Super Audio CD A Technical Overview

September 2001

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The Superiority of Direct Stream Digital Encoding

The 1980s saw the full-scale emergence of the digital format on the recording scene. This caused quite a stir among the recording engineers who experienced the digital recording format for the first time, free as this is from the noise and inter-modulation distortion associated with analog recorders. For digital recording a method known as PCM (Pulse Code Modulation) was adopted.
Since that time, with the advent of PCM digital audio and compact disks, there has been a vast increase in the sampling frequency and bit rates used in order to increase the resolution of recordings. It has proved elusive, however, to achieve a faithful playback of silent passages, when the objective is to convey the feeling of atmosphere during a performance, and this is something that sound engineers, producers and recording artists have wished to create.
This was the situation as of the end of the 1990s, with efforts being made to reproduce digital audio with the meticulous nuance of an analog signal. The DSD (Direct Stream Digital) method was developed based on this idea. Now 20 years after digital audio was developed, recording engineers have come in for yet another surprise, with new DSD technology that makes it possible to create “atmosphere,” in other words transferring the performer’s breathing and even the exciting tension of the venue to a Super Audio CD.

Superiority of Multi Channels.

The highest form of sonic purity adds new dimensions.
The Super Audio CD goes multi-channel.

You can have the sound in your own room as if you are at the concert hall. You can feel the excitement of the concert as well as innovative creativity of artists. Welcome to the world of new impressive sound that you have never experienced.

Every concert hall in the world has its own specific sound field called “hall tone.” Another fascination of live concerts is buzzing and cheers of a quite a number of audiences participating in the concert. To reproduce such excitement of live concerts as much as possible, it is indispensable to integrate various kinds of sound factors surrounding the listeners, namely, the echoing and reverberation from the hall walls and miscellaneous sound made by audiences, to the sound source.

Multi-channel Super Audio CD system is a sound reproduction system with the highest form of sonic purity. It records all those kinds of sound with multiple channels, each of which are reproduced independently via multiple speakers. Music instruments are three-dimensionally located in the sound field to realize affluent and profound sound so that listeners can feel the space of the concert hall. Surrounding sound and noise produced by audiences make the listeners feel as if they also join the concert. Once you listen to the Super Audio CD sound, you can experience the ambience and strong excitement that you have never had. This innovative potential for sound reproduction may inspire artists’ creativity to produce completely new music experience. Multi-channel Super Audio CD system will thus open the door for new potentiality for sound reproduction.

Enabling Technologies.

Super Audio CD accomplishes so many goals because it embodies several powerful, key technologies. In fact, there are five enabling technologies behind :

DSD
Direct Stream Digital

1 **Direct Stream Digital™(DSD™) : source coding technology for superior high-quality sound.**

2 **Stereo and Multi-channel on one disc using Digital Stream Transfer (DST) technology.**

3 **Secure technologies for contents protection.**

4 **Various Super Audio CD disc types.**

5 **Production system.**

Each of these technologies is new. Each opens up important possibilities. And each deserves a more detailed description.

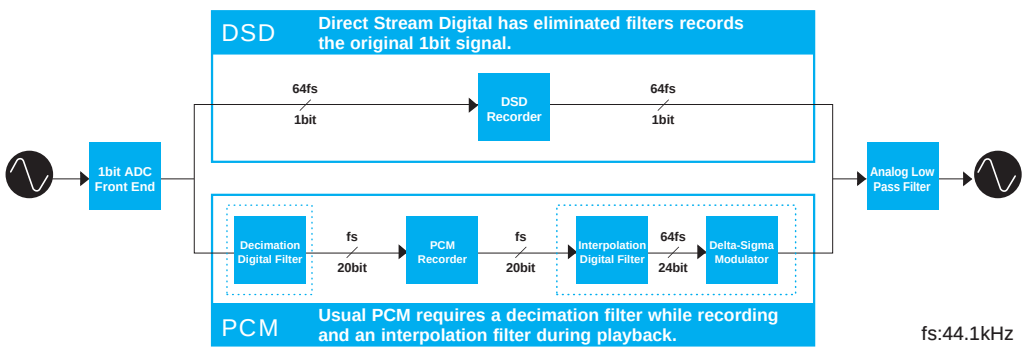
Direct Stream Digital™ (DSD™) Encoding.

Sony and Philips both have a well-known history of accomplishment in Pulse Code Modulation (PCM) digital audio. Starting in the late 1970's with commercial 14-bit systems, and moving up to 16-, 18-, 20- and 24-bit systems, these two companies have made an unmatched investment in PCM technology, generating an unequaled string of PCM products. So it's not casually that these two companies now propose a fundamental move away from PCM.

Successively higher bit rates and higher sampling rates for PCM systems have, in fact, improved sound quality. But the improvements are getting smaller and smaller. And the reason for these diminishing returns is becoming clear: *filtering*. Every PCM system requires steep filters at the input to absolutely block any signal at or above half the sampling frequency. (In conventional 44.1 kHz sampling, "brick wall" filters must pass 20 kHz audio, yet reject 22.05 kHz — a difficult task.) In addition, re-quantization noise is added by the multi-stage or "cascaded" decimation (downsampling) digital filters used in recording and the multi-stage interpolation (oversampling) digital filters used in playback.

This problem was the inspiration for Direct Stream Digital. By simply eliminating decimation and interpolation in existing processes — we developed a whole new way of capturing audio signal digitally. As in conventional PCM systems, the analog signal is first converted to digital by 64x oversampling delta-sigma modulation. The result is a 1-bit digital audio signal. Where conventional systems immediately decimate the 1-bit signal into a PCM code, Direct Stream Digital records the 1-bit pulses *directly.*

Direct Stream Digital eliminates the filters and records the original 1-bit signal *directly.*



fs:44.1kHz

Conventional PCM requires decimation filters on the record side plus interpolation filters on the playback side.

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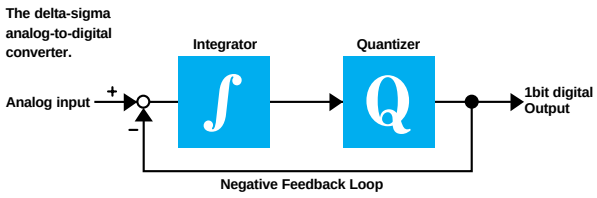
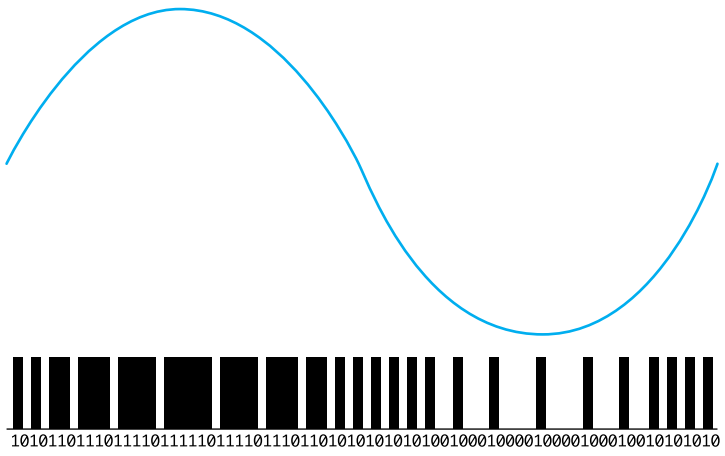
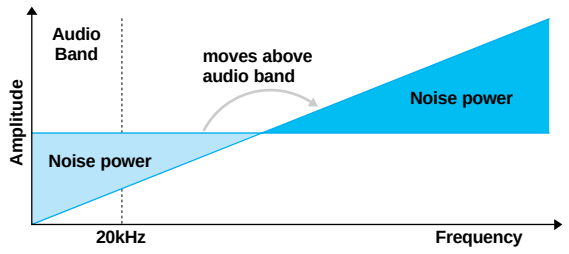


The delta-sigma analog-to-digital converter basically consists of integrator, 1bit quantizer and negative feedback loop path.

The amplitude of the input analog signal is represented by the density of pulses output. The density of output pulses increases with increasing input signal amplitude.



A simplified relationship between analog input (above) and 1bit digital output pulse train (below) of the delta-sigma analog-to-digital converter (The pulse train has been shaded for clarity.)



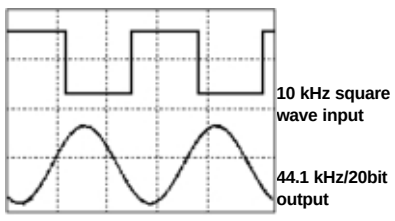
A simplified illustration of the effect of noise shaping. The maximum audio frequency, f_m, is nominally 20,000 Hz. Noise shaping moves most of the noise power far above the audio band (20kHz-), where it will be inaudible.

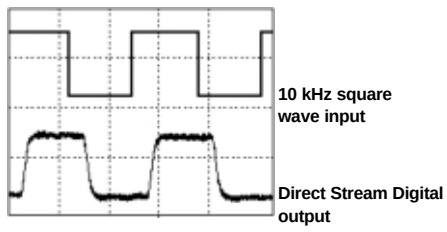
Meanwhile digital-to-analog conversion can be as simple as running the pulse train through an analog low-pass filter!

Ultra-high signal-to-noise ratios as required for DSD in the audio band are typically achieved through 5th-order delta-sigma modulator. These effectively shift the noise up in frequency, out of the audio band: *noise shaping.*

Sony and Philips designed DSD to capture the complete information of today's best analog systems. The best 30ips half-inch analog recorders can capture frequencies past 50 kHz. DSD can represent this with a frequency response from DC to 100 kHz. To cover the dynamic range of a good analog mixing console, the residual noise power was held at -120 dB through the audio band.

A notorious torture-test for recording systems, the 10 kHz square wave (left figure : top trace) includes component frequencies well above the audio band. The PCM system approximates this with a 10 kHz sine wave (left figure : bottom trace). In comparison, the 1-bit Direct Stream Digital captures the wave's true shape (right figure : bottom trace).





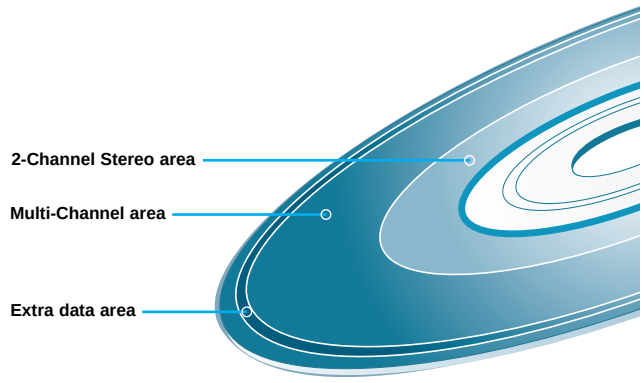
Multi-channel disc.

• Stereo and Multi-channel on one disc. Direct Stream Transfer (DST)※ loss-less coding makes it possible to store 70-80 minutes of both stereo and multi-channel DSD content on a disc. Separate data areas are provided for stereo and multi-channel content, giving artists the flexibility to provide two discrete mixes of the same content on a disc. Moreover, an “extra data” area has been reserved for expansions of the format that will make it possible to include information such as lyrics, credits, and still images in the future.

※ In general, there are two types of bit rate reduction technologies. One is DST: loss-less coding, and another is “Lossy”. Data reduction actually chooses parts of the signal that can be ignored, for example, based on psychoacoustic models. Examples include MPEG-1 and MPEG-2 for video, ATRAC, Dolby® Digital (AC-3®) and DTS® for audio.

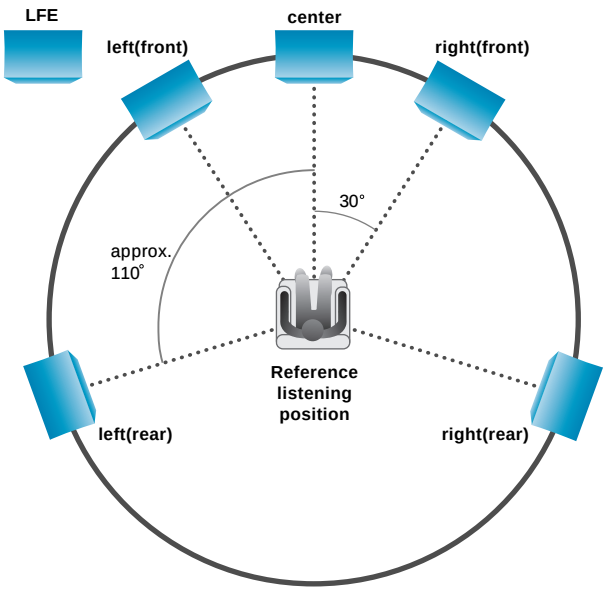
• Super Audio CD Multi-channel audio software applications. Faithful rendition of concert hall ambience is just one of the many possibilities of Super Audio CD multi-channel sound. The discrete surround channels, which are totally separate from the main front channels, can theoretically be used to record any content the artist or producer desires, whether it be sound effects, choruses located in the rear, or other innovative recording techniques. Moreover, archived 3-channel and 4-channel recordings can be faithfully re-released in the Super Audio CD format, while the future may bring a variety of new multi-channel recording methods yet to be invented.

• Speaker placement in a Super Audio CD Multi-channel playback system. A typical multi-channel Super Audio CD playback system includes a multi-channel capable player, a multi-channel power amplifier, and a corresponding number of speakers.
As shown in the chart, five speakers typically surround the listener in circular fashion in accordance with ITU recommendations and the sixth channel is used for low frequency enhancement (sub-woofer).



Multi-ch

All Super Audio CDs containing multi-channel DSD content will carry the "Multi-ch" logo to indicate that they are capable of providing multi-channel sound when played on a multi-channel compliant Super Audio CD player.



Speaker placement in accordance with the ITU-R BS.775 recommendation: the sixth channel can be optionally used for low-frequency enhancement.

Super Audio CD content protection is built with five lines of defense. Each line provides different obstacles against piracy. The independency of these lines of defense means that, even if one of the lines is broken, the others still protect the content against piracy.

- First line of defense: Existing PC disc drives cannot read data from Super Audio CD disc.
- Second line of defense: If Super Audio CD data has been copied, it cannot be used
- Third line of defense: Hacking the scrambling of a title is expensive and must be done for each new title again.
- Fourth line of defense: Details of the scrambling system are never exposed
- Fifth line of defense: Sophisticated protection against commercial piracy and counterfeiting

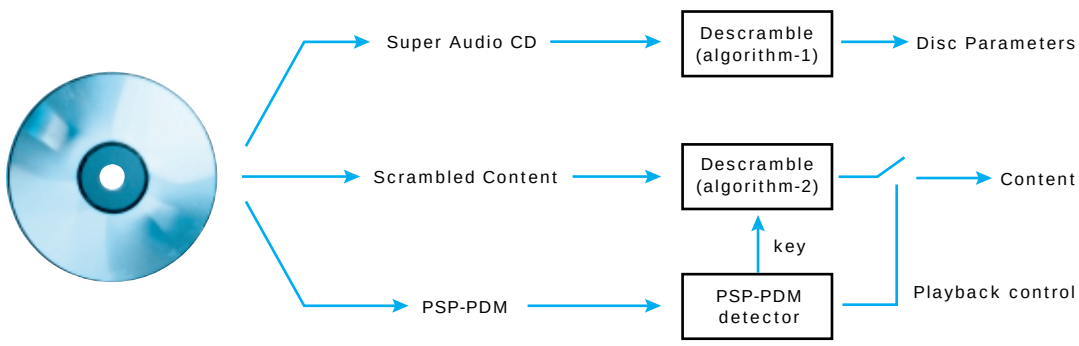
Super Audio CD content protection technologies:

• The invisible watermark. The invisible watermark is also called the PSP-PDM (Pit Signal Processing-Physical Disc Mark).
The PSP-PDM is very difficult to write on a recordable disc. It can only be mastered with Super Audio CD licensed equipment
The PSP-PDM is used for playback control (its presence is necessary to initiate the playback of an Super Audio CD disc). The PSP-PDM is also used for content access control (part of the descrambling key is hidden in PSP-PDM).

• Content Access Control. The DSD content is scrambled using the Super Audio CD cipher. The Super Audio CD crypto algorithm is a synchronous stream cipher. The key-stream generator used in this stream cipher is based on clock-controlled shift registers. The crypto algorithm is optimised to achieve high performance in hardware.
The Super Audio CD crypto algorithm needs two keys for descrambling:
1. The PSP-PDM key that is hidden in the disc; and
2. The “Initial Values”, a key that is hidden in the IC. The value of these keys is not available outside a single IC and is not transmitted between IC’s.

• Super Audio CD mark: Disc Access Control. The Super Audio CD mark hides certain disc parameters. Drives need this information before they can start reading the disc. A non compliant drive will, therefore, not be able to get data from any Super Audio CD disc.

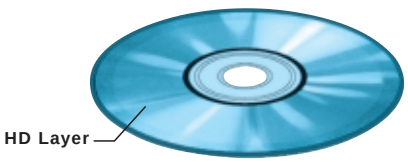
• Playback Control. DSD playback is allowed only when the PSP physical disc mark is found.
The PSP-PDM is very difficult to write on recordable disc.
It is an excellent mark to signal that a disc is an original disc.



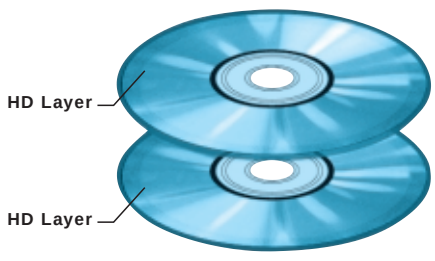
The Three Types of Super Audio CD Discs.

• Backward compatibility with the conventional CD : Super Audio CD disc variations. The Super Audio CD offers three different disc variations including the Single Layer Disc (which contains one High Density Layer) the Dual Layer Disc (which contains two High Density Layers for extra recording time) and the Hybrid Disc (which contains one High Density Layer and one standard CD Layer, allowing for playback on any conventional CD player).

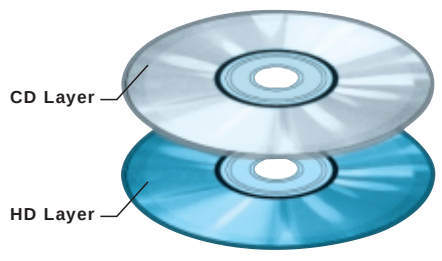
<Single Layer Disc>



<Dual Layer Disc>



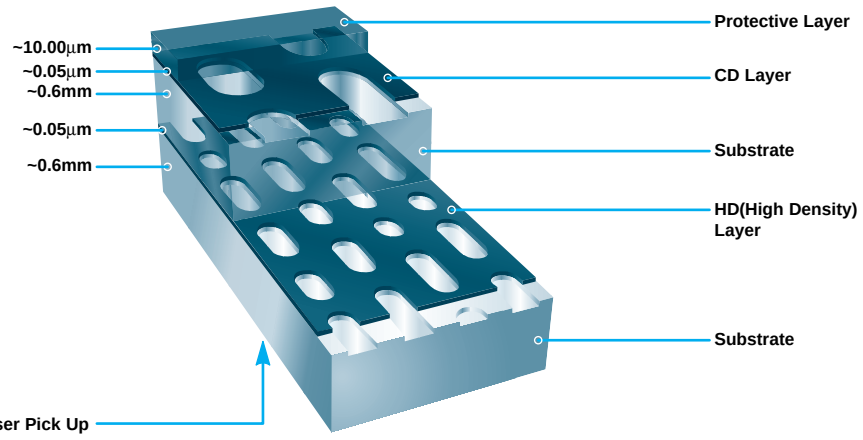
<Hybrid Disc>



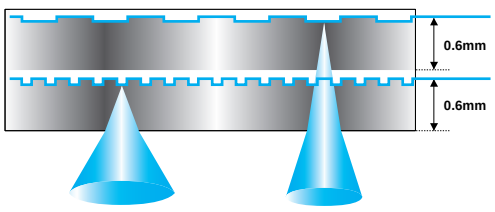
Disc Features.

Super Audio CD discs are very flexible, allowing the creative community to have many options of what they can provide on a disc. Rather than go through the full range of options we will describe what we call a fully loaded disc, all other disc are subsets of this. A fully loaded disc is a Hybrid Disc and it can contain the following:

<Hybrid Disc Construction>



<Hybrid Disc Signal Reading>



CD layer(entirely reflective)

HD layer
Layer reflects 650nm wavelength is penetrated with 780nm laser rays.

HD (High Density) Pick up
Wavelength:650 nm
Aperture:0.6
Focused only on the HD layer

CD Pick up
Wavelength:780 nm
Aperture:0.45
Focused only on the CD layer

DSD in Recording.

Recording in DSD may seem a daunting task. However simple calculation show differently. DSD samples music at 64 times the sample rate of Compact Disc (64 x 44,100 Hz = 2,822,400 Hz) and uses just one bit per sample. Comparing this with regular PCM recording (16 bits/sample at 44,100 Hz), the resulting DSD sample bit rate is only 4x higher, which is well within current available recording system capabilities both tape as well as hard disk.

DSD in Production.

From the beginning of the Super Audio CD development, Sony and Philips have been working together to develop key devices and technologies necessary for production equipment. They therefore achieved the functions such as mixing, cross-fading, equalizing, and obtaining relevant dynamics of DSD 1-bit signals. A variety of field verifications were conducted on these functions with prototype equipment. Engineers from Sony and Philips are working together to help several professional audio equipment manufacturers market recording machines and audio workstations.
Thus, DSD in production is incrementally being actualized.

Of course, while DSD establishes new standards in the recording studio, the consumer marketplace remains enthusiastically wedded to the Compact Disc. Clever technology is required to downconvert 1-bit DSD into 16-bit PCM for distribution on Compact Disc. That technology is called Super Bit Mapping Direct™ processing.

Super Bit Mapping Direct.

Downconverting Direct Stream Digital from 1-bit/64fs to 16-bit/1fs is not theoretically difficult. Every DAT recorder and A/D converter has a circuit that does much the same thing. But we needed to downconvert DSD in such a way as to retain the maximum possible signal quality in the 16-bit world. The answer was to completely filter and noise shape the DSD signal *in a single stage*.Thus, interstage requantizing errors would be eliminated. Aliasing would be minimized. And ripple would be suppressed. Sony designed a super-power one-stage FIR digital filter/noise shaper with an amazing 32,639 taps. This is Sony's real-time Super Bit Mapping Direct™ processor.

Just as Sony's existing Super Bit Mapping™ circuit helps approach 20-to-24-bit precision in 16-bit digital audio, the new Super Bit Mapping Direct™ processor enables DSD to be released on industry-standard Compact Discs with audibly superior performance. Subjective comparisons conclude that much of the original DSD benefit is preserved in 16-bit Compact Disc release.

SBM Direct™ processors have already been built. And they've already been used in the creation of commercial Compact Disc titles.

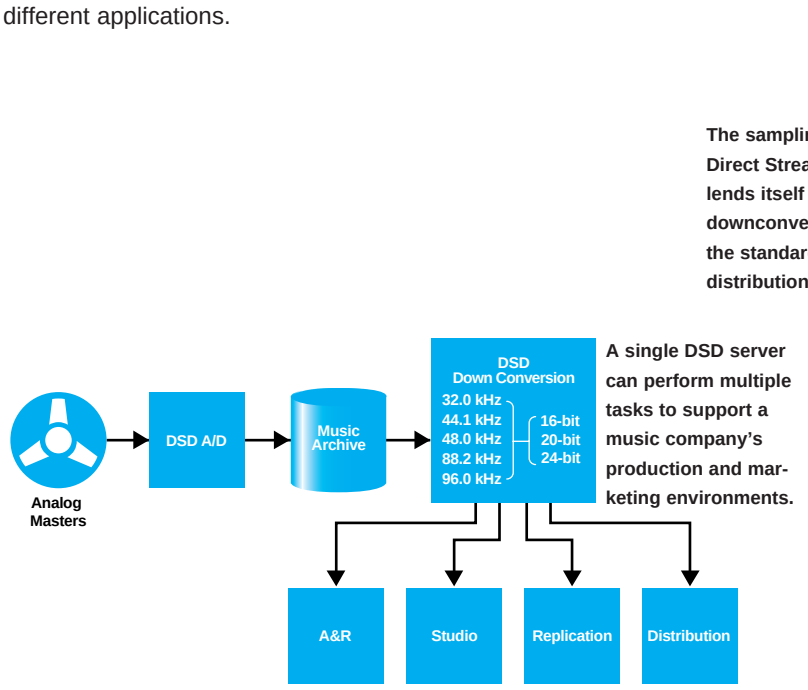
The arithmetic of DSD conversion.

Downconversion to 16-bit/44.1 kHz digital audio is just one option for the DSD bit stream. The system's 2.8224 MHz sampling rate is specifically designed for high precision downconversion to all current PCM sampling rates. In all cases, the conversions in sync are performed with simple integer multiplies and divides.

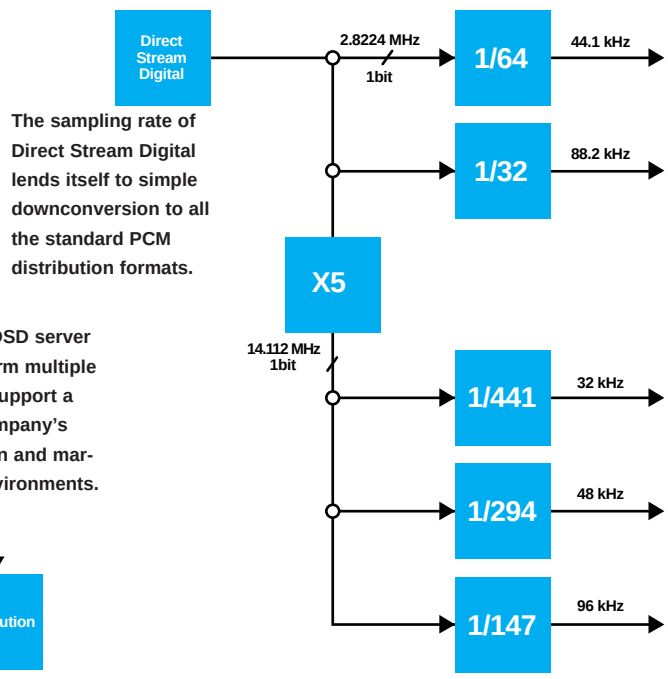
As a result, music companies can use DSD for both archiving and mastering. And DSD masters can be easily downconverted for release at any sampling rate or wordlength. This makes DSD a digital "Rosetta Stone," able to speak all languages with equal facility. It also means that DSD can support a "hierarchy of quality" for distribution that allows the music company to precisely position different products for different applications.

Direct SBM

Super Bit Mapping Direct



A single DSD server can perform multiple tasks to support a music company's production and marketing environments.



The sampling rate of Direct Stream Digital lends itself to simple downconversion to all the standard PCM distribution formats.

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	Super Audio CD	CD
Diameter (mm)	120	120
Thickness (mm)	1.2	1.2
Track pitch (µm)	0.74	1.6
Data Capacity (Mbytes)	4700	780
Wavelength (nm)	650	780
Numerical Aperture (NA)	0.6	0.45
Audio Coding:	Direct Stream Digital	Linear PCM
Sampling Rate (kHz)	2822.4	44.1
Sampling Bit Length	1	16
Channels	2, 3, 3.1, 4, 4.1, 5, 5.1	2
Tracks	255 (max)	99 (max)
Indexes	255 (max)	99 (max)
Playback time (min.) Stereo	109	74
Multi + Stereo	70-80 *1	-
Supplementary Data (kbps)	73-900	43.2
Frequency Range (Hz)	DC-100,000 (DSD)	5-20,000
Dynamic Range (dB)	over 120 (~20kHz)	96

*1 : 12cm Single Layer Disc, 2ch and Multi channel with DST

Conclusion-

With the Super Audio CD format Sony and Philips have come with a new music carrier that covers the full range of needs. No other format satisfies so completely the desires of recording artists, producers, sound engineers, record companies, retailers, audiphiles and music lovers in general. The format guarantees that the discs are compatible with the installed base of nearly 600 million CD players and that the players can play the 10 billion existing CDs.

Further Reading

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