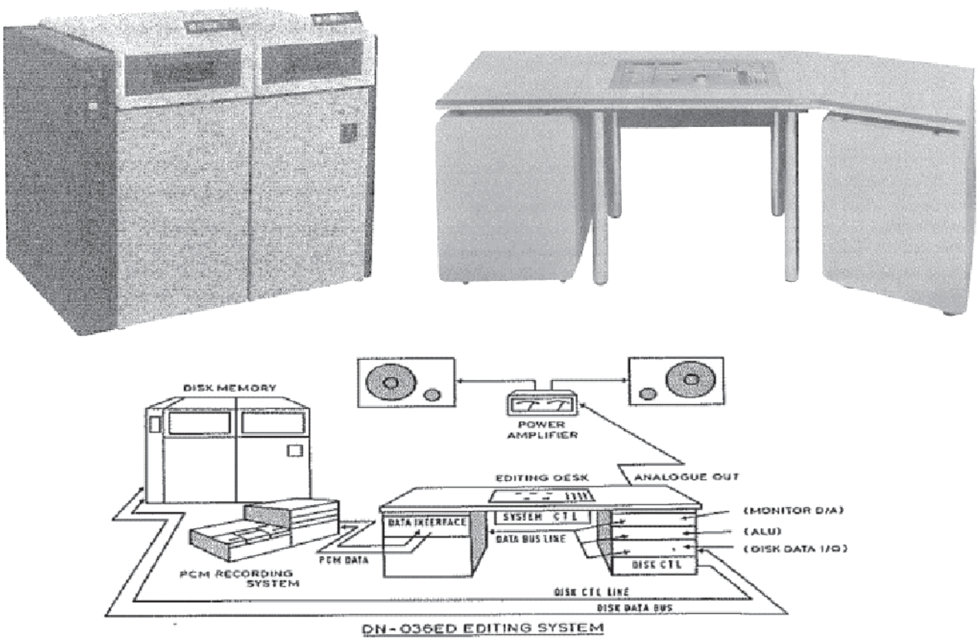


Fig. 5.36 DENON DN-036ED random access editing system.

In some cases, an LP or CD with approximately 50 minutes of playing time will require editing in over 200 or even 300 locations. In such cases, the question of how to guarantee the artistic qualities of the performance is important.

Later, the Denon DN-050MD digital mastering/mixing console for cutting (Fig. 5.37) was released, establishing a digital process from recording through to the cutting amplifier.

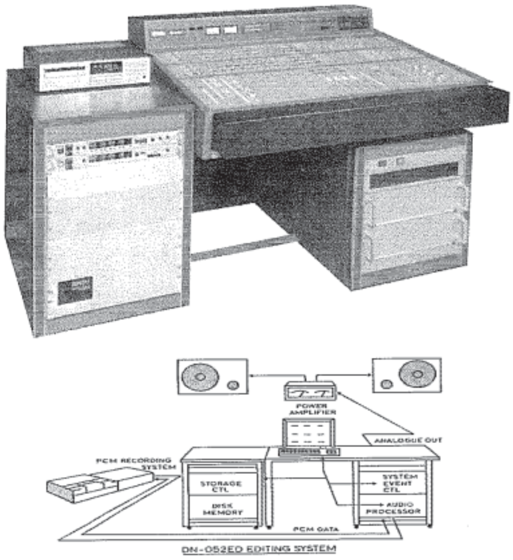


Fig. 5.37 DENON DN-050MD digital mastering/mixing console. (Nippon Columbia Co., Ltd.)

5.1.5 Cutting (Mastering)

Before magnetic recorders were introduced, master disks (wax disks made of montan wax with beeswax and vegetable wax) were cut in disk recorders and then sent to be duplicated. After magnetic recorders were introduced, audio was put through editing, mixing down, further adjustment and inspection processes, and then the content for the disk record was put on a magnetic tape (called a master tape) and sent to the cutting room. The cutting process was called "cutting" or "disk mastering."

During cutting, the cutting stylus of a cutting machine (a cutting lathe with a groove cutting unit called a cutter head attached) cuts a master disk called a lacquer. This lacquer disk consists of a flat aluminum core disk coated with a mixed solution of nitrocellulose, benzole, butyl acetate, butyl alcohol, ethyl acetate, DOP, castor oil, ethyl alcohol, and dye.

The cutter head was usually a single-resonance system with a resonance frequency of around 1 kHz, and with the addition of a lot of dynamic feedback (30 dB or more), a flat characteristic from 50 Hz to 18 kHz could be obtained relatively easily. To allow dynamic feedback, the cutter heads were equipped with sensing coils as well as driving coils. These sensing coils could not check the grooves themselves, but obtained signals from the movement of the cutting stylus, allowing sound quality to be checked during cutting. Therefore, the technician would usually listed to this signal during cutting to check the state of the cutting system's operation.

The disk records are essentially limited by their speed limit as determined by their rate of rotation and groove diameter. With regard to the driver of the cutter head, it is necessary to drive an amplifier with enough output (300 W or greater, with an 8 ohm conversion in the case of the Neumann SX-74, which was a typical cutter head) for the speed limit of the record with the intended rpm and groove diameter. Another limitation of cutting systems is that the level is the amplitude of bass signal levels at the cutter head (± 150 microns in the case of the SX-74). However, as the maximum amplitude of a normal disk record is approximately ± 50 microns, an amplitude limitation of ± 150 microns is more than sufficient. When records are cut with a signal close to the maximum amplitude of the cutter, playing time is shortened and tracing is difficult, making stable reproduction a challenge.

The preceding paragraph discussed the limitations of the cutting side; there are limitations that appear during playback also. One limitation of reproduction is the playback stylus' radius or curvature (e.g. a 16.5-micron spherical stylus). Another is the diameter of the groove, and then there is also the noise created on the disk during playback.

Figure 5.38 illustrates the limitations (excluding noise) when recording and reproducing (LP) disk records.

The playback limitations are more noticeable toward the interior, and although this can be improved by reducing the radius of curvature of the playback stylus, caution is required as this can sometimes damage the grooves on the disk. Although Fig. 5.38 does not show noise from the disks as a lower limit, it is still important to take noise into consideration, and it is necessary to reduce it as much as possible by taking other measures, such as improving the materials from which disks are made.

Figure 5.39 shows the shape of a cutting stylus.

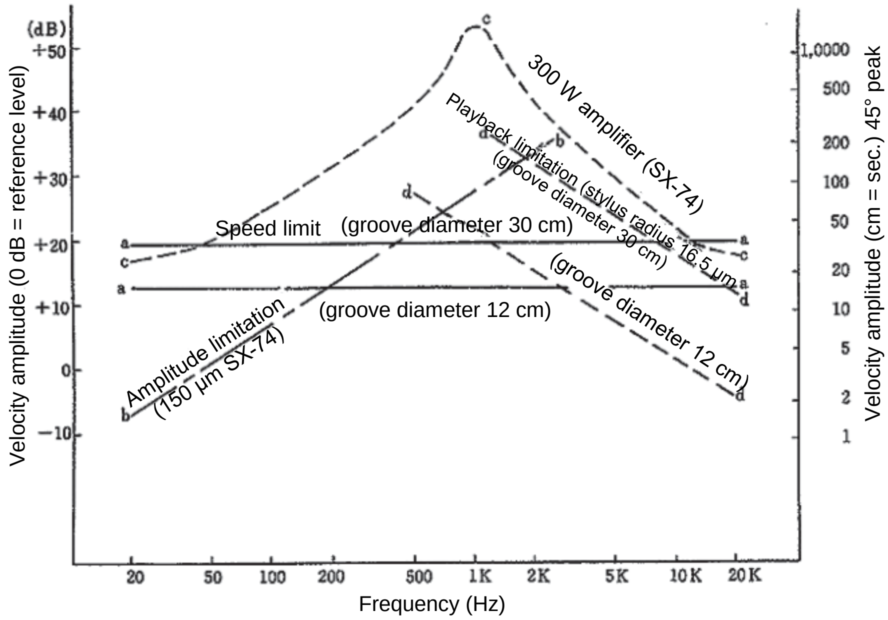


Fig. 5.38 Disk record recording and playback limitations (with 33 1/3-rpm disks).

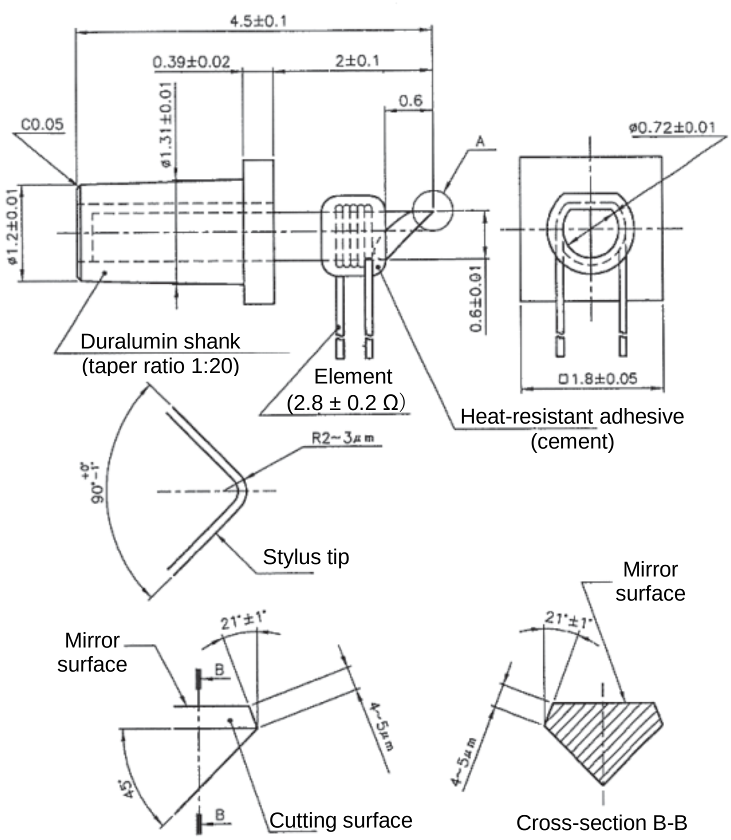


Fig. 5.39 Stereo LP-era cutting stylus shape.

To improve the machinability of the grooves during cutting, and to reduce noise (by improving the sharpness of the grooves, nichrome wire was wound around the tip of the cutting stylus as shown in Fig. 5.39 and heat was applied. In addition, inert gas (helium) injection is widely used to prevent the coils that drive the cutting stylus from breaking due to oxidation and heat.

Various kinds of playback stylus tip shapes and their relation to contact area are shown in Fig. 5.40.

When cutting lengthy stereo content on a disk record, in order to cut the left signal at 45 degrees and the right signal at minus 45 degrees (or cut the sum of the left and the right horizontally, and the difference vertically), it is necessary to know the groove pitch and depth in advance, and set the pitch and depth that is most appropriate for the content.

	Point contact styli		Line contact stylus
	0.5 mil spherical stylus	Elliptical stylus	S.A.S.
Front view	13μR A A'	18μR A A'	75μR A A'
A-A' section	13μR	6μR	2.5μR
Record contact point	L¹ 3.3μ, 3.3μ L²	L¹ 4.5μ, L² 2.5μ	L¹ 9μ, L² 1μ
Contact area	23.4 μm^2	20.6 μm^2	62.1 μm^2
L_1 / L_2	1	1.8	9

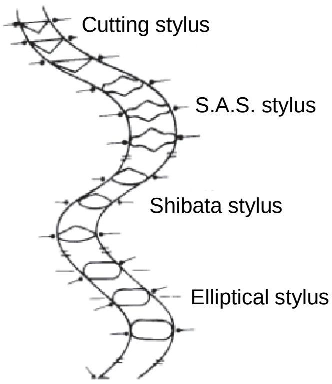


Fig. 5.40 The relationship between playback stylus tip shape and contact area.

Magnetic recorders/reproducers (see Fig. 5.14 for an example) and digital recorders/reproducers (see Fig. 5.23 and 5.29) used in cutting (mastering) are equipped with an advanced head that enables them to know what kind of signal will come before the cutting signal arrives, sets the pitch (the distance between grooves) of the cutting lathe, and also sets the average depth of the groove by regulating the vertical controller part of the cutter head. If the average pitch is too narrow, then the groove will come into contact with the adjacent groove, causing sound from the adjacent groove to be heard; and if it is too wide, then extended recording becomes impossible. Moreover, if the average depth is too shallow, then the groove will be broken and the playback stylus sill not be able to track the groove properly during playback; and if it is too deep, then extended recording becomes impossible, and in extreme cases the groove will reach the aluminum core of the lacquer disk, damaging the cutting stylus. Extended recording also becomes difficult if there is a large difference in bass between the left and the right signals, so elliptical equalizers (which control the difference in bass between the left and the right), etc., are used. Using these equalizers has the merit of allowing records to be played back with old monaural cartridges, to a certain extent.

Although cutter heads are an inconspicuous technology as compared with cartridges, rarely being noticed, they are one of the fundamental technologies that support analog disk records, and, as described in 4.3, their foundation was laid during disk recorder development prior to WWII.

Some typical cutter heads and cutting machines will be presented in the following paragraphs.

The four cutter heads shown in Fig. 5.41 to 5.44 are typical cutter heads from the end of the SP era, through to the early stages of the LP and stereo era. Blumlein’s cutter head used permanent magnets and electromagnets, and was enormous, as can be seen by comparing it with the Neumann SX-74 (Fig. 5.41), which was the most widely used cutter head when stereo was thriving.

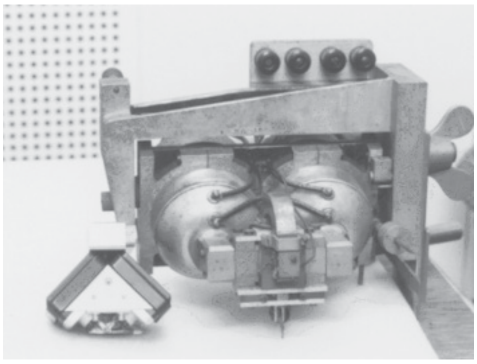


Fig. 5.41 Blumlein’s cutter head (an SX-74 is shown on the left for reference). (Nippon Columbia Co., Ltd.)

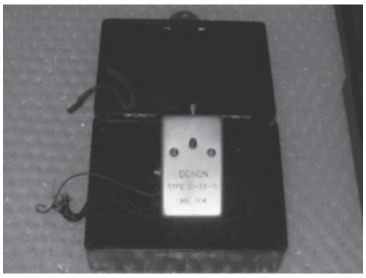


Fig. 5.42 DENON C-28-G cutter head. (Nippon Columbia Co., Ltd.)

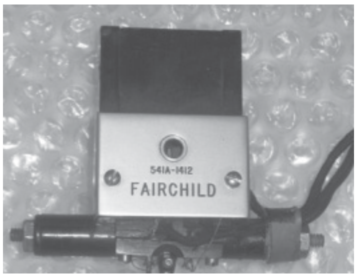


Fig. 5.43 A Fairchild cutter head. (Nippon Columbia Co., Ltd.)

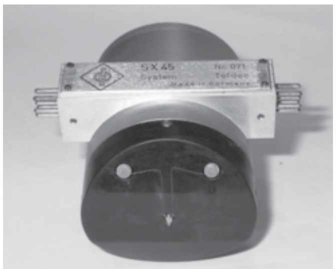


Fig. 5.44 Neumann SX-45 cutter head. (Nippon Columbia Co., Ltd.)

A number of different cutter heads made by various companies during the golden age of stereo LPs are shown in Fig. 5.45 to 5.47.

Fig. 5.45 Denmark Ortofon cutter head. (Nippon Colombia Co., Ltd.)

Fig. 5.46 Westrex 3D cutter head. (Nippon Columbia Co., Ltd.)

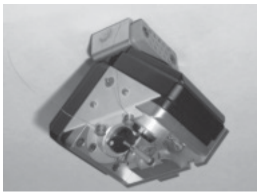
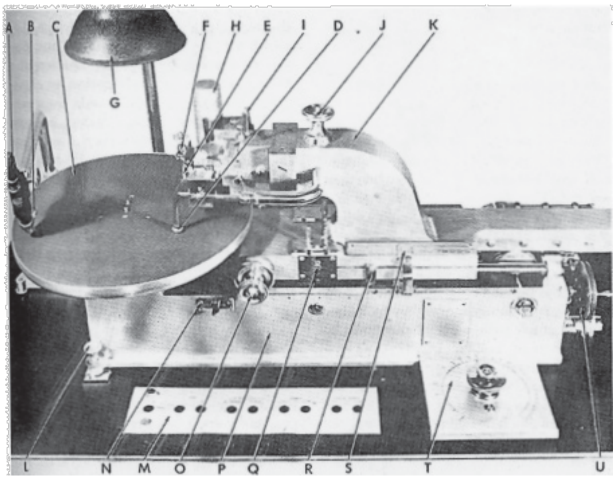


Fig. 5.47 Neumann SX-74 cutter head. (Nippon Colombia Co., Ltd.)

Figure 5.48 shows a Scully (USA) cutting lathe and its components as an example of a cutting lathe (cutting machine) equipped with the cutter head shown above.



A Microscope
B Microscope light
C Turntable
D Vacuum suction pipe
E Cutting head
F Depth adjustment
G Light stand
H Cutting head dash pot
I Cutting head connector
K Sled

L Level adjustment screw
M Push button controls
O Carriage handle
P Recorder base
Q Feed nut adjustment
R Carriage stop position selector
S Groove scale
T Groove pitch adjustment
U Lead screw/handle

Fig. 5.48 Components of a Scully cutting lathe from the US.
(Nippon Colombia Co., Ltd.)

Figure 5.49 shows a wax disk-era cutting lathe made by Denon.

Fig. 5.49 Wax disk-era cutting lathe made by Denon.
(Nippon Colombia Co., Ltd.)

Figure 5.50 shows a cutting lathe from around 1956 made by Denon.

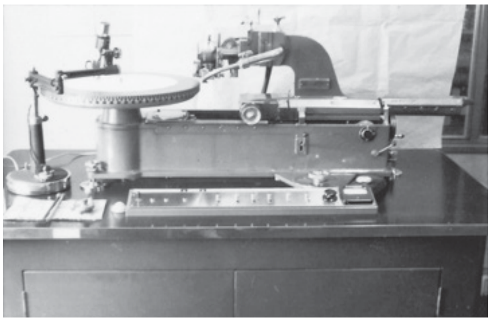


Fig. 5.50 DENON cutting lathe made circa 1956.
(Nippon Colombia Co., Ltd.)

Figure 5.51 shows a Lyrec cutting lathe with an Ortofon cutter head (both Danish).

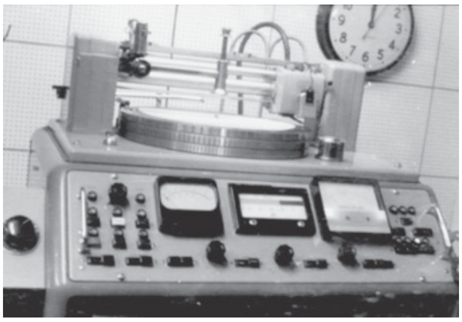


Fig. 5.51 Lyrec cutting lathe and Ortofon cutting head.
(Nippon Colombia Co., Ltd.)

Figure 5.52 shows a Scully (USA) cutting lathe with a Westrex 3D cutter head.

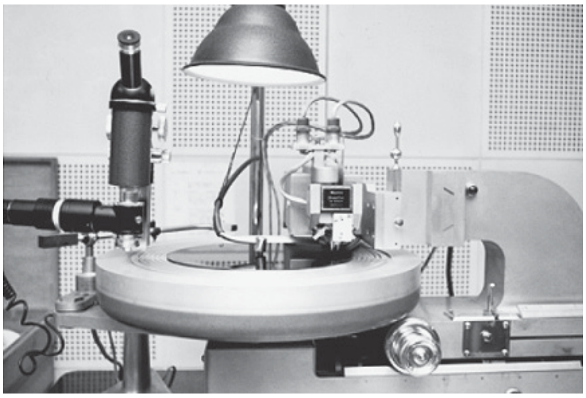


Fig. 5.52 Scully cutting lathe with a Westrex 3D cutter head.
(Nippon Columbia Co., Ltd.)

Figure 5.53 shows a Neumann (Germany) cutting lathe with a Neumann SX-74 cutter head.

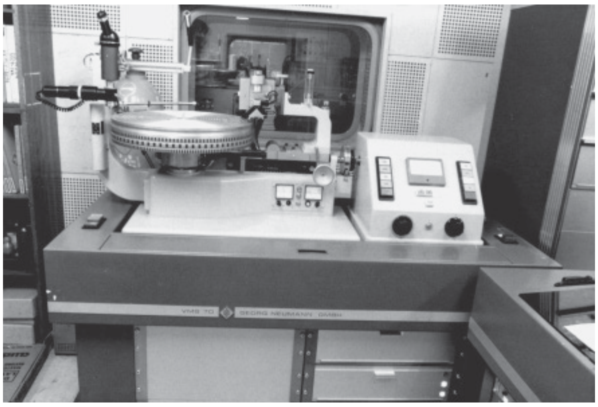


Fig. 5.53 Neumann cutting lathe and SX-74 cutter head. (Nippon Colombia Co., Ltd.)

When direct-drive turntables for consumer record players began to be introduced, direct-drive turntables for cutting machines also appeared. A Denon direct-drive motor is shown in Fig. 5.54.

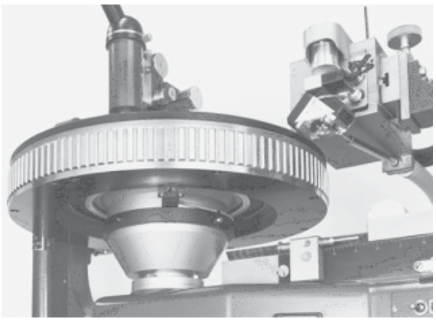


Fig. 5.54 Direct drive motor for DENON cutting machine.
(Nippon Colombia Co., Ltd.)

Figure 5.55 shows an example of a cutting machine used in the present day.

Fig. 5.55 Configuration of one of the latest cutting machines.
(Nippon Colombia Co., Ltd.)

Behind the cutting machine is a tank containing helium for cooling the coils in the cutter head. The helium tube passes through a flow meter on the right-hand edge, through an opening in the front of the SX74 cutter head, and injects helium over the coils. Lacquer disks placed on the turntable are held onto it by means of suction from the pipe in the center and holes in the top of the turntable. The pickup beyond the turntable is used for correction and checking the sound quality, etc., and the Denon DL-103 cartridge (shown in Fig. 4.12 and 4.13) is still used to this day. The microscope to the left of the turntable is used to check groove geometry and cutting state.

5.2 Standardization of Recording/Playback Equalizer Characteristics

As described above, there exists an upper limit to the speed of disk records that is determined by their rate of rotation and groove diameter, and an upper limit to the amplitude of the signal that depends on the ability of the cutter head and the playback head to trace it. There are also limitations on playback that are determined by the radius of curvature of the playback stylus and the diameter of the groove on the record. In addition to these upper limits, there are also lower limits, such as the noise on the disk itself. In many places there were attempts to introduce equalization curves that were optimally suited to music reproduction that took these limitations and also the frequency distribution of the content into consideration. The frequency distribution level of signals was therefore measured for types of content, such as such orchestral music, etc., that it was thought would require an exceedingly large dynamic range. Unfortunately, this hard work did not bear fruit during the era of electrically-recorded SP records, and these equalization curves were not able to be standardized. As the various companies adopted different equalization curves after the introduction of LP records, records players were equipped with at least 11 different equalization curves, which had to be selected with a switch according to the record (the various labels). This problem was solved when an equalization curve was standardized in the form of the RIAA curve in February 1954 by the Recording Industry Association of America® (RIAA). The same curve was also adopted by the IEC, and it was later revised in 1976. The RIAA and IEC equalization characteristics are shown in Tables 5.5 and 5.6 respectively.

Table 5.5 RIAA equalization characteristic (1954).

RIAA Recording/Playback Characteristic		
Frequency (Hz)	Recording Characteristic (dB)	Playback Characteristic (dB)
30	−18. 61	+18. 61
50	−16. 96	+16. 96
70	− 15. 31	+15. 31
100	− 13. 11	+13. 11
200	− 8. 22	+8. 22
300	− 5. 53	+5. 53
400	− 3. 81	+3. 81
700	− 1. 23	+1. 23
1, 000	0	0
2, 000	+ 2. 61	−2. 61
3, 000	+ 4. 76	−4. 76
4, 000	+ 6. 64	−6. 64
5, 000	+ 8. 23	−8. 23
6, 000	+ 9. 62	−9. 62
7, 000	+ 10. 85	−10. 85
8, 000	+ 11. 91	−11. 91
9, 000	+ 12. 88	−12. 88
10, 000	+ 13. 75	−13. 75
11, 000	+ 14. 55	−14. 55
12, 000	+ 15. 28	−15. 28
13, 000	+ 15. 95	−15. 95
14, 000	+ 16. 64	−16. 64
15, 000	+ 17. 17	−17. 17

Table 5.6 IEC equalization characteristic (amended 1976).

IEC Recording/Playback Characteristics				
Frequency (Hz)	Recording Characteristic (dB)		Playback Characteristic (dB)	
	Coarse groove	Fine groove	Coarse groove	Fine groove
2	-	-	-3.2	-0.2
2.5	-	-	-1.3	+1.8
3.15	-	-	+0.7	+3.7
4	-	-	+2.7	+5.7
5	-	-	+4.5	+7.6
6.3	-	-	+6.4	+ 9.4
8	-	-	+8.2	+11.2
10	-	-	+9.7	+12.8
12.5	-	-	+11.1	+14.1
16	-	-	+12.4	+15.4
20	-16.3	-19.3	+13.3	+16.3
25	-16.0	-19.0	+13.8	+16.8
31.5	-15.5	-18.5	+14.0	+17.0
40	-14.8	-17.8	+13.8	+16.8
50	-14.0	-16.9	+13.3	+16.3
63	-12.9	-15.9	+12.5	+15.4
80	-11.6	-14.5	+11.3	+14.2
100	-10.2	-13.1	+10.1	+12.9
125	-8.8	-11.6	+8.7	+11.5
250	-4.5	-6.7	+4.5	+6.7
315	-3.3	-5.2	+3.3	+5.2
400	-2.3	-3.8	+2.3	+3.8
500	-1.5	-2.7	+1.5	+ 2.7
630	-0.9	-1.6	+0.9	+1.6
800	-0.4	-0.8	+0.4	+0.8
1,000	0	0	0	0
1,250	+0.4	+0.8	-0.4	-0.8
1,600	+0.9	+1.6	-0.9	-1.6
2,000	+1.4	+2.6	-1.4	-2.6
2,500	+2.1	+3.7	-2.1	-3.7
3,150	+3.0	+5.0	-3.0	-5.0
4,000	+4.2	+6.6	-4.2	-6.6
5,000	+5.5	+8.2	-5.5	-8.2
6,300	+7.0	+10.0	-7.0	-10.0
8,000	+8.7	+11.9	-8.7	-11.9
10,000	+10.5	+13.7	-10.5	-13.7
12,500	+12.2	+15.6	-12.2	-15.6
16,000	+14.3	+17.7	-14.3	-17.7
20,000	+16.2	+19.6	-16.2	-19.6

The IEC standard shown in Table 5.6 includes the equalization curves for SP records (the “Coarse Groove” columns), The LP columns (Fine Groove) in Tables 5.5 and 5.6 differ because the frequencies set by the RIAA and the IEC are different. It is widely known that humans perceive the difference in pitch between 100 Hz and 200 Hz to be the equivalent of the difference between 1 kHz and 2 kHz and not 1 kHz and 1.1 kHz. As this corresponds with frequencies expressed logarithmically, even though the frequencies specified as standard frequencies are chosen differently in the bass range, they are mostly chosen evenly from the logarithmic axis. As the characteristic can deviate on the recording system or the playback system at higher frequencies, both the RIAA and IEC specify higher frequencies more closely. These equalization curves are designed to effectively utilize the dynamic range of disk records that exists between the upper limits imposed by speed and amplitude and the lower limits imposed by noise levels (caused by the disk materials).

To decide on these levels, it is necessary to consider the sound pressure levels and the frequency distribution of the sound source in question. Note that these equalization curves were established with the sound pressure and frequency distribution of a front-row seat at a full orchestra performance in a concert hall (where especially high sound pressure levels are needed) in mind. The results of Bell Laboratories' pre-WWII research (completed with the cooperation of the famous conductor Leopold Stokowski and the Philadelphia Orchestra) live on in the form of these equalization characteristics.

When changing the recording media from records to cassette tapes and CDs, different equalization characteristics are required. Cassette tapes actually need a different equalization curve, and CDs have a simple equalization curve called "pre-emphasis" for people who want to use it; this is set on or off on the CD itself, and a de-emphasis circuit automatically removes the emphasis when the CD is played back.

As described above, equalizers for analog records were standardized for the frequency distribution of orchestral music, but analog record cutting engineers are vexed by music and sound effects that have a completely different frequency distribution from western orchestral music. One such type of sound is the sound made by insects, for example, the chirping of katydids. In Japanese traditional music is one type of music in which there are instruments that produce sounds that contain such high-frequency components. The frequency distribution of such music is skewed to the treble region, and includes variations in amplitude (amplitude modulation) and slight variations in frequency (frequency modulation) in the treble range. If nonlinearity (which is the primary cause of distortion at higher frequencies) exists, then the small amplitude and frequency variations in the bass that were inaudible in the original sound become audible, and if this is emphasized by the equalization curve (which raises the bass), then the resulting sound will not remotely resemble the chirping of a katydid. Such phenomena occur when the band is widened unnecessarily and the signal is transmitted with uncontrolled bands (nonlinear bands), therefore it is important in all cases to restrict the signal to manageable transmission bands.

5.3 Frequency Sweep Records and Disk Record Calibration

The systems of recording and reproduction can generally be divided into entities such as record companies (which record sound) and households (which reproduce it), with both parties having the same point of contact: disk records.

Special records, called frequency sweep records or test records, are used to manage the characteristic of the playback system at this point of contact. To make frequency sweep records, it is first critical to establish methods of measuring the grooves, and then it is necessary to accurately measure groove displacement/shape, wavelength and cutting direction, etc., using methods such as those shown in Table 5.7.

Table 5.7 Methods of measuring grooves on records.

i)	Light pattern method
ii)	Light pattern method using interference (B-line technique)
iii)	Variable speed method
iv)	Methods using interference microscopes
v)	Methods using electron microscopes

Optical microscopes are installed on cutting machines for inspecting the sides and the bottoms of the grooves for damage, and for checking the approximate size and spacing of the grooves. These microscopes are used whenever a disk is cut.

The Buchmann-Meyer light pattern method that was invented in 1930 was the most widely used method used for measuring the amplitude and velocity of the groove during cutting without physical contact. This method takes advantage of the fact that the width of the reflection of a beam of light projected onto the face of the groove directly corresponds with the velocity amplitude of the signal being recorded. With the light pattern method, the recording wavelength shortens as the signal frequency increases, causing the reflected light to scatter, and making measurement of a well-defined band of reflected light more difficult. The light pattern method offsets this weakness with a fringe pattern, an improvement introduced by Buer in 1955. On the other hand, if the signal frequency decreases, then it becomes difficult to cut a fixed velocity amplitude due to the amplitude limitations of the cutter head, so measurement accuracy using the light pattern method decreases as velocity amplitude decreases. The variable speed method, which varies the playback speed and calibrates the levels of different frequencies, is an effective means of ensuring accuracy under such conditions. Although absolute calibration is impossible with this method, it is possible to easily carry out calibration and ensure good precision to the extent that pickup remains linear.

Methods using interference microscopes work by observing the grooves under a direct interference microscope and determining the groove displacement, shape, and amplitude from the shape and spacing of the interference pattern. These methods generally used a light source with a wavelength of 0.546 microns, and the spacing in the interference pattern corresponds to half of this, or 0.273 microns.

When observing a JIS reference level 1 kHz sine wave, the theoretical displacement of the groove face (peak-to-peak) is 11.26 microns, allowing approximately 0.1 dB of accuracy (supposing a margin of error of 50%). Crosstalk could be measured to within approximately −38 dB, and accuracy can be improved by raising recording levels. Measurement techniques that use electron microscopy have become an indispensable method of observing the vertical and horizontal cutting angles, the characteristics of the stylus, and the finish from the electroplating stage. When frequency records are actually made, a number of methods are used in combination instead of relying on a single method. Table 5.8 shows the main things frequency records are used to measure in playback systems.

Table 5.8 Main items measured when checking playback using a frequency sweep test record.

(a)	Sensibility (reference level)
(b)	Frequency characteristic (ultra-low, audible, ultra-high)
(c)	Playback loss
(d)	Crosstalk
(e)	Distortion (harmonic distortion, intermodulation distortion, etc.)
(f)	Wow/flutter
(g)	S/N ratio (blank groove)
(h)	Electrical impedance
(i)	Mechanical impedance
(j)	Vertical tracking angle
(k)	Phase characteristic (between 2 channels)
(l)	Delay characteristics
(m)	Transient characteristics

Table 5.9 lists examples of well-known pre-1975 frequency sweep records that were capable of measuring most of the items listed in the table above.

Table 5.9 Main frequency records and their content.

Company	Record No.	Main Content
Audio Fidelity	XMS-100AF	Frequency range (30–15 kHz spot), low-frequency resonance (70–15 Hz) demo music
Capitol	LF-1002	Demo music
CBS	STR-100	Frequency range (40–20 kHz sweep), low-frequency resonance (200–10 Hz)
CBS	STR-110	Transients, intermodulation distortion
CBS	STR-120	Frequency range (10–500–50 kHz sweep) playback loss
CBS	STR-130	Frequency range (40–20 kHz sweep) RIAA
CBS	STR-140	1/3Oct pink noise (30–15 kHz) RIAA
CBS	BTR-150	Broadcast standard text codes
CBS	STR-101	Test record for better listening
Clarkstan	WR J-105R	Frequency range (70–15 kHz sweep)
Clarkstan	WR J-103L	
Command	SC-1	Frequency range, wow/flutter, balance, demo music
Concert Disk NAB	PTX-10	Frequency range (60–10kHz, spot), wow/flutter, S/N, trackability
Pacific Transducer	STR-103 、105	Frequency range (30–15kHz spot), wow/flutter, crosstalk
Shure	TTR-101	Frequency range, phase test
Stereo Review	SR-12	Trackability
Stereo Review	MODEL-211	Frequency range (20–20 kHz) wow/flutter, S/N trackability
B&K	QR-2009	Frequency range, wow/flutter, S/N channel balance
Decca	T22-222	
DIN	45541	Frequency range (20–20 kHz)
DIN	45542	Demo music
DIN	45543	Frequency range (31.5–20 kHz sweep/spot), low-frequency resonance (5–125 Hz)
DIN	45544	Vertical tracking angle test / intermodulation distortion
DIN	45545	Crosstalk measurement
EMI	TCS-101	Rumble measurement
EMI	TCS-105	Wow/flutter measurement
HiFi STEREO TEST	No1	Frequency range (30–20 kHz spot)
HiFi STEREO TEST	No2	Frequency range (30–20 kHz spot) vertical
London	SLC-1107	Sound, music explanations
London	SLC-1650	Frequency range (20–20 kHz), phase, rumble, crosstalk
TELEFUNKEN	TST-72212	Frequency range (40–12 kHz spot)
TELEFUNKEN	TST-72213	Test record for better listening
Audio Technica	AT-6601	Frequency range (60–12 kHz spot)
Toshiba EMI	LF-1003	Measurement of groove alignment variation
Toshiba EMI	LF-9001	Frequency range, wow/flutter, arm resonance, trackability
JVC	TRS-1001	Frequency range, wow/flutter, S/N (monaural)
JVC	TRS-1002	Frequency range (20–1 kHz, sweep, spot), S/N, transients, music
JVC	TRS-1003	Frequency range (30–15 kHz spot), wow/flutter, S/N
JVC	TRS-1004	Frequency range (30–15 kHz spot)
JVC	TRS-1005	Frequency range (1K–50 kHz sweep), spot, 50 k, 40 k, 30 k, 20 kHz
JVC	TRS-1	CD-4 cartridge check, spot, 40 k, 30 k, 20 k, 10 kHz, crosstalk

Nippon Colombia	XL-7001	Frequency range (1K–50 kHz sweep), Frequency range (30–15 kHz spot)
Nippon Colombia	XL-7002	Frequency range (20–20 kHz sweep), low-frequency resonance (4–100 Hz), S/N, wow/flutter, differences in sound according to microphone type, position, playback conditions, etc.
Nippon Colombia	XL-7003	Changes in music (frequency range crosstalk, wow/flutter, distortion, dynamic range)

In Japan, the reference levels on disk records are specified by JIS and are therefore not named in a confusing manner, but in other countries, the reference levels and nomenclature are different. Some examples are given in Table 5.10. It goes without saying that when using frequency records with non-JIS reference levels that the levels must be converted at the time of measurement.

Table 5.10 1 kHz reference levels and differences in labeling.

	JIS Stereo Reference Record JIS C-5514	NAB TEST RECORD	DIN FREQUENZ-MESS-SCHALLPLATTE 45541		CBS-Lab. TEST RECORD STR-100
Displayed Level	Horizontal direction 50 mm/sec.·peak	Horizontal direction 7 cm/sec.·peak	Stereo (each channel) 8 cm/sec.·peak	Monaural (horizontal direction) 10 cm/sec.·peak	Horizontal direction 5 cm/sec.·peak
Stereo Single channel conversion Peak	3.54 cm/sec.	5 cm/sec.	8 cm/sec.	7 cm/sec.	5 cm/sec.

5.4 Development of Cutting Technology and Distortion Reduction through Playback Distortion Compensation

Efforts to compensate for tracing distortion (caused by the difference in shape between cutting and playback styli) by creating an inverted signal to correct the playback distortion and adding it to the cutting signal were undertaken by companies such as RCA, Telefunken, Nippon Columbia and Toshiba EMI during the period between the mid-1960s and early 1970s, Some examples of this effect are shown in Fig. 5.56 to 5.59.

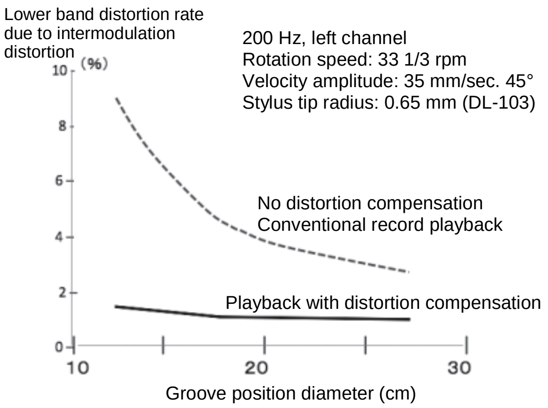


Fig. 5.56 The effect of playback distortion compensation (signal frequency 200 Hz, left channel).

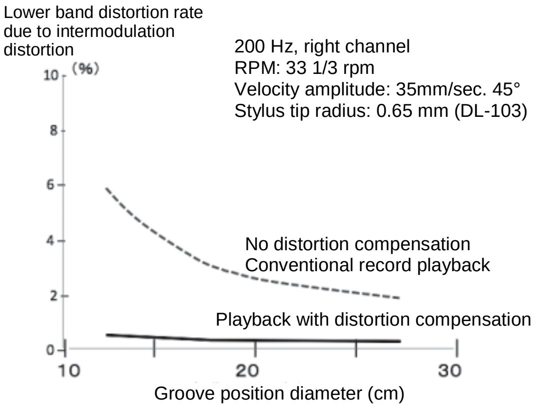


Fig. 5.57 The effect of playback distortion compensation (signal frequency 200 Hz, right channel)

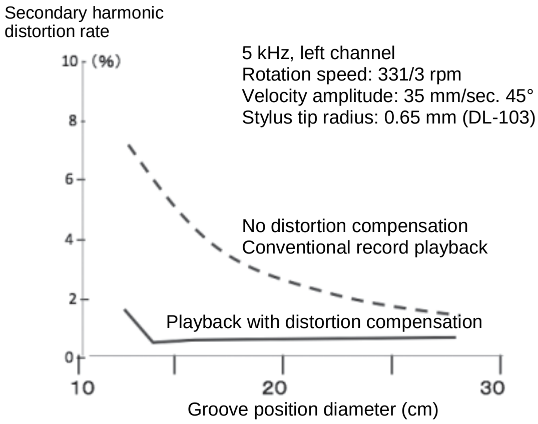


Fig. 5.58 Playback distortion compensation (signal frequency 5 kHz, left channel)

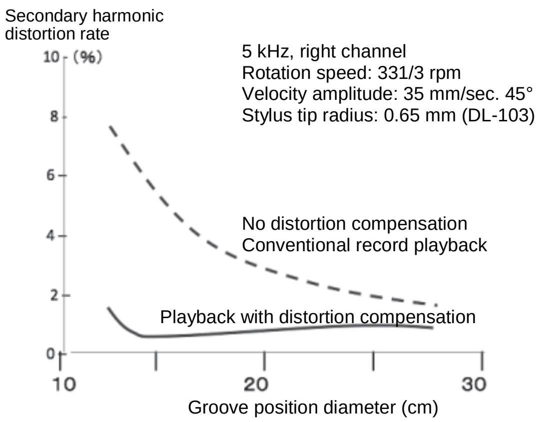


Fig. 5.59 The effect of playback distortion compensation (signal frequency 5 kHz, right channel)

The effects shown above were obtained by calculating the playback distortion for a spherical stylus, creating a inverted compensation signal, cutting the disk, and reproducing the sound with a spherical stylus. That the correction is a great improvement is obvious. It is common knowledge that playback distortion is caused by the difference in shape between recording and playback styli, and that the improvement gained by using an elliptical stylus is highly variable, as illustrated in Fig. 5.60.

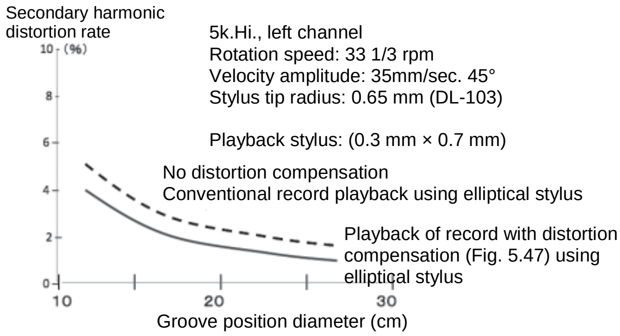


Fig. 5.60 The effect of playback distortion compensation (signal frequency 200 Hz, right channel) compared with carrying out playback distortion compensation on a conventional record using an elliptical stylus.

The graph above clearly shows that playing the record with an elliptical stylus produced nearly as much distortion as a spherical stylus without compensation. The state of the industry was such that if all of the playback styli were spherical, then a great deal of the distortion could be compensated for; but when elliptical styli, which are narrower than spherical ones, began to be sold in the latter half if the 1960s, the audio maniacs jumped on them immediately. Thanks to this audio mania, the effect of playback distortion compensation was limited, and it failed to become popular in spite of all the trouble and effort that had gone into its development.

Nevertheless, this research into distortion compensation and stylus geometry has proven to be useful. In September 1970, JVC developed a discrete 4-channel record called the CD-4. As shown in Fig. 5.61, the sum of the front and rear signals were recorded in the normal left and right channels respectively, and the difference between the front and rear signals was recorded in the left and right channels on a frequency modulated 40 kHz carrier signal.

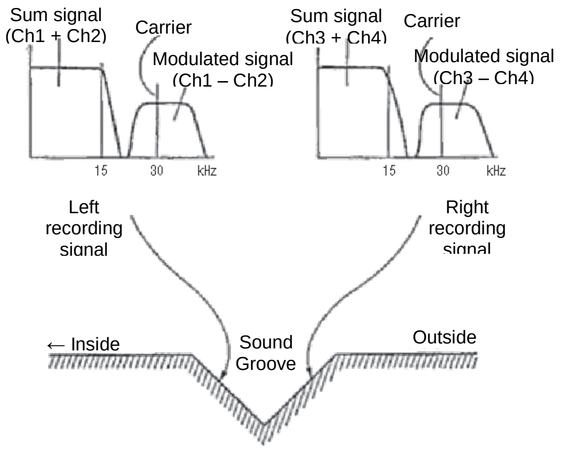


Fig. 5.61 CD-4 record signal configuration.

As CD-4s required low playback distortion at high frequencies, and as narrow styli such as the Shibata stylus were being developed and introduced, distortion compensation for these narrow styli was also implemented. Unfortunately, even though the CD-4 brought together all of the latest technologies, it was short-lived due to a lack of demand for content.

Regarding 4-channel records, it is interesting to note that (with the exception of surround sound for movies on DVD, etc.) there is the same lack of demand for content even now (when multi-channel digital audio is easy to implement and its adoption should be expected) as there was when Miura *et al.* conducted the evaluation experiments described in Section 5.1.3.

5.5 Improvements in Record Manufacturing Technology and Record Materials

Figure 5.62 provides a rough outline of the process of manufacturing a master disk, from lacquer disk to stamper.

The evolution of this process and the materials used will be explained below.

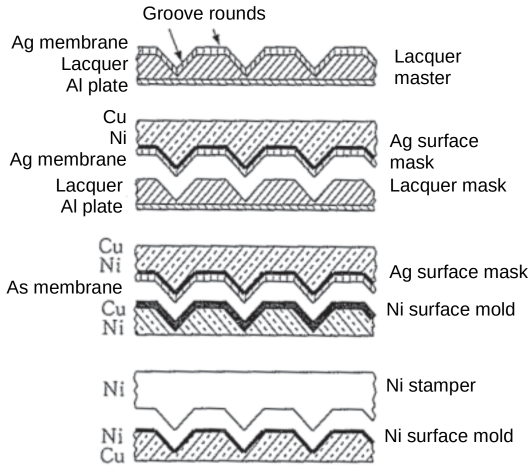


Fig. 5.62 Record master disk process outline.

5.5.1 Attempts to Make the Master Disk Conductive

Master disks were made by the methods described in the following paragraphs. Montan wax, beeswax, and vegetable wax were melted together in a suitable ratio and poured into a mold to make a wax disk. The cooled wax disk was smoothed on a lathe to a thickness of 30 mm and was used for recording, Wax disks lacked electrical conductivity and needed to be treated, so methods such as brushing on graphite or embedding a copper wire in the periphery of the disk were used to give the disk conductivity before electroplating. However, the size of the graphite crystals or damage caused by the brush during application could cause surface noise problems because the smoothness of the record face could not be guaranteed. The graphite process to add conductivity was replaced by a gold sputtering process developed by Bell Laboratories in the late 1930s. This method was not perfect either: the wax disks, lacking homogeneity, would degas in the vacuum, causing the gold vapor to be deposited unevenly. Another problem was the excessive temperatures at the disk face during vapor deposition, which would reach 80°C to 100°C.

Such were the conditions when lacquer disks appeared. However, as with wax disks, when it came to depositing a gold layer on them, the problem of plasticizers and residual solvents evaporating from the master due to the heat of vacuum sputtering remained unsolved, and silver and copper sputtering did not offer any improvement. Furthermore, sputtering equipment was apparently expensive at the time. One might suppose that this state of affairs prevented sputtering from becoming popular, and led to the transition to silvering.

5.5.2 Silvering Lacquers

Although silvering was already being used to coat glass mirrors long before it was used to make master disks conductive, it wasn't until around 1950 that it began to be applied to lacquer disks. Table 5.11 shows an example of a silvering solution and a reducing solution used for silvering lacquer disks.

Table 5.11 An example of a silvering solution and a reducing solution used for silvering lacquer disks to provide conductivity.

Silver solution	Silver nitrate	5 gms
	Water	600 mL
	Ammonia water	As required
Reducing solution	Formalin solution	9 mL
	Water	100 mL

The 1950s saw the introduction of spraying methods, and the process gradually came to be automated.

An example of an actual process would be as follows: A lacquer disk would be mounted on a turntable and rotated, and then it would be rinsed, washed with a cleaning fluid, rinsed, sensitized with stannous chloride, rinsed, sprayed with silver solution, and rinsed again. These processes were on timers, with many records being processed in parallel automatically.

5.5.3 Making Masters, Mothers, and Stampers

Electrotyping is used to precisely reproduce the microscopic grooves found on lacquers. Fundamentally similar to electroplating, this method enables an exact duplicate of a matrix to be produced by electrically depositing metal (nickel) onto the matrix until it reaches the required thickness, after which it is detached. This requires the creation of an atomically-thin metal oxide layer on the surface to serve as a release liner to allow the deposited metal to be detached, a process using anodizing which is referred to as "passivation." Electrotyping allows things that are impossible to machine or difficult to process to be duplicated with great precision, Sub-micron tolerances are said to be possible.

First, the master disk is electroplated with nickel using a Watts bath. A typical example of the solution used in a Watts bath is shown in Table 5.12.

Table 5.12 Watts bath solution and operation conditions (example).

Nickel sulfate	250–350 g/L
Nickel chloride	15–45 g/L
Boric acid	30 g/L
pH	3.0–4.0
Solution temperature	40–60°C
Current density	15–30 A/dm^2
Electroplating is carried out at a current density of 10–25 A/dm^2 for approximately 1 hour to produce a layer 0.05 mm thick.	

After nickel plating, copper electrotyping is performed. Copper electrotype has a long history, having been used for electrotype printing plates, etc., since the 19th century. Copper electrotypes have less internal stress than electrotypes made using other metals, and are quite appropriate. However, copper stampers required enough strength and flexibility to withstand the stress of pressing records in LP manufacturing. Attempts were made at nickel electrotyping, but the great internal stresses hindered progress. Then, shortly before the outbreak of World War II, an electrotyping process using nickel sulfamate that produced very little internal stress was developed in the United States. Table 5.13 gives an example of the composition of a nickel sulfamate bath.

Table 5.13 Nickel sulfamate solution composition and operating conditions (example).

Nickel sulfamate	350–450 g/L
Boric acid	300 g/L
pH	3.0–4.0
Solution temperature	40–60°C
Current density	15–30 A/dm^2

Under these conditions, approximately 0.2 mm of nickel would be deposited over the course of one to two hours, and after chrome plating, the back of the disk would be sanded and the disk finished to facilitate pressing.

By the end of the 1950s, electrotyping was being used to make not only stampers, but mothers as well. Nickel masters and nickel mothers became widespread, and are still used to this day.

Today, analog record manufacturing has dwindled, continuing only as small-scale production in a few countries, having been replaced by CD and DVD manufacturing. The manufacturing process for CDs, LaserDiscs and DVDs is similar to that for analog records, and the same technology is used. Without electrotyping technology, the mass production of LaserDiscs, CDs and DVDs, would be impossible. Master disk and stamper manufacture involves many aspects of electrotyping technology, such as rendering the matrix conductive, separating the electrotype from the matrix, uniform deposition, managing stresses in the electrotype caused by plating conditions, such as current density, and considering the physical and mechanical properties of the metal used (nickel), each of which demands a high level of technology.

5.5.4 Changes in the Record Manufacturing Process

SP records were manufactured from 1910 until 1959. Until 1928, single-sided (solid) records were manufactured, and from 1929 until 1959, double-sided laminated records made from surface and core materials with superior sound quality, wear resistance, and noise levels were manufactured. Both types had an overflow attached to the edge of the record, which would be trimmed off with a cutter.

In Japan, manufacturing of LPs was commenced in 1951, and EP manufacturing began in 1954.

It was in 1951 that Nippon Columbia released the first Japanese vinyl LP record: Beethoven's Symphony No. 9 in D minor, op. 125 "Choral" conducted by Bruno Walter with the New York Philharmonic Orchestra. This record (shown in Fig. 5.63) is registered as one of the Essential Historical Materials for Science and Technology by the National Museum of Nature and Science as the "First Japanese-made vinyl LP record" (No. 00097).

Fig. 5.63 The first Japanese vinyl LP record.

EP records were designed with autochangers in mind and were called "donut disks" because of the large hole in the center. The first Japanese EP record was released in 1954 by JVC, and featured "Blue Canary" sung by Dinah Shore.

LP and EP records were made from different materials from SP records (being made from a vinyl resin base) and solved many of the drawbacks of SP records, having low surface noise, excellent durability, light weight, toughness, high fidelity characteristics, and coming in many colors.

At first, Japanese records were pressed from imported biscuit-shaped material from the United States, but efforts were made to domesticate vinyl chloride resin production and this finally became possible in 1956.

Disk records go through many stages such as pressing, preheating, extrusion, pressing, packaging, previewing and inspection, which includes passing through an automatic noise detection unit. In 1965, some EP records were made using injection molding.

5.5.5 Changes in Record Materials

Wax disks were used for recording SP records until around 1951, after which they were replaced by acetate disks. Shellac remained the dominant record material for over fifty years after Emile Berliner first thought of using it, only being superseded when the LP record was invented in 1948. Shellac is a natural resin secreted by the lac insect (a kind of scale insect) that is produced in places such as India and Thailand. Shellac was mixed with natural resins such as rosin and copal, fillers such as clay and baryte, and carbon black, and was kneaded using a heating roller. Early solid SP records mainly used shellac. Later laminated records also used shellac as the main surface material.

Double-sided lacquer disks (aluminum disks coated with nitrocellulose lacquer; sometimes called “acetates”) were used to record LPs and EPs. These disks were supplied by the US companies Transco and Capitol Audio Disk for many years.

Regarding LP and EP disk materials, Union Carbide Plastics Co. researched materials for records for over 20 years beginning in 1930, and perfected a vinyl chloride/vinyl acetate copolymer for LP and EP records. This material was developed with the aim of using it in the same presses used for pressing 78-rpm shellac records.

This copolymer displayed better workability than other plastics during pressing, and other advantages included a shorter pressing time, excellent mechanical strength and abrasion resistance, minimal loss of high frequencies, and excellent acoustic characteristics.

Generally, adding plasticizers to vinyl records proportionally increases their susceptibility to temperature, groove wear, and sound quality deterioration at high frequencies. The PVC must therefore not use plasticizers, but still have good plasticity. Records are made with a rigid PVC resin, and a copolymer with a relatively low degree of polymerization and a high copolymerization ratio is used. A rigid PVC composition contains stabilizers, fillers, lubricants and colorants; these are mixed uniformly in the kneading process and compacted to make vinyl records.

One kind of vinyl resin for records that was well known around the world was Vinylite VYHH-3, a copolymer resin made by the Bakelite Company that contained 87% vinyl chloride and 13% vinyl acetate. This resin used to be imported into Japan. Japan began to develop rigid vinyl for records around 1950, with Zeon Corporation, Shin-Etsu Chemical Co., Ltd., Kaneka Corporation and others beginning to supply vinyl from around 1956.

An example of the composition of the Bakelite Company’s VYHH-3 is shown in Table 5.14, and the composition of Zeon Corporation’s 400X150P is shown in Table 5.15.

Table 5.14 Composition of LP or EP records containing VYHH-3 (example)

For black records	VYHH-3	97.5%
	DS-207	1.5%
	Carbon black	1.0%
For red records	VYHH-3	98.4%
	DS-207	1.5%
	Oil red dye	0.1%

Table 5.15 Composition of records containing Zeon Corporation’s 400X150P.

For black records	400 x 150 P	100%
	Dibasic lead stearate	1.5%
	Carbon black	1.0%
For red records	400 x 150 P	100%
	Dibasic lead stearate	1.5%
	Oil red die	0.5%
For transparent records	400 x 150 P	100%
	Organic tin stabilizer	1.5–2.0%
	Transparent colorant	A little

The process of making records with a stamper and the materials described above is known as molding. Methods of pressing can be generally classified into pressing and injection molding. Twelve-inch and 10-inch records are usually made with the first process, and CDs and 17-cm records with the second.

It is widely known that molding conditions have a great effect on manufacturing efficiency, characteristics, and sound quality. Record companies work to find the optimal conditions and treat this information as a trade secret, so there is not much information available on this subject.

During the pressing process, the nickel and chrome stampers are mounted on the press, preheating is applied, the labels and materials are added, and heat and pressure are applied to ensure the materials spread evenly. Then, the record is cooled to finish the process. Manufacturing efficiency would be increased if the preheating, heating, pressure, and cooling stages were shortened, but this may increase the number of disks where the grooves are not faithfully reproduced, or where noise is increased. The pressing characteristics of the material also change if composition is changed.

Table 5.16 lists conditions that can affect the pressing cycle.

Table 5.16 Conditions that can affect the pressing cycle.

(1)	Record size
(2)	Fluidity of materials
(3)	Stamper groove shape
(4)	Mold structure/thermal conductivity
(5)	Molding equipment structure
(6)	Molding conditions
(6)-1	Materials
(6)-2	Temperature
(6)-3	Steam pressure
(6)-4	Cooling water temperature/pressure
(6)-5	Press pressure

5.5.6 Special Records

5.5.6.1 Card Records

From the days of SP records, attempts were made to produce paper records by pressing grooves onto postcards or cards with photos or paintings. Initially, grooves were pressed onto the surface of printed card paper directly, but commercial quality was unable to be achieved due to the noise generated. Next, grooves were pressed onto card paper laminated with cellulose acetate film, and such records were used to promote tourism (sometimes they contained folk songs), as well as for other advertising purposes. However, this type of record had to be pressed one by one in order to prevent misalignment of artwork and grooves, meaning that there were disadvantages, such as the difficulty of mass production and inconsistency in terms of sound quality due to the undulating nature of the surface material. Playback could also sometimes be affected by the problem of warping, which was caused by differences in constriction rate between the film and base paper. Cellulose acetate film subsequently gave way to vinyl chloride film and double-sided records with pictures appeared, as mentioned in the following section.

5.5.6.2 Records with Pictures

Although various methods of production were developed to produce records with pictures, the main method was to dust paper with a printed picture on it with vinyl powder and then to cut grooves on it. The other method was to use photogravure to print a picture on the back of vinyl acetate film that had already been punched out in a certain record size and to have the back of the picture painted in white to make the picture stand out, in which case two sheets were placed together back to back and then pressed in the normal way.

5.5.6.3 Phonosheets

In the fall of 1958, the French record manufacturer SAIP developed a technology that made continuous production of records from thin, flexible vinyl sheet (0.13–0.2 mm thick) possible using a stamper. These flexi discs, which were also called phonosheets or soundsheets, were sometimes included in magazines. In Japan, the monthly Asahi Sonorama magazine included them and they were referred to as “Sonosheets.” Phonosheet production peaked at 6 million per month between 1963 and 1965, after which it declined.

5.5.6.4 Mystery Records

In March 1932, during the era of SP records, JVC released a record that had multiple grooves and made different sounds according to the place where the needle was dropped. This was called a Mystery Record and became a topic of conversation at the time.

5.5.6.5 Sonopic and Panapic

These were non-rotating phonosheet playback systems that employed a small moving pickup cartridge with a stylus to play a stationary record engraved on a plastic patch. Uses ranged from children’s storybooks to educational material, such as English conversation.

5.5.6.6 Other Record Formats

Although the main sizes of records during the SP era were 10-inch (25 cm) and 12-inch (30 cm) for SP records, there were also other sizes on the market, such as 8-inch and 5-inch records.

Once LP and EP records became more popular, 12-, 10- and 7-inch records became the mainstream, but 8-inch, 6.3-inch and 3-inch records were also available at the time.

5.5.6.7 The Filmon

Please refer 2.3.2 of this paper for the unique Japanese Filmon media.

5.6 Playback Pickup and Record Player Developments

5.6.1 Phonographs

The competition between cylinder records and disk records continued even after entering the 20th century. Although Edison tried to promote cylinder records by developing the cylinder phonograph, he ended up developing a record player for high quality vertically-cut disk records that could record vertical high-amplitude signals, which brought confusion into this competition, resulting in the dominance of disk records.

5.6.2 Electric Gramophones

Until 1924, all records had been recorded acoustically and without electricity. Although that method was suitable for recording vocal pieces, the lower frequencies of which it is difficult to capture, it was not suitable for recording orchestral music. Furthermore, it seems that the sound quality from the radio (150–1,500 Hz), which was free to listen to, was better than that of records (300–1,500 Hz). With the commercialization of electrical audio equipment that utilized vacuum tubes shortly after they were invented, such as the microphone, it became possible to record bass more clearly and electric gramophones grew in popularity. In terms of pickups, the crystal pickup was gaining attention due to the fact that it was compatible with high-impedance vacuum tubes, it was not susceptible to mains hum, and its large output level and relatively cheaper price.

5.6.3 LP Cartridges

While compact and cheap crystal pickups contributed to the popularization of LPs, in the 1950s, specialist audio manufacturers appeared in the US. The three famous types were GE variable reluctance (VR) cartridges, Pickering balanced armature (BA) cartridges and Fairchild moving coil (MC) cartridges. Although Japanese cartridges were brought to market around the same time, they were mostly imitations of American products, except for the STAX CP-20 (Showa Photo-Acoustic Industries KK), which was a condenser pickup system uniquely and proudly made in Japan and exhibited at the first Japanese Audio Fair in 1952. Pickup oscillation was extremely light and it could playback LP records with a tracking force of only 1 g.

5.6.4 Stereo Cartridges

The prototype for the 45/45 stereo disk recording system was completed by Westrex Corporation in 1957 and was adopted by the RIAA as the industry standard (stylus tip of 0.7-1.0 mil radius and vertical force of 6 grams) in March 1958. That same year, stereo records were released from 19 labels in the United States, followed by JVC and Nippon Columbia in Japan. It is no exaggeration to say that the advent of stereo records caused the 1960s audio industry boom in the US followed by the boom in Japan in the 1970s. In terms of crystal pickups, in 1960 Takeo Shiga (former director of Nippon Columbia) invented the “cigar cartridge,” which picks up stereo signals using a pair of piezoelectric crystal elements that were cut using a proprietary method. Although crystal cartridges had the advantage of being light and cheap, the high impedance required of the crystal cartridges caused problems when impedance was lowered with the introduction of transistors into amplifiers, while the lightness of the needle meant that trackability was poor. So, crystal pickups were only really popular for the first half of the stereo age, after which they became obsolete.

5.6.5 VLP Tonearms

When LP records were introduced, heavy tonearms were still used, such as the oil-damped Gray 108B tonearm, which was often used in combination with GE variable reluctance (VR) cartridges. Once stereo cartridges were introduced, this type of tone arm faded away because such arms rested on a single pivot, which meant that the arm could move freely to the left and right, causing crosstalk when combined with stereo cartridges. Furthermore, due to their high equivalent mass, when combined with stereo high compliance cartridges the resonant frequency of these tonearms was reduced to only a few Hertz, and there was noise during playback due to record warping and eccentricity.

5.6.6 Stereo Tonearms

Although the oil-damped Gray tonearm captured the market during the monaural era, once stereo records were introduced in 1958, tonearms required a different design where playback had to be achieved with a low equivalent mass and light tracking force of 2–3 g, with the resonant frequency set at around 10 Hz. A mechanism called an inside force canceler, which cancels the inside force that occurs due to the centrifugal force produced when playing records using a light tracking force, was also adopted on many tonearms. A mechanism for adjusting the vertical tracking angle of the cartridge during playback of stereo records to 15 degrees, the same as the cutting angle, also came to be used on many tonearms. Tonearm tracking force adjustment consisted of statically balanced tonearms and dynamically balanced tonearms, which used a spring.

5.6.7 Turntable Motors

Ordinary shaded-pole induction motors or permanent-split capacitor motors were used to drive turntables, while hysteresis synchronous motors were used for high-quality players. Development of idler drive turntables (also called rim drive turntables) by The Alliance Manufacturing Company (the U.S.) in 1938 started the low-cost record player boom. It is also worth-mentioning that autochangers for LP players became popular in Europe and the US, although they did not catch on in Japan.

5.6.8 Direct Drive Turntable Motors

In the 1960s, although rim drive turntables were replaced with belt-drive turntables on account of the improved wow and flutter, the degree of improvement was still not sufficient. Around the same time, servomotors started to be used in various units. In terms of turntable motors, Matsushita Electric Industrial Co., Ltd. announced the technology for the first direct-drive turntable motor in June 1969, followed by the introduction of a DC servo direct-drive turntable motor. Nippon Columbia followed suit by releasing an AC servomotor ahead of other companies that released similar products.

Bibliography

[1] *Fifty Years of Audio History*, Japan Audio Society, Disk records, III Record players, IV Microphones, (December 1986)

[2] *Stereo Recorders*, Kenji Hayashi, NHK STRL News, Vol.12, No.11, pp. 12–17 (November 1969)

[3] Hideaki Hayashi, Atsushi Miyashita, Koichi Oshinden, Shigeo Todoroki, Tateaki Anazawa, *PCM Recording Equipment for Disk Record Masters*, Lectures and Collected Papers of The Acoustical Society of Japan, 3-4-20 (October 1972).

[4] Akira Terashima, Kaoru Yamamoto, Tateaki Anazawa, *Digital Mastering/Mixing Console and PCM/Digital Recorders*, Broadcasting Technology, April 1985, pp. 78–84.

[5] Yukio Takahashi, Hiroyuki Yazawa, Hajime Ishihara, *Random Accessing Type Editing Device DN-036ED*, Broadcasting Technology 35 (1982).

[6] Tateaki Anazawa, *Problems Associated with Digital Tape Editing*, Acoustical Science and Technology Vol. 39, No. 9 (1983) pp. 624–630.

[7] Keisuke Kinoshita/Tomohiro Nakatani (NTT Communication Science Laboratories), Masato Miyoshi (Kanazawa University), *Subjective Assessment of Stereo Music Surround Playback Sound Created Based on the Principle of Reverberation Rejection*, Lectures and Collected Papers of The Acoustical Society of Japan, pp. 759-760 (September 2009).

[8] Tateaki Anazawa, *Frequency Records*, Acoustical Science and Technology Vol. 30, No. 2 (1974).

[9] *Non-Distortion Cutting*, Radio Technology, November 1970.

[10] Hideo Ise, *Electroforming Technology and Application*, Makishoten.

[11] Hideo Ise, *Record Materials and Molding*, Vinyls and Polymers Vol. 10, No. 10.

6 Changes and Shipment Trends in the Record Industry and Record Player Industry

6.1 Changes and Shipment Trends in the Record Industry

The history of the record industry in Japan began in October 1907, when F.W. Horn Trading Company of Yokohama established Japan-American Phonograph Manufacturing Co., Ltd. in Kawasaki and commenced to manufacture disk records and phonographs. Two years later this company was taken over by Japan Phonograph Trading Co., Ltd. (one of Horn’s other companies and the predecessor to today’s Columbia Music Entertainment, Inc.) and by 1912, monthly production volumes had jumped to 150,000 units for records and 5,000 units for phonographs.

Although both single- and double-sided records were being produced at the time, from 1915 onwards, only double-sided records were produced.

After that, in May 1927, Nippon Polydor Chikuonki Co., Ltd. was established, followed in September of the same year by the Victor Talking Machine Company of Japan, Ltd.

Colombia acquired a controlling interest in the Nipponophone Company, the successor to The Japan Phonograph Trading Co., Ltd., and the following year (1928) the first electrically-recorded record in Japan was released by the company, which had been renamed Japan Colombia Phonograph.

In 1931, Kodansha, Ltd. established King Record Co., Ltd. as its music division and Teikoku Gramophone Co., Ltd. (predecessor of Teichiku Entertainment, Inc.) was established in 1934.

In April 1942, the Japan Phonograph Record Cultural Association (predecessor of the Recording Industry Association of Japan (RIAJ)) was established.

After the end of the war, record production commenced once again in October 1945.

Japan’s first 30 cm LP record was released by Nippon Columbia in 1951, and Japan’s first 17 cm 45-rpm EP record was released by Victor Company of Japan, Ltd (JVC) three years later in May 1954.

Meanwhile, the aforementioned Japan Audio Society was established in October 1952.

In August 1958, the first 45/45 stereo records were manufactured in Japan and within a year, all Japanese record companies were producing them.

As restrictions on foreign capital investment were lifted in July 1967 as part of the gradual promotion of foreign investment, in record manufacturing industry it became possible for foreign companies to hold 50%. As a result of such measures, Sony Corporation and Columbia Broadcasting System, Inc. of the US established CBS-Sony Record in Japan as a fifty-fifty joint venture in March 1968.

Major events in the history of the Japanese record industry are listed in Table 6.1, while changes in analog record annual production volumes and annual sales are shown in Fig. 6.1.

As you can see, the annual production volume for 78-rpm SP records reached 30 million units in 1936, and 94.6 million units for 30 or 25 cm LP records in 1976 (worth ¥12.36 billion), and was in excess of ¥100 million for 17 cm 45-rpm EP records in 1979.

Table 6.1 Important events in the history of the Japanese record industry.

1877	Cylinder phonograph invented by Thomas Edison.
1887	Flat disk phonograph record and gramophone invented by Emile Berliner.
1907	Japan-American Phonograph Manufacturing Co., Ltd. established. Disk record and phonograph manufacturing commenced.
1909	Japan-American Phonograph Manufacturing Co., Ltd. and Japan Phonograph Trading Co., Ltd. (predecessor to today's Columbia Music Entertainment, Inc.) took over manufacturing and sales.
1912	Japan Phonograph Trading Co., Ltd. monthly production volume reached 150,000 units for records and 5,000 units for phonographs.
1915	Japan Phonograph Trading Co., Ltd. stopped producing single-sided record and focused on double-sided records.
1927	Nippon Polydor Chikuonki Co., Ltd. and Victor Talking Machine Company of Japan, Ltd. were established.
1928	First electrically recorded records in Japan released by Japan Colombia Phonograph.
1930	Kodansha, Ltd. established King Record Co., Ltd. as its music division.
1931	RCA Victor US released 33 1/3-rpm long-play (LP) records.
1934	Teikoku Gramophone Co., Ltd. (predecessor of Teichiku Entertainment, Inc.) was established.
1942	Japan Phonograph Record Cultural Association (predecessor of the Recording Industry Association of Japan) was established.
1948	Columbia Recording Corporation in the US introduced 33 1/3-rpm LP records.
1949	RCA Victor US released 7-inch EP records.
1951	Nippon Colombia released Japan's first 12-inch LP records.
1955	First successful commercial production of polyvinyl chloride in Japan.
1958	Victor Company of Japan, Ltd. (JVC) released Japan's first 45/45 stereo records in August, ahead of any other companies. Toshiba commenced sales of records with an anti-static agent.
1959	Publication of Asahi Sonorama magazine and Sonosheet sheet records was commenced.
1966	JVC commenced sales of the Philips compact cassette system.
1967	First deregulation of foreign capital investment in Japan (50% foreign capital share allowed in record industry). Nippon Columbia released 30 cm 45 rpm records.
1968	CBS-Sony Record Inc. was established with foreign capital of 50%.
1969	Nippon Victor announced 4-channel system (CD-4). Nippon Columbia released record produced using direct-cutting method.
1970	Nippon Columbia released records produced using non-distortion cutting (playback distortion adjustment records).
1971	Nippon Columbia released records produced using pulse code modulation (PCM)/digital recording. Four-channel matrix systems adopted by other companies in Japan.
1972	Nippon Columbia continued using PCM/digital recording for record production and sales inside and outside Japan.
1982	Sales of domestically produced CDs commenced by CBS-Sony, Epic/Sony and Columbia in October.
1986	Licensing of CD rentals commenced. Domestic sales for CDs superseded domestic sales for 30 cm/25 cm LP record.
1987	Sales of DAT made in Japan commenced by Matsushita, Aiwa and Sharp.
1989	Athens Agreement signed (serial copy management system (SCMS adopted).
1990	The Ministry of International Trade and Industry overseas the incorporation of SCMS in commercialization of DAT. First international meeting regarding recording technology held and introduction of International Standard Recording Code (ISRC) agreed on.

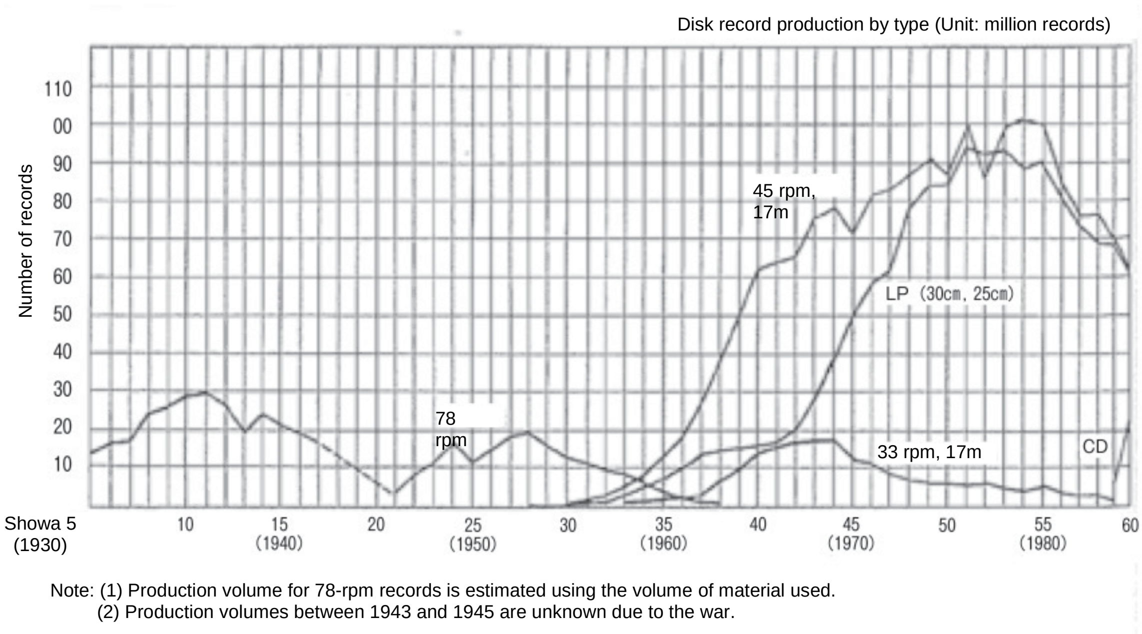


Fig. 6.1 Annual production volumes and sales for analog records in Japan. (Source: Recording Industry Association of Japan)

In the mid-1980s, LP and EP record production volumes dwindled while compact discs (CDs) took their place. This phenomenon can also be observed in the state of record player sales (Table 6.3).

In terms of analog record imports/exports, LP record production volumes peaked in Japan in 1976 (Table 6.2).

Table 6.2 Analog record exports/imports.

Exports (number): Approx. 720,000	Exports (value): Approx. ¥430 million
Imports (number): Approx. 3.6 million	Imports (value): Approx. ¥2.95 billion

The volume of imported records was five times the volume of exports, while the import value was seven times the value of exports. This figure becomes even greater when the licensing fee to produce hit records of overseas artists in Japan is included. Most of the exported records were bought by foreigners who appreciated the good sound and quality of Japanese audiophile records, Japanese who lived overseas and the people around them. Once digital recording outside Japan became common practice, the destinations of record exports were mostly these countries where such recording was carried out.

Needless to say, it takes songs, singers, producers and recording technologies that can hold their own on the world stage to counter the imbalance caused by excessive imports. The phenomenon that was ridiculed by Charles de Gaulle still continues.

6.2 Changes and Shipment Trends in the Record Player Industry

Although the audio industry can be categorized into various fields, in the same way as for records, the starting point for audio equipment in Japan was the establishment of Japan-American Phonograph Manufacturing Co., Ltd. in Kawasaki by F.W. Horn Trading Company of Yokohama in October 1907 and the subsequent production of the first disk records and record players. By 1912, monthly production volumes had jumped to 150,000 units for records and 5,000 units for phonographs.

The situation with regard to analog records and record players is somewhat of a “chicken and egg” relationship, meaning that it is wholly dependent on the stereo record player ownership rate. As shown in Table 6.3, the ownership rate of 3.7% in 1961 gradually grew to exceed the 30% mark in 1970, the point that had been awaited by many stakeholders, and reached 53.8% in 1976, when LP record production peaked. First, non-electric record players gave way to electric record players, and then came the age of the all-in-one stereo systems that became a prominent part of the consumer electronics industry. After that, as shown in Fig. 6.2, all-in-one stereo systems gave way to stereo record player units with detachable speakers (peaked around 1973 with an ownership rate at 44.4%), followed by compact 3-piece stereo systems (peaked around 1974 with an ownership rate of 46%), component stereo systems (popular around 1977, 1988 and 2001), modular component systems (peaked around 1979 with an ownership rate of 56.5%), and compact stereo component systems (peaked around 1984), changing about every eight (six to ten) years.

In terms of component stereo systems, however, thanks to constant technological innovation over the last 40 years, supply of such systems has continued right throughout that time. Analog record players were included in such component stereo systems, even after sales of analog disk records were discontinued.

Table 6.3 Stereo system/tape recorder ownership trends in Japan (Economic Planning Agency *Consumption and Saving*)

Month/Year	Farmers	Non-Farmers	Cities with a Population of 50,000 or More	All Households	Tape Recorder Ownership in All Households
February 1961	-	-	3.7%	-	-
February 1962	-	-	7.2%	-	-
February 1963	2.1%	-	10.8%	-	-
February 1964	3.4%	11.3%	13.4%	9.0%	8.7%
February 1965	5.0%	17.2%	-	13.5%	14.6%
February 1966	5.5%	20.2%	23.9%	16.7%	17.9%
February 1967	9.2%	23.5%	25.8%	19.8%	22.5%
February 1938	13.4%	27.5%	28.9%	24.1%	24.5%
February 1969	15.8%	30.5%	32.5%	27.3%	28.6%
February 1970	18.6%	34.6%	36.6%	31.2%	30.8%
February 1971	21.9%	37.1%	38.7%	33.9%	33.3%
February 1972	27.3%	43.6%	43.1%	40.4%	38.1%
February 1973	31.5%	47.0%	48.5%	44.4%	42.1%
February 1974	35.0%	49.2%	50.4%	47.0%	47.0%
February 1975	41.5%	53.7%	55.6%	52.1%	51.6%
February 1976	43.7%	55.4%	56.2%	53.8%	55.9%
February 1977	46.6%	56.8%	57.9%	64.9%	56.2%
February 1978	48.8%	57.6%	57.8%	56.3%	59.3%

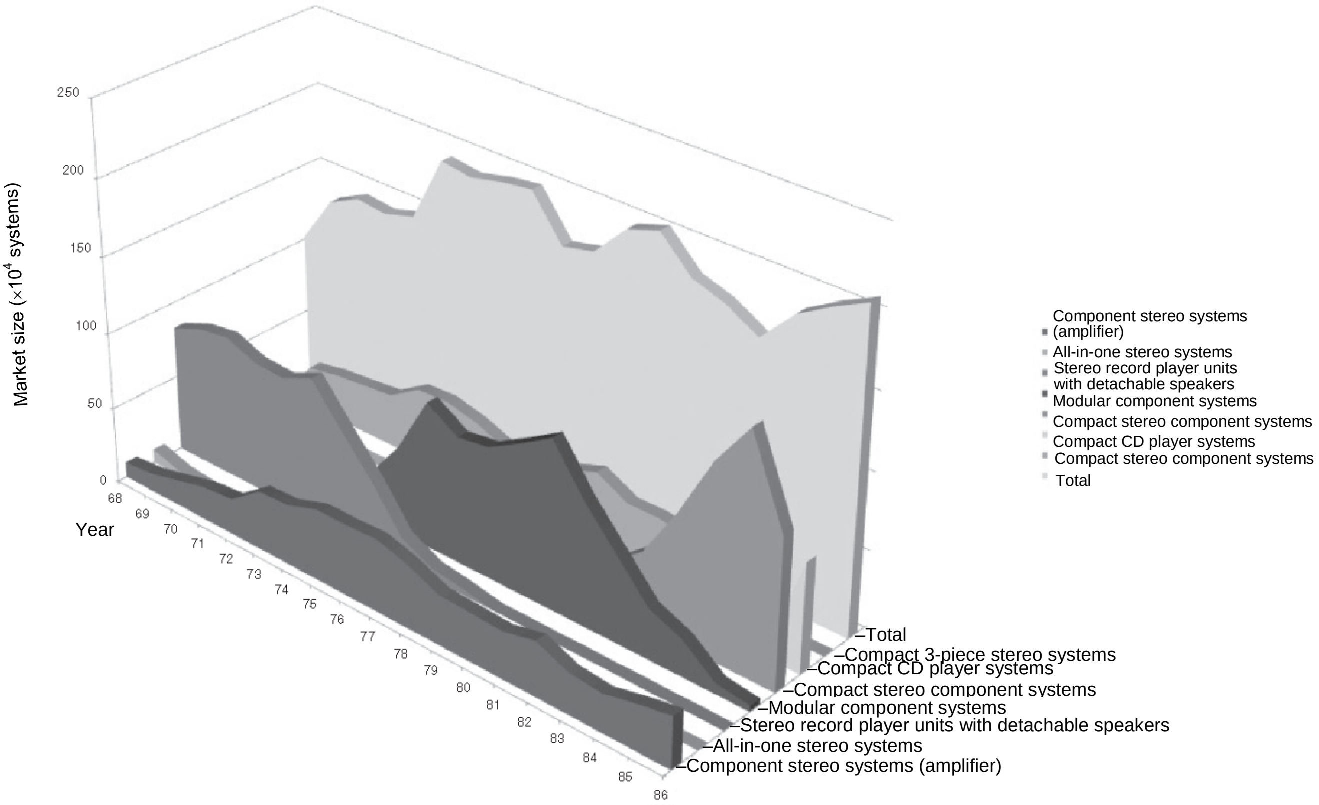


Fig. 6.2 Audio equipment market trends in Japan (1968–1986)

President Charles de Gaulle partly gave up on the situation regarding France's export and import of stereo record players in 1962, in that in terms of home stereo system imports/exports, unlike the situation with analog records, in 1963, exports, at 600,000 units, were 20 times higher than imports, which amounted to 30,000 units.

After CD records became well-accepted by the general public, radio cassette player with CD players hit the market, peaking around 1988, followed by smaller compact stereo component systems and even smaller micro stereo component systems, which peaked around 1995, before we entered the age of the Internet and online music.

Bibliography

[1] *Recording Industry Association of Japan – A 50-year History of a Cultural Industry*, published on March 1, 1993 by the Recording Industry Association of Japan.

[2] *The Record Industry in Japan, 2013 Edition*, published in April 2013 by the Recording Industry Association of Japan.

[3] Economic Planning Agency, *Consumption and Saving Trends*.

[4] Ministry of International Trade and Industry, Statistics Department, Customs Clearance Records, Electronic Industries Association of Japan shipment records, etc.

7 Audio Record-Related Standards/Codes

Audio records are marketed throughout the world and as such must be able to be replayed on any record player in the world.

Therefore, standards and codes to ensure compatibility and to make that a reality are essential. They must also eliminate the possibility of entry barriers.

In terms of standards, there are international standards set by international organizations, domestic standards set by governments, and industry standards set by industry organizations. In order to ensure worldwide compatibility in the analog disk record market and to facilitate international trade, the establishment of such standards is necessary. In Japan, MITI (the Ministry of Economy, Trade and Industry (METI)), the Agency of Industrial Science and Technology (predecessor of the National Institute of Advanced Industrial Science and Technology (AIST)), the hardware industry and the record industry were all actively engaged in developing these standards and made it possible for the audio industry – especially the hardware industry – to flourish. However, in the case of the record industry in Japan, even though there are no problems in terms of compatibility, exports from Japan are still almost non-existent as the industry is still unable to shake off the problem of a lack of content.

The outline of codes for analog disk records is explained as follows.

7.1 International Standard Recording Code System and Related International, Domestic and Industry Codes Concerning Analog Record

Due to the connection with electricity, international standards for analog disk records are established by the International Electrotechnical Commission (IEC), which has its headquarters in Geneva. Standards such as the International Standard Recording Code (ISRC), which is an international standard code for identifying sound recordings, are set by the International Standardization Organization (ISO), which also has its headquarters in Geneva. Japanese Industrial Standards (JIS) are set in accordance with the ISRC for analog disk records. Industry organizations, such as RIAJ, determine standards regarding labeling content and format, as well as packaging jackets and accessories, in order to ensure that products are produced in accordance with both JIS and international standards and JIS, product distribution and is carried out in a streamlined manner and to avoid confusion in the marketplace. However, such standards do not prohibit the use of non-standard types for specific uses. Furthermore, there are cases where an industry organization sets administrative regulations for information-related standards.

Analog record standards are shown in Table 7.1.

Table 7.1 Analog Record standards.

Analog Record Standards:		
International	IEC 60098 Analog Audio Disk Records and Reproducing Equipment	
Japanese	JIS Standards	
Industry	RIAJ Standards:	
	RIS202	Analog disk record labeling content and format
	RIS201	Disk record jackets and accessories

Such analog record standards are the result of efforts made by the industry as a whole over many years to prevent confusion and ensure compatibility.

ISRC-related standards are shown in Table 7.2.

Table 7.2 ISRC-related standards.

ISRC-related Standards:	
International:	ISO 3901 International Standard Recording Code
Japanese:	JIS X 0308 International Standard Recording Code
Industry:	RIAJ Standards:
RIS503:	International Standard Recording Code
RIS505:	ISRC Administration Regulations

The ISRC system was developed by the music content industry over many years and was subsequently officially adopted by the ISO. Matters such as the administration of the country code used in the ISRC system and selection of the administrative organization for each country are overseen by the International Federation of the Phonograph Industry (IFPI), and the RIAJ was selected by IFPI to carry out such activities in Japan. Therefore, it is the RIAJ that determines regulations regarding the administration of ISRCs in Japan.

7.2 Other Standards

The analog disk and ISRC standards mentioned in the previous section were originally developed and used by the industry as a whole. Of these, some were originally private standards developed by a certain company and later, in the interests of facilitating marketing and ensuring compatibility, after sufficient discussion they were adopted by organizations that set international standards, including the International Electrotechnical Commission (IEC), to became international standards. Examples of such standards can be still be observed with audio cassette tapes and CDs.

Standards for audio cassette tapes are shown in Table 7.3, while standards for CDs are shown in Table 7.4.

Table 7.3 Audio cassette tape standards.

Audio Cassette Tape Standards:	
International:	IEC60094 “Magnetic Tape Sound Recording and Reproducing System” Psrt1-7
Japanese:	JIS S 8604 Cassette Tape Recording
Industry:	RIAJ Standards:
RIS306:	Audio Cassette Tape Recording Label Content and Format
RIS307:	Cassette Tape Recording Accessories

Table 7.4 CD standards.

CD Standards:	
International:	IEC908 Compact Disc Digital Audio System
Japanese:	JIS S 8605 Compact Disc Digital Audio System
Industry:	RIAJ Standards:
RIS204:	Audio CD Label Content and Format
RIS203:	Compact Disc Accessories

The abovementioned industry standards (RIAJ RIS Codes) are available for download in PDF format at the following website:
http://www.riaj.or.jp/issue/ris/

In addition to the above, there are other industry standards for, among other things, preventing confusion among users. These include many industry standards regarding testing methods and connections for speakers, amplifiers and players that compliant with JIS standards.

The main reference material referred to in this chapter can be found in the text.

8 Methods of Identification and Protection for Recorded Materials

8.1 ISRC Identification of Recorded Materials

In an age where the music content business has become established as a business in its own right and recorded music is recognized as a commodity, identification is a key factor. Unique identification methods for music recordings with or without video were investigated by the ISO, and the ISO3901 International Standard Recording Code (ISRC) system was established in 1986. Following the establishment of the ISRC system by the ISO, JIS codes and RIAJ codes (RIS codes) were also established, including JIS X 0308. ISRC administration standards were discussed by the International Federation of the Phonograph Industry (IFPI), which was appointed by the ISO as an international administrative organization for the ISRC system, and enacted in November 1989, after which by July 1991 the RIAJ formulated administrative guidelines and obtained the approval of the Board of Directors in October of the same year. These codes and guidelines explain the composition of the 12-alphanumeric character ISRC, as well as related administrative standards. Administration of these codes is overseen internationally by the IFPI, which delegates administrative organizations in each country, with administration in Japan being carried out by RIAJ. The 12-character code contain a two-character country code, a three character-alphanumeric registrant code, two characters referring to the year and a five-character code that is unique to the recording.

8.2 Protection of Recorded Materials

When it comes to protecting recorded materials there are both legal and technical aspects to consider. Although mainly the technical aspects will be dealt with in this paper, basic matters regarding the legal aspects are touched on below.

As copyrights cover not only property rights, but also some personal rights, with music, there are rights for the composer and lyricist in the form of copyrights, while a distributor of such copyrighted work is entitled to related rights (or neighboring rights), as shown in Fig. 8.1. Related rights are granted to entities such as performers, arrangers, record producers, broadcasting organizations and cable broadcasting companies.

As shown in Fig. 8.1, rights concerning recorded materials are, in actual fact, related rights, meaning that as long as the uniqueness of the ISRC can be ensured, it is a convenient identification system for neighboring right holders. For example, many CDs contain the ISRC as part of a subcode and although an attempt was made to use the ISRC to establish an automatic payment system for neighboring rights, which entailed the broadcasting of the ISRC when the work was played, unfortunately the system found only limit use.

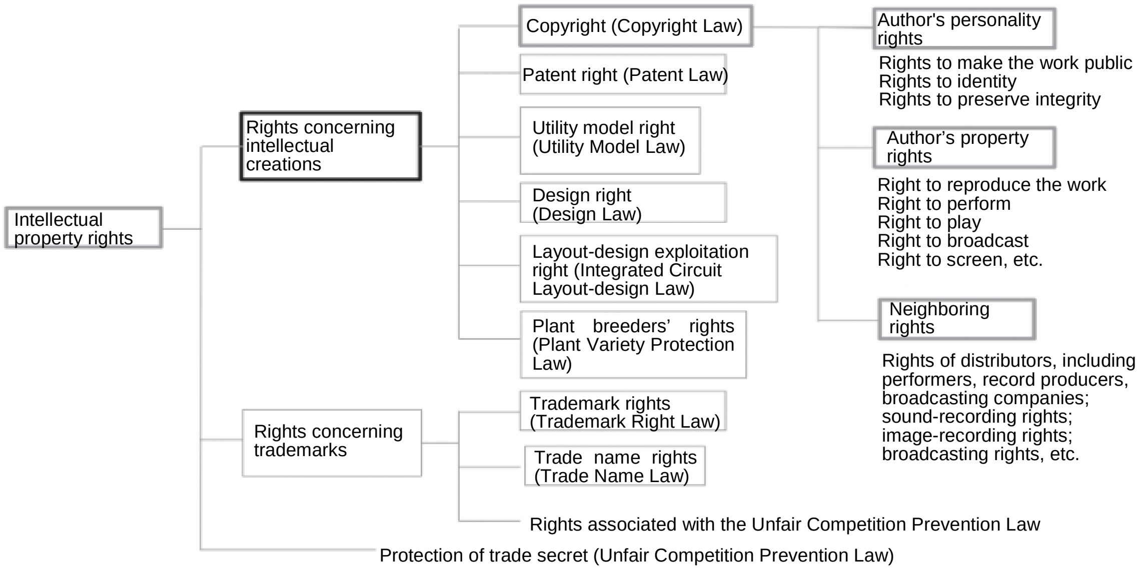


Fig. 8.1 Major types of intellectual property rights
(Bold line-squares indicate rights for intellectual creations in association with music)
(Source: Intellectual Property Rights, by Nobuhiro Okida, Masahiro Murakami and Seiya Uchida, page 153)

The main reason for such is the different way in which personality rights and neighboring rights are handled under copyright laws in the US, Japan and Europe, meaning that even though music is universal, it was not possible to handle copyrights in the same way in each country where the music was sold. Although the rights of broadcasters were traditionally stronger in the US, allowing them to use recorded materials, including disk records, in their broadcasts without paying royalties, in Europe and Japan, royalties must be paid. In Europe, for more than half a century, broadcasting stations have been reporting titles of recorded materials and how many minutes they were played for each program broadcast and paying a royalty to right holders. In Japan, for a long time, no accurate records were kept of royalties owed and right holders and users met together once a year to agree on the amount for the year. When it was paid, right holders would then divide that amount up among themselves through negotiation. Only recently did the industry start to keep accurate records of recorded material usage in order to collect and distribute the royalties justly and fairly. Under such circumstances, although the ISRC system works well in Europe, it was not eagerly adopted in the US due to the lack of prospects for increasing revenue for right holders, while in Japan, despite some improvements, the traditional way of negotiating has been hindering the promotion of the ISRC system.

After the war, content businesses and software business based on intellectual property rights came into the limelight and this was the first field in which capital liberalization was carried out in Japan. Although large electronics companies in the US and Europe had been investing in this field since before the war, it was only during the 1960s that Japanese electronics companies showed interest in record companies and capital started flow. Immediately following such investment from electronics companies into record companies, the digitization of music recordings began and digital recording devices for consumers hit the market. However, as such devises made cloning of recorded material easy, friction between electronics industry and music industry suddenly materialized in the form of copyright issues. Differences in copyright laws, especially with regard to neighboring rights, between Japan, the US and Europe made this issue even more complicated. As it was difficult for the European electronics industry and record industry to introduce new restrictions on copying digital material as they had already acknowledged the right to remuneration for payment of damages incurred by copyright holders and holders of neighboring rights, they suggested a serial copy management system (SCMS) that allows one generation copying of digital material. The electronics industry in the US was on the decline at the time and although the music industry was increasing its exports to the world, the US was hesitant to use the same system as Europe due to differences in neighboring rights. On the other hand, as the electronics industry in Japan was flourishing and global sales of audio equipment were increasing, due to concerns regarding the standardization of rights to remuneration in Japan and the US, the aim was to establish an SCMS that did not come with the right to remuneration. The music industry in Japan, on the other hand, insisted on establishing a fair and safe solution in the form of a debit system, which was different from an SCMS but still protected the right to remuneration (preliminary meeting for Athens DAT meeting, Washington D.C., May 1989). Later, due to lobbying by the electronics industry in Europe, etc., the IFPI, the organizer of the Athens DAT meeting, demanded that the RIAJ skip the meeting. As a result, the SCMS was adopted and DAT was introduced without the consent of the RIAJ.

In light of the above, in terms of the protection of recorded materials, it is clear that the current state is far from “protected” and that drastic improvements are still required.

Generally speaking, there are thought to be three ways of ensuring that rights related to recorded materials are protected.

1. This method only works with users who have plenty of funds: Users, such as content providers and distributors, enter into agreements with holders of neighboring rights, assume all responsibility for protecting the recorded materials, and in cases where rights are breached, users make compensation for damages. In such cases, even if there is a revolt among users, nonetheless, all responsibility will rest with such users.
2. Conventional method: Users come up with distribution systems and protection systems and present them to right holders. This scenario requires the establishment of a security plan, but this had hardly ever happened before. Right holders can only trust users and no consideration has been given to internal revolts among users.
3. The method that it is hoped can be used in the future: Considering that recorded materials are the property of all of mankind, users and right holders will discuss how to build a fair and safe system to effectively utilize recorded materials while protecting them. Security plans and responses to revolts will also be considered.

With DVDs, method No.2 above was adopted by the industry. Although they decided to use encryption technology, trusting their colleagues the hardware companies, the protection was broken due to the negligence of one of the hardware companies, causing huge problem for the other hardware companies and users. Today, these kind of internal revolts occur on a daily basis inside companies, so it is unreasonable to say that such events only happen to someone else.

In order to achieve method No.3 above, which is thought to be the most desirable way, RIAJ established the Content Security Management Center, which is an agency to authorize and democratically manage public encryption keys, in order to protect content based on public-key cryptography, and was consulted by users. Although this method did not become the standard, it did show the importance of encryption key management in content management, as well as the way in which such content should be managed in the future.

In order to be able to solve the above-mentioned problems in a timely manner, the introduction of a safe system is required that is compatible with laws regarding copyrights and neighboring rights from all countries, and under which recorded data can be fairly and democratically managed.

Bibliography

[1] *Open Distribution Base that Achieved Flexible and Secure Content Protection*, by Anazawa, Takemura, Tsunehiro, Hasebe and Hatakeyama, Information Processing Society of Japan, Special Interest Group Report, EIP14-5 November 30, 2001.

9 Current State of Reference Materials

The names of the world's first/Japan's first analog recording equipment and related products are shown below, including details regarding the current state.

The first SP record that was recorded in Japan (Fig. 3.4) is held by Kanazawa Phonograph Museum.

The first series of SP records that were produced in Japan, including the music played by Ijuro Yoshimura (Fig. 3.5), are held by Kanazawa Phonograph Museum.

Pirated versions (Rabbit Record, Yoshino Record, etc.) (Fig. 3.6) of Ijuro's records (Fig. 3.5) are held by Kanazawa Phonograph Museum.

Phonographs made in Japan (Fig. 3.7, 3.8 and 3.9).
The first record player made in Japan was the Nipponophone record player with horn, model No. 35 (Fig. 3.7), and working units of this model are held by Kanazawa Phonograph Museum, Nippon Columbia Co., Ltd. and others, with one on display in Kanazawa Phonograph Museum. The number of metal sheets comprising the horn of the model held by Nippon Columbia is different from the one held by Kanazawa Phonograph Museum, and it is assumed that this is because the horn on the Nippon Columbia unit was replaced at a later stage. Kanazawa Phonograph Museum also holds a Model No. 50 (Fig. 3.8), which went on the market at the same time as the Model No. 35 mentioned above, as well as a model without a horn, the Eufon (Fig. 3.9), which was released during the year following the release of the Model No. 35. It is well known that Kenji Miyazawa had a Eufon unit and cherished it.

The present state of reference materials regarding the first phonographs produced in Japan (in 1910) is as follows.

- Nipponophone No. 25: Document only.
- Nipponophone No. 32.5: Document only.
- Nipponophone No. 35: Unit held by Kanazawa Phonograph Museum (Fig. 3.7).
- Nipponophone No. 50: Unit held by Kanazawa Phonograph Museum (Fig. 3.8).
  Two models of phonograph without horn were released in 1910, following the release of Nipponophone No. 50. One was the Eufon (Fig. 3.9), was owned and loved by Kenji Miyazawa.

The general purpose cutter head (Fig. 4.2) used on the disk recorder that was used for broadcasting the imperial edict at the end of the war, which is on display at NHK Museum of Broadcasting (Fig. 4.6).

The disk used for the imperial edict at the end of the war is on display in the NHK Museum of Broadcasting (Fig. 4.7).

A cutter head smaller than the one shown in Fig. 4.2 is used on the disk recorder held by Kanazawa Phonograph Museum.

The Denon DL-103 moving coil type stereo cartridge for broadcasting (Fig. 4.12) is still on the market today.

A Filmon sound belt (Fig. 4.14) is jointly held by the Tsubouchi Memorial Theater Museum and Tokyo National Research Institute for Cultural Properties. Kanazawa Phonograph Museum also holds five rolls of the same.

A Filmon tabletop Filmon/record player (Fig. 4.16) is held by Kanazawa Phonograph Museum. However, as this particular one has been modified, it is desirable to have it restored to its original state.

The first tape recorder that was made in Japan (Fig. 4.17) is held by the NHK Museum of Broadcasting and is currently on display.

The successor model to the STAX electrostatic earspeaker SR-1 (Fig. 4.18) is currently on the market. The initial model is held by multiple numbers of individuals and it still produces good quality sound.

With regard to the transmission test that was conducted by Kenjiro Takayanagi using a letter "イ" (Fig. 4.19), the reproduced testing system is displayed in the NHK Museum of Broadcasting and the original plate showing "イ" is kept at the Kenjiro Takayanagi Foundation.

The MH microphone (Fig. 5.1) is held and displayed by the NHK Museum of Broadcasting.

The following microphones that were made overseas are held by Nippon Columbia and are still used for recording.
ALTEC 639B microphone (Fig. 5.2).
RCA 44BX microphone (Fig. 5.3).
RCA 77DX microphone (Fig. 5.4).
77DX microphone used to record traditional Japanese music (Fig. 5.5).
Telefunken M49 condenser microphone (Fig. 5.6).
First broadcasting condenser microphone made in Japan CU-1 (Fig. 5.7).
Neumann 69 Stereo condenser microphone (Fig. 5.8).
Neumann KU-100 Dummy head binaural microphone (Fig. 5.9).
Schoeps microphones (Fig. 5.10).

The first Type A velocity microphone made in Japan was developed by Tokyo Electric (now Toshiba Corporation) and is on display at the NHK Museum of Broadcasting (Fig. 4.6 left).

These Danish B&K prototype field-type and pressure-type microphones (Fig. 5.11) are held by Nippon Columbia and are still used for recording.

Direct Cutting Disks
All three pairs of direct cutting disks shown in Fig. 5.17, Fig. 5.18 and Fig. 5.19 are held by Nippon Columbia.

Records recorded using the recorder developed by NHK STRL (Fig. 5.20), with which no editing was possible, were released in January 1971 (Fig. 5.21).
Nippon Columbia NCB7003 "Something" by Steve Marcus with Jiro Inagaki & Soulmedia held by Nippon Columbia.

Record containing the music recorded using the recorder developed by NHK STRL (Fig. 5.20), with which no editing was possible, was released in April 1971 (Fig. 5.22): Nippon Columbia NCC8004-N "Hit!" by Tsutomu Yamashita.

The world's smallest PCM/digital recorder for master recording, DN-023R (Fig. 5.23) is owned by Nippon Columbia under the safekeeping of The Sumitomo Warehouse Co., Ltd.

The first record recorded using the world's first PCM digital recorder for master recording, with which no editing was possible (Fig. 5.23), was released in October, 1972: Nippon Columbia NCC8501 Mozart string quartet No. 17 "The Hunt" and No. 15 by the Smetana Quartet performed on April 24, 25 and 26 1972 at Aoyama Tower Hall. It is held by Nippon Columbia.

The current status of digital recorders developed by Nippon Columbia after 1974 is as follows:

- DN-023RA: First PCM digital recorder used in Europe. 1974. Four-head VTR. Document only.
- DN-034R: Four-head VTR. 1977. Unit held by Nippon Columbia in Minami-Azabu (Fig. 5.29).
- DN-035R: U-matic VTR. 1979. Unit held by Nippon Columbia in Minami-Azabu.
- DN-035RMK II: U-matic VTR. 1982. Unit held by Nippon Columbia in Minami-Azabu (Fig. 5.31).
- DN-039R: U-matic VTR. 1984. Unit held by Nippon Columbia in Minami-Azabu.

The following digital recorders that were developed by Sony were in great demand

among CD producers and are still used by many studios today.
Sony Digital audio processor PCM-1630 (held by Nippon Columbia) (Fig. 5.30)
Sony 2-channel Digital Audio Stationary Head (DASH) recorder PCM-3402 (held by Nippon Columbia) (Fig. 5.32)
Sony 48-track Digital recorder PCM-3348 (held by Nippon Columbia) (Fig. 5.34)

The following digital recorders that were developed by Mitsubishi Electric Corporation have been and still are used for CD production.
Mitsubishi X-86 2-channel DASH recorder (Fig. 5.33)
Mitsubishi X-850 32 track digital recorder (Fig. 5.35, held by Nippon Columbia)

The world's first random access PCM audio editing system DN-036ED (Fig. 5.36) was developed in 1982 and was introduced to the industry, but is no longer in use anywhere.

The world's first digital mixing console for mastering was developed in 1984 and introduced to the industry (Fig. 5.37). This unit is owned by Nippon Columbia and still in use by the same.

Blumlein cutter head (Fig. 5.41) is held by Nippon Columbia.

Denon cutter head (Fig. 5.42) is held by Nippon Columbia.

Fairchild cutter head (Fig. 5.43) is held by Nippon Columbia.

Neumann SX-45 cutter head (Fig. 5.44) is held by Nippon Columbia.

Ortofon cutter head (Denmark) (Fig. 5.45) is held by Nippon Columbia.

Westrex 3D cutter head (Fig. 5.46) is held by Nippon Columbia.

Neumann SX-74 cutter head (Fig. 5.47) is still used by Nippon Columbia.

Denon direct drive motor for cutting machine (Fig. 5.54) is still used by Nippon Columbia.

Neumann cutting lathe (Fig. 5.55) is still used by Nippon Columbia.

First PVC LP record made in Japan (Fig. 5.63) has been already registered in the list of important scientific material in history of Japan ("Engineering heritage for future generation").

10 Epilogue

Records are unique products that differ from ordinary consumer products. Although they do have things in common with other products in terms of their need to be patented, manufactured and distributed, they are special in that they involve art, copyrights and neighboring rights, as well as being classed as resalable products on account of their being involved in culture. Furthermore, it is impossible to establish a business with records alone, and they require content, such as attractive music, and playback devices. Therefore, there is the need to have excellent audio technology at every stage of the record production process, including recording, record manufacturing, and also the production of playback devices.

As can be seen in this paper, at the dawn of the audio era, much new development came about as a result of motivated research by AT&T's Bell Labs and its peripheral companies in the US. In Japan, even though the scale was somewhat more limited, there were still passionate researchers who developed audio technologies that exceeded the level of American technology, including Tsubota, who developed a cutter head with properties superior to those of heads developed by AT&T, Hayashi, who developed condenser pick-ups and condenser ear speakers ahead of everyone else in the world, and Ibuka, who developed consumer magnetic recorders.

As audio-related technology matured, it brought forth the development of the audio industry in Japan, which produced many world-class consumer audio products. In terms of record-related technology developed around that time, compact discs should be mentioned especially as they possible the distribution of digitally recorded music to general consumers.

Although up until now audio technology has been developed on the basis of analog technology, further improvements are eagerly awaited through the utilization of digital technology. However, it is often said that while the music industry has benefited from the development of digital technology in terms of cost-performance, it has not been possible to surpass the level of analog recording in terms of artistic quality. I hope that one day this challenge will be conquered through the collaboration of audio technicians in Japan.

Lastly, I would like to express my sincere gratitude to the many people who have assisted me in the writing of this paper.