Direct Stream Digital

Direct-Stream Digital

DSD Direct Stream Digital	
Media type	Audio recording process Disc format
Encoding	Digital
Read mechanism	DSD
Write mechanism	Super Audio CD
Developed by	Sony Philips
Usage	Audio recording
Extended from	1999
Extended to	present

Direct-Stream Digital (**DSD**) is the trademark name used by Sony and Philips for their system of digitally recreating audible signals for the Super Audio CD (SACD). Practical DSD conversion was pioneeredWikipedia:Avoid peacock terms by Andreas Koch and Ed Meitner of EMM Labs. Koch and Jonathan Tinn later founded Playback Designs, which pioneeredWikipedia:Avoid peacock terms the transfer of DSD files over USB connections.[1] DSD technology was later developed and commercialized by Sony and Philips. Philips later sold its DSD tool division to Sonic Studio, LLC in 2005 for further development.

DSD uses pulse-density modulation encoding—a technology to store audio signals on digital storage media that are used for the SACD. The signal is stored as delta-sigma modulated digital audio; a sequence of single-bit values at a sampling rate of 2.8224 MHz (64 times the CD Audio sampling rate of 44.1 kHz, but only at $^{1}/_{32768}$ of its 16-bit resolution). Noise shaping occurs by use of the 64-times oversampled signal to reduce noise/distortion caused by the inaccuracy of quantization of the audio signal to a single bit. Therefore it is a topic of discussion whether it is possible to eliminate distortion in one-bit Sigma-Delta conversion.

DSD-CD has been marketed as an audiophile medium, primarily in Hong Kong with music by Cantopop artists such as Sally Yeh. DSD technology may also have potential for video applications. A similar structure based on pulse-width modulation, which is decoded in the same way as DSD, has been used in Laserdisc video.[*citation needed*]

History

Development

DSD is a method of storing a Delta-Sigma signal before applying a "decimation" process that converts the signal to a PCM signal. Delta-Sigma conversion was originally described in patent 2,927,962, filed by C. C. Cutler in 1954, but was not named as such until a 1962 paper by Inose, et al. Previously, decimation had not existed and the intention was to have oversampled data sent as-is. Indeed, the first proposal to decimate oversampled delta-sigma data to convert it into PCM audio did not appear until 1969, in D. J. Goodman's paper "The Application of Delta Modulation of Analog-to-PCM encoding".[2]

Practical DSD converter implementations were pioneeredWikipedia:Avoid peacock terms by Andreas Koch and Ed Meitner, the original founders of EMM Labs. Andreas Koch later left EMM Labs and along with Jonathan Tinn, founded Playback Designs who have pioneeredWikipedia:Avoid peacock terms the transfer of DSD files over USB connections.

DSD technology was later developed and commercialized by Sony and Philips, the designers of the audio CD. However, Philips later sold its DSD tool division to Sonic Studio in 2005 for further development.[3]

Use of the format

Major label support

DVD-Audio was endorsed by the Warner Music Group, while the SACD format was endorsed by Sony and Universal Music Group, with an especially high profile by UMG imprint Virgin Records.[4][5] Despite this, in 2011 *The Warner Premium Sound series* of albums was released by Warner Music Group, marking the first time the label released titles in a SACD format, with recording in DSD.[6] The series grew to ten rock and pop albums, with Super Audio CD/CD hybrid discs containing both an SACD layer and a standard CD layer.[7]

Sony did not promote SACD actively in North America, with the result that DVD-Audio gained competitive traction in the market. Elsewhere, such as in Europe or Japan, SACD gained more of a foothold.[8] Examples include the German Stockfisch Records, which releases vinyl editions of albums and DSD-recordings, released as hybrid SACDs.

Independent label use

Many music companies that specialize in Super Audio CD products therefore use DSD encryption. A number of independent record labels have also worked directly with Sony to focus on DSD products or the DSD recording process.

DMP Digital Music Products was an early user of the SACD digital audio format.[9] In 1997 their release *Alto* by Joe Beck & Ali Ryerson was the first commercial recording captured with Sony's Direct Stream Digital recording technology. The label's *Just Jobim* by Manfredo Fest in 1998 was the first project captured with the new Meitner DSD conversion technology. In 2000, DMP released the world' s first multichannel SACD - Gaudeamus's *Sacred Feast*.[10]

The majority of Telarc International Corporation's releases are on (generally hybrid) SACD, based on DSD recordings.[11] Telarc often works with early audiophile company Soundstream, and has re-released many of its original Soundstream recordings in SACD format, with a DSD-equivalent sampling rate of 50 kHz.[12]

The record label Mobile Fidelity had engineers who decided to adopt the Super Audio CD over the DVD-Audio disc as a high resolution digital format after listening tests and technical evaluations. On the label's Hybrid SACD releases, the SACD layer is a direct DSD recording of the analog master tape, while the CD layer is a digital down conversion of the DSD, with Super Bit Mapping applied. Post 2001 CD-only are sourced from DSD, but omit the SACD layer.[13]

Blue Coast Records was founded in California in 2007 for the purpose of recording and releasing music recorded with the DSD format, primarily focusing on jazz and acoustic artists.

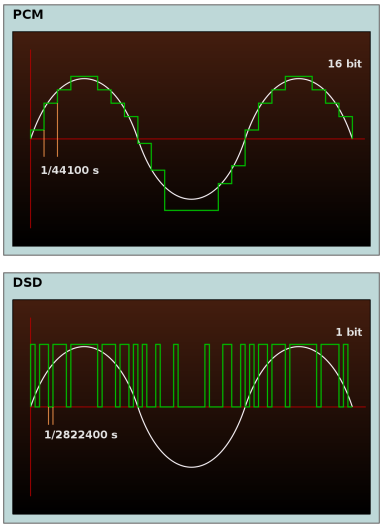
On Aug. 28, 2013, the Acoustic Sounds label launched SuperHiRez.com, which sells mainstream albums from major record labels that were produced with Direct Stream Digital or PCM audio formats.[14][15] On Sept. 4, 2013, Acoustic Sounds announced an agreement with Sony Music Entertainment to provide the company's new digital download service with albums that have been produced or remastered in Direct Stream Digital format.[16]

The format is used on albums such as *Pop, Songs & Death* in 2009, and the remastered The Rolling Stones album *Their Satanic Majesties Request* in 2002.

DSD technique

SACD audio is stored in DSD, which differs from the conventional PCM used by the compact disc or conventional computer audio systems.

A DSD recorder uses sigma-delta modulation. DSD is 1-bit, has a sampling rate of 2.8224 MHz. The output from a DSD recorder is a bitstream. The long-term average of this signal is proportional to the original signal. DSD makes use of noise shaping techniques in order to push quantization noise up to inaudible ultrasonic frequencies. In principle, the retention of the bitstream in DSD allows the SACD player to use a basic (one-bit) DAC design which incorporates a low-order analog filter. The SACD format is capable of delivering a dynamic range of 120 dB from 20 Hz to 20 kHz and an extended frequency response up to 100 kHz, although most currently available players list an upper limit of 80–90 kHz and 20 kHz is the upper limit of human hearing.



Comparison with PCM.

The process of creating a DSD signal is conceptually similar to taking a one-bit delta-sigma analog-to-digital (A/D) converter and removing the decimator, which converts the 1-bit bitstream into multibit PCM. Instead, the 1-bit signal is recorded directly and in theory only requires a lowpass filter to reconstruct the original analog waveform. In reality it is a little more complex, and the analogy is incomplete in that 1-bit sigma-delta converters are these days rather unusual, one reason being that a one-bit signal cannot be dithered properly: most modern sigma-delta converters are multibit.

Because of the nature of sigma-delta converters, one cannot make a direct comparison between DSD and PCM. An approximation is possible, though, and would place DSD in some aspects comparable to a PCM format that has a bit depth of 20 bits and a sampling frequency of 96 kHz.[17] PCM sampled at 24 bits provides a (theoretical) additional 24 dB of dynamic range.

Because it has been extremely difficult to carry out DSP operations (for example performing EQ, balance, panning and other changes in the digital domain) in a one-bit environment, and because of the prevalence of studio equipment such as Pro Tools, which is solely PCM-based, the vast majority of SACDs—especially rock and contemporary music which rely on multitrack techniques—are in fact mixed in PCM (or mixed analog and recorded on PCM recorders) and then converted to DSD for SACD mastering.

To address some of these issues, a new studio format has been developed, usually referred to as "DSD-wide", which retains the high sample rate of standard DSD, but uses an 8-bit, rather than single-bit digital word length, yet still relies heavily on the noise shaping principle. It becomes almost the same as PCM—and is sometimes disparagingly referred to as "PCM-narrow"—but has the added benefit of making DSP operations in the studio a great deal more practical. The main difference is that "DSD-wide" still retains 2.8224 MHz (64Fs) sampling frequency while the highest frequency in which PCM is being edited is 352.8 kHz (8Fs). The "DSD-wide" signal is down-converted to regular DSD for SACD mastering. As a result of this technique and other developments there are now a few digital audio workstations (DAWs) that operate, or can operate, in the DSD domain, notably Pyramix and some SADiE systems.

Another format for DSD editing is Digital eXtreme Definition (DXD), a PCM format with 24-bit resolution sampled at 352.8 kHz (or alternatively 384 kHz).

Note that high-resolution PCM (DVD-Audio, HD DVD and Blu-ray Disc) and DSD (SACD) may still technically differ at high frequencies. A reconstruction filter is typically used in PCM decoding systems, much the same way that bandwidth-limiting filters are normally used in PCM encoding systems. Any error or unwanted artifact

introduced by such filters will typically affect the end-result. A claimed advantage of DSD is that product designers commonly choose to have no filtering, or modest filtering. Instead DSD leads to constant high levels of noise at these frequencies. The dynamic range of DSD decreases quickly at frequencies over 20 kHz due to the use of strong noise shaping techniques which push the noise out of the audio band resulting in a rising noise floor just above 20 kHz. The dynamic range of PCM, on the other hand, is the same at all frequencies. However, almost all present-day DAC chips employ some kind of sigma-delta conversion of PCM files that results in the same noise spectrum as DSD signals. All SACD players employ an optional low-pass filter set at 50 kHz for compatibility and safety reasons, suitable for situations where amplifiers or loudspeakers cannot deliver an undistorted output if noise above 50 kHz is present in the signal.

Double-rate DSD

The Korg MR-1000 1-bit digital recorder samples at 5.6448 MHz, twice the SACD rate. This is also referred to as DSD128 because the sample rate is 128 times that of CD. Since its establishment content creators have started to make 5.6 MHz DSD128 recordings available, such as the audiophile label Opus3.[18] Additionally a 48 kHz variant at 6.144 MHz has been supported by multiple hardware devices such as the exaSound e20 Mk II DAC.

Quad-rate DSD

The Merging Technologies Horus AD/DA Converter offers sample rates up to 11.2 MHz, or four times the SACD rate. This is also referred to as DSD256 because the sample rate is 256 times that of CD. The Pyramix Virtual Studio Digital Audio Workstation allows for recording, editing and mastering all DSD formats, being DSD64 (SACD resolution), DSD128 (Double-DSD) and DSD256 (Quad-DSD). A 48 kHz variant of 12.288 MHz has been established. The exaSound e20 DAC was the first commercially available device capable of DSD256 playback at sampling rates of 11.2896/12.288 MHz.

Octuple-rate DSD

A further extension to the development of DSD is DSD512, with a sample rate of 22.5792 MHz (512 times that of CD), or alternatively 24.576 MHz (512 times 48 kHz). Hardware such as the Amanero Combo384 DSD output adapter, and exaU2I USB to I2S Interface, and software such as JRiver Media Player, foobar2000 with SACD plugin and HQPlayer are all able to handle DSD files of this advanced sampling rate fully natively.

DSD playback options

Sony developed DSD for SACD, and many disk players support SACD. Since the format is digital, there are other ways to play back a DSD stream; the development of these alternatives has enabled companies to offer high-quality music downloads in DSD.

DSD disc format

Some professional audio recorders (from Korg, Tascam, and others) can record in DSD format. Transferring this signal to a recordable DVD with the appropriate tools, such as the AudioGate software bundled with Korg MR-1/2/1000/2000 recorders, will render a "DSD Disc". Such discs can be played back in native DSD only on certain Sony VAIO laptops and PlayStation 3 systems. HQPlayer from Feb. 16, 2011, version 2.6.0 beta includes support for direct/native playback from DSD Interchange File Format (DSDIFF) and DSD Storage Facility files (DSF) to ASIO devices with DSD support. Moreover, Sony produces two SACD players, the SCD-XA5400ES and the SCD-XE800, that fully support the DSD-disc format. Only the DSF format is supported. DSF is a stereo-only, simplified form of DFF, the format used for SACD mastering and 5.1-channel downloads. However, since most personal computers have only PCM audio hardware, DSD discs must be transcoded to PCM on the fly with the proper software plug-ins with questionable quality benefits compared to native high resolution PCM sources like

DVD or Blu-ray Disc Audio.

In June 2012, Pioneer launched a series of SACD players compatible with DSD-disc. The PD-30 and PD-50.

In January 2013, TEAC announced a DSD-disc compatible player, the PD-501HR.[19]

DSD over USB

An alternative to burning DSD files onto disks for eventual playback is to transfer the (non-encrypted) files from a computer to audio hardware over a digital link such as USB.

The USB audio 2.0 specification defined several formats for the more common PCM approach to digital audio, but did not define a format for DSD. Playback Designs' players and converters and Mytek Digital's 192 Stereo DAC both feature DSD over USB capability.

In 2012 representatives from these companies and others developed a standard to represent and detect DSD audio within the PCM frames defined in the USB specification; the standard, commonly known as "DSD over PCM", or "DoP", is suitable for other digital links that use PCM.

Many manufacturers are now offering DACs for sale which support DoP. John Atkinson of Sterophile found with the pioneeringWikipedia:Avoid peacock terms Playback Designs DoP DAC/SACD player, "The relatively high level of background noise limits the MPS-5's resolution with SACD and external 24-bit data to not much better than 16-bit CD".

DSD-CD (CD-DA)

While having a different name, DSD-CD is actually the same format as CD-DA. The difference from the standard version of CD is that the sound is assured to be derived from a DSD master. Other audio CDs, even those derived from DSD masters, are rarely marketed as DSD-CD. A DSD-CD however does not achieve the same sound resolution as SACD because the high-sample rate, low-resolution DSD sound has to be converted to 44.1 kHz, 16-bit PCM in order to be compliant with the Red Book audio CD standard. DSD-CDs are fully compatible with CD.

Sally Yeh's music has been marketed on DSD-CD in Hong Kong.

DSD-CD has been marketed as an audiophile medium, primarily in Hong Kong with music by Cantopop artists.

DSD vs. PCM

There has been much controversy between proponents of DSD and PCM over which encoding system is superior. In 2001, Stanley Lipshitz and John Vanderkooy from the University of Waterloo stated that one-bit converters (as employed by DSD) are unsuitable for high-end applications due to their high distortion. Even 8-bit, four-times-oversampled PCM with noise shaping, proper dithering and half data rate of DSD has better noise floor and frequency response.[20] In 2002, Philips published a convention paper arguing against the contrary.[21] Lipshitz and Vanderkooy's paper has been criticized by Jamie Angus.[22] Lipshitz and Vanderkooy later responded.[23]

There are fundamental distortion mechanisms present in the conventional implementation of DSD.[24] These distortion mechanisms can be alleviated to some degree by using digital converters with a multibit design. Historically, state-of-the-art ADCs were based around sigma-delta modulation designs. Oversampling converters are frequently used in linear PCM formats, where the ADC output is subject to bandlimiting and dithering.[25] Many

modern converters use oversampling and a multibit design. It has been suggested that bitstream digital audio techniques are theoretically inferior to multibit (PCM) approaches: J. Robert Stuart notes, "1-bit coding would be a totally unsuitable choice for a series of recordings that set out to identify the high-frequency content of musical instruments, despite claims for its apparent wide bandwidth. If it is unsuitable for recording analysis then we should also be wary of using it for the highest quality work."[26]

When comparing a DSD and PCM recording of the same origin, the same number of channels and similar bandwidth/SNR, some still think that there are differences. A study conducted at the Erich-Thienhaus Institute in Detmold, Germany, seems to contradict this, concluding that "hardly any of the subjects could make a reproducible distinction between the two encoding systems. Hence it may be concluded that no significant differences are audible."[27]

In the popular Hi-Fi press, it had been suggested that linear PCM "creates [a] stress reaction in people", and that DSD "is the only digital recording system that does not [...] have these effects".[28] This claim appears to originate from a 1980 article by John Diamond.[29] The core of the claim that PCM recordings—the only digital recording technique available at the time—created a stress reaction rested on tests carried out using the pseudoscientific technique of Applied Kinesiology.[30]Wikipedia:No original research#Synthesis of published material that advances a position Diamond had previously used a similar technique to demonstrate that rock music was harmful due to the presence of the "stopped anapestic beat".[31] Diamond's claims regarding digital audio were taken up by Mark Levinson, who asserted that while PCM recordings resulted in a stress reaction, DSD recordings did not.[32][33][34]

A double-blind subjective test between high resolution linear PCM (DVD-Audio) and DSD did not reveal a statistically significant difference. Listeners involved in this test noted their great difficulty in hearing any difference between the two formats.

The future of DSD

DSD has not been broadly successful in the consumer markets, though the SACD format has gained more traction than its direct competitor, DVD-Audio. DSD brings new challenges if immediate manipulation of the recorded data is desired. PCM is far easier to manipulate and is more easily built into existing applications such as the advent of very-high-resolution PCM media and tools, such as DXD. DSD however is used as a master archive format in the studio market and seen as a possible low noise replacement for analog tapes. As a little quality is lost when converting from DSD to PCM, and as PCM cannot be converted back into true DSD, the debate continues as to whether the ultimate quality digital audio can be found by using DSD players or recording directly into a high quality PCM format in the first place.

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External links

- Audio Engineering Society Convention Paper 5396: Why Direct Stream Digital is the best choice as a digital audio format (http://tech.juaneda.com/en/articles/dsd.pdf)
- Audio Engineering Society Convention Paper 5616: Enhanced Sigma Delta Structures for Super Audio CD Applications (http://www.diyaudio.org.ua/download/file.php?id=242)
- Audio Engineering Society Convention Paper 5619: The Effect of Idle Tone Structure on Effective Dither in Delta-Sigma Modulation Systems (http://www.acoustics.salford.ac.uk/research/angus_files/angus_files/publications/publications.htm)Wikipedia:Link rot
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- DSF and DSD Disc Format specifications (http://www.dsd-format.sony.net/en/index.php) by Sony
- 'How to create a DSD Disc' guide (http://www.ps3sacd.com/dsddiscguide.html) including DSD plug-in for Windows Media Player
- Multi-channel DSD over USB (http://www.rigisystems.net/index.php/usbpalen.html) DSD recording playback over USB software and hardware development kit
- DSD downloads (http://www.ps3sacd.com/dsd_downloads.html)

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