DCC history

Peter W. Mitchell: The public debut of Philips's digital compact cassette (DCC) was the biggest event at the 1991 CES in Las Vegas, which began with a large press conference that drew a crowd of about 200 audio journalists. Philips executives laid out the logic underlying the DCC's design, how it will be marketed, and the technical principles of its operation. Except for an awkward moment when a cassette-well door on a prototype DCC deck refused to open, the presentation was persuasive and the free buffet supper—featuring sinfully delicious lamb chops—was the best I've tasted at any CES press conference in years. During the next two days audio writers were invited upstairs in smaller groups of 10 to 20, to ask questions and hear the system in a hotel-room setting.

There are three stories in the DCC debut: what it sounded like, how it works, and how its performance was refined. Of these, the last proved to be the most surprising.

Sound

A DCC recording uses only a fourth as many bits per second as a CD thorugh bit-rate reduction (footnote 1). Since the DCC is intended to be a mass-market product, and since the CD has already been accepted as the mass-market standard for sound quality, Philips set up a demonstration whose aim was to illustrate that the DCC provides CD-quality sound in a smaller and conveniently home-recordable package. For each group of a dozen or so audio writers, Philips played a comparison of CD vs DCC sound through a system of good but not ultimate quality, a system that might retail for between $5000 and $10,000.

The signal from the CD player was fed to a preamp and also to a prototype DCC encoder/decoder. By the time the system goes into production the DCC processing circuits will have been shrunk to a handful of ICs that will fit within a standard-size cassette deck; at present the circuits fill a cube about 24" on each side. The DCC signal was encoded for recording and then decoded for playback, but was not actually recorded on tape. (In principle, that should not affect the comparison, since the system has enough error-correction capacity to handle normal tape imperfections.) The output from the DCC unit was precisely matched in level to that from the CD, and a switch enabled an A/B comparison between the CD "original" and the encoded/decoded DCC "copy."

How did it sound? "It was not obviously flawed." This is an audiophile reviewer's cover-your-butt way of saying that he didn't hear any difference but doesn't want to go out on a limb and say that the sound was identical, because he doesn't want fellow reviewers to think him cloth-eared. In fact, most of the people I spoke with afterward heard no difference in most of the comparisons. Some of the invited writers challenged the system with their favorite CDs of music or test signals. Ironically, as I will explain later, two widely used test signals, pink noise and pure sinewave tones, are very useful for detecting faults in analog and conventional (linear PCM) digital products but are especially easy for the DCC to handle. The most challenging test may be simple music, a signal that has energy at several frequencies but also has empty spaces in the spectrum, in which the ear might hear low-level artifacts.

One writer felt that the DCC's noise floor was not quite as low as that of an optimally dithered CD (notably the low-level glide tone on the CBS test disc). Others felt that the DCC sounded slightly brighter and coarser than the CD. However, when the A/B switch was operated there was a switching transient (a short noise burst) and an audible time offset caused by slight delays in DCC encoding which might have produced an illusion of a sonic difference even where there was none. I remained after a group demo and was treated to an additional private A/B comparison in which I selected CDs that I thought would be particularly revealing, sat in the optimum stereo-center seat, and operated the A/B switch myself. I soon became convinced that I heard a slight difference (B was brighter than A). Then, after I deliberately lost track of the switching order, I found it easy to persuade myself that A sounded slightly brighter than B—indicating that my perceptions were indeed being affected by the switching transient.

Of course, conditions were not conducive to the most critical evaluation. The all-Philips playback system (Philips electronics and four-way Philips speakers) did not seem as transparent and revealing of subtle differences as, for example, a system based on Apogee Stage speakers. And while the Philips personnel thoughtfully switched off the room's noisy airconditioning unit during the comparisons, the ambient noise level was still higher than in most homes.

So I tried to think of a way to enhance the audibility of any subtle flaw the DCC might have. Two possibilities immediately came to mind. First, since the DCC uses only a fourth as many bits as the CD, its handling of low-level hall ambience might be impaired, especially if the compressed digital bitstream is not optimally dithered to minimize quantizing distortion. Second, one historically popular way of boosting the apparent information-carrying capacity of a limited channel is to use matrix encoding.

For example, stereo FM radio produces an illusion of decent sound by combining mono FM (an L+R signal having inherently wide dynamic range and fairly low distortion) with an L–R subcarrier that has high distortion and limited range. The poor quality of the L–R subcarrier is often masked by the much louder L+R portion of the composite signal. Similarly, the analog LP began as a low-distortion, wide-range medium that used purely lateral modulation for its mono (L+R) information; then it was converted to stereo by adding an L–R stereo "difference" signal as a vertical modulation that has much higher distortion and a very limited dynamic range.

This is mathematically equivalent to modulating the two walls of the LP groove at 45° with separate left and right signals. But the vertical/horizontal picture leads to a clearer understanding of the medium's limits. In the early days of the stereo LP there were great debates in hi-fi magazines about whether the improved perspective of stereo was valuable enough to offset the new distortions (pinch effect, etc.) that became a problem when the stylus had to detect deliberate vertical modulation.

Historically, one of the most important aspects of an LP mastering engineer's job was to artfully limit the vertical excursion of the stylus in ways that didn't obviously compromise the sound. It was crucially important to make sure that the cutting stylus could never rise completely out of the lacquer (producing a discontinuous groove) or penetrate all the way through to the bottom of the acetate and scrape the glass or metal backing plate that the lacquer was coated on. The stereo LP, even more than stereo FM, succeeded because most of the time the L+R (horizontal) portion of the signal is much louder than, and effectively masks the flaws of, the L–R (vertical) stereo difference portion of the composite modulation.

There's a very easy way to discover how well any audio medium handles low-level ambience, and also to learn whether it uses matrix encoding to mask its limitations: listen to the L–R portion of the signal separately, without the louder L+R portion. In this mode one can also listen for variations in the level or timbre of the L–R signal, which may be caused by the two channels going partly or wholly out of phase at high frequencies—a common fault in phono pickups, analog tapes (both cassette and quarter-track open-reel), and early CD players. In stereo playback this fault causes problems in soundstage imaging. In FM broadcasting it causes severe dulling of the highs (and, in severe cases, comb-filter coloration) when a stereo broadcast is heard in mono.

Anyone who still has the classic Apt/Holman preamp can do this test easily: just rotate the Mode knob from Stereo to the L–R position. To achieve an equivalent result, I asked the Philips folks to disconnect the speaker wires at the back of the amplifier and connect the wires from one speaker to the left and right "hot" terminals, so that the speaker would reproduce just the L–R portion of the stereo signal. After a brief hesitation while they wondered if this connection might risk the amplifier's stability, they proceeded to do it.

I was impressed, and a little surprised, by this cooperative attitude. It suggested that although they hadn't tried this test themselves, the Philips people were so confident of the DCC's sound quality that they didn't expect to be embarrassed. Their implied vote of confidence was doubly impressive because by the time I suggested this rewiring of the demo system, the next group of audio writers had arrived—and when they heard about the proposal they were as eager as I to hear the result. This group included Michael Riggs, now an editor at Stereo Review, and Ken Pohlmann, whose informed writings on digital audio are published in several big-circulation consumer and pro audio magazines. If the L–R test revealed a flaw in the DCC, the bad news would be published far and wide.

Not to worry; the DCC passed with flying colors. To challenge it, I chose a nicely recorded Philips CD of Schubert songs for solo voice and piano. In the L–R mode the soprano voice, imaged precisely in the center of the stereo stage, was substantially canceled out, dropping in level by about 20dB. The direct sound of the piano also declined in level. With most of the low-frequency and midrange body of tone removed, what remained were high-frequency harmonics and all of the recorded hall ambience, including the delicate tail end of the reverberation. Recall that the DCC encoder was still handling the full stereo signal; the L–R subtraction took place only at the amplifier output. As we listened alternately to the CD and to the DCC "copy," even the L–R mode did not reveal any clear difference in timbre, ambience, or low-level resolution.

Of course, a CD is not itself an absolute standard of sound quality, especially since most available CDs were recorded through the Sony PCM-1610 or 1630—digital processors with sonic limitations of their own. At the show the Philips folks mentioned that the next phase in refining the DCC encoder would involve comparisons with new CDs that were recorded with "20-bit equivalent" oversampling delta-sigma A/D converters—for instance, the UltraAnalog (formerly dbx) converter used by Chesky (footnote 2) and the Bitstream A/D that is now used in some Japanese studios.

To sum up: the DCC, while using only a fourth as many bits as the CD, successfully duplicates average-quality CD sound. If it isn't an exact match, the disparity is about on the same scale as the differences among CD players. We don't know yet whether it may prove unsatisfactory by high-end audiophile standards (footnote 3), or whether it will sound as good as the very best R-DATs. But it is better than it needs to be for the mass market—and is light-years ahead of the analog cassette that it is destined to replace.

Technology

The impetus to develop DCC came not from a technical breakthrough but from a marketing problem. When Japanese manufacturers launched the R-DAT format five years ago, they proclaimed it the digital successor to the analog cassette, just as the CD is supplanting the LP. An interesting idea, but is it likely?

At the high end of the home recording market, and among hi-fi hobbyists who are actively involved in taping, the answer is yes. It's worth remembering that Japanese hi-fi gear is developed first for the domestic market and is then sold to the rest of the world. Japanese audio hobbyists love tape recording. (Open-reel tape machines continued to flourish in Japan long after they died in every other market.) And because Japanese hi-fi buffs like to assemble their own compilations of favorite music, and to fool around with sound effects, the first DAT recorders were designed to facilitate easy digital dubbing from CDs. In early R-DAT brochures the new format was presented as the heart of a complete living-room digital studio for every hi-fi enthusiast. Of course, when major record companies understood this, they launched a legal and political war against DAT that is still going on.

Even assuming that R-DAT might someday capture the entire market for living-room tape decks, is that where the analog cassette market is? Not at all. This year Americans will buy more than 30 million cassette mechanisms, but only 3 million will be AC-powered living-room decks. The other 90% operate in motion: headphone portables, radio/cassette boomboxes, and car stereos. The majority of these are play-only; even those equipped for recording (eg, boomboxes and some headphone portables) are used mainly to play prerecorded tapes.

In the US there are as many cassette mechanisms as people. The average household has three. Worldwide, a billion cassette mechanisms are in use. This year people will buy 180 million new machines and a billion prerecorded music cassettes (fig.1). Another billion and a half blank cassettes are sold annually, many for non-musical applications (telephone answering machines, taping college lectures, journalist interviews, talking books for the blind, et al).

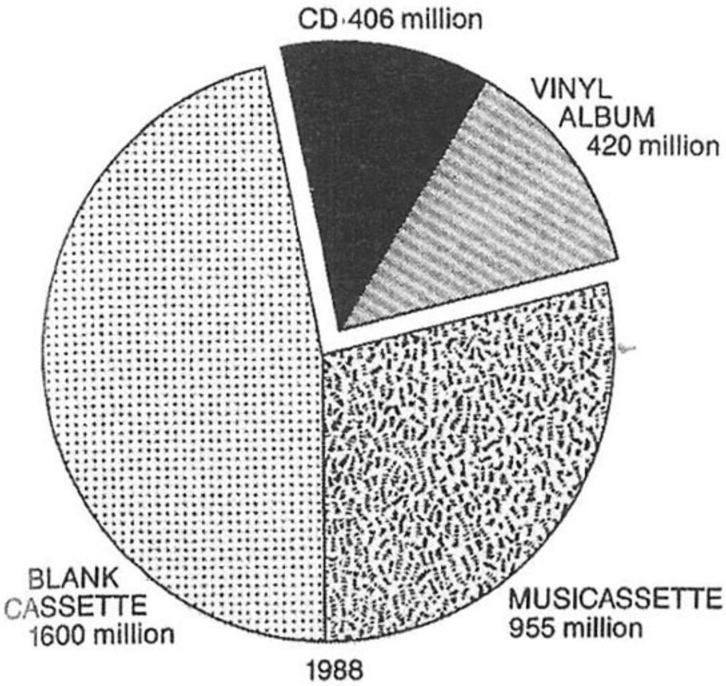

Fig.1 Worldwide recorded and blank media market, 1988 (© Bureau Contekst).

Philips invented the cassette format in 1963 and may be more aware than anyone else of its worldwide dominance as the leading carrier of recorded music. Looking at the numbers, Philips concluded that regardless of how successful the R-DAT might be among hi-fi hobbyists and living-room component systems, these account for only a tiny share of the market. There is no possibility that R-DAT could be the true digital successor to the analog cassette. It faces two fundamental obstacles: cost and software.

Sony and Panasonic have done an impressive job of shrinking the price of DAT recorders from $2000 to $800. But how much lower can they go? A DAT mechanism is a miniature helical-scan VCR, with many precision parts in exacting alignment. If mass-production is the key to getting the price down, consider camcorders; they sell in the millions and still cost $500 to $1000 apiece. Yet CD players sell for as little as $99, while analog cassette mechanisms add less than $50 (often only $20) to the retail price of a product. My teenage niece has a $180 boombox that contains AM/FM radio, cassette, and a CD player that proved surprisingly competent when I connected its Line outputs to my brother's stereo component system. Could R-DAT conceivably have any future in this application, or in $40 headphone portables? Not a chance.

As for software, copying discs onto tape is OK for hobbyists, but most people don't want to bother. They just want to buy music in a convenient package and enjoy it. There are tens of thousands of software titles available on analog cassette but only a few hundred on DAT. Sony recently announced plans to double the production capacity for prerecorded DAT at its Indiana factory. But that will still be mainly for Sony Classics and a few independent labels that want to produce DAT recordings for sale. Sony hasn't even managed to persuade the pop-music division of CBS Records (which it owns) to release DAT versions of Michael Jackson and Bruce Springsteen hits, much less the other large record companies (RCA, Warner, Arista, et al) that remain united in their opposition to DAT.

Even if record companies accept DAT, recordings are duplicated by dubbing in real time onto racks of Sony DAT recorders, a slow and costly process. If enough demand developed, they could adopt Sony's $100,000 Sprinter, a high-speed duplicator that uses a magnetic "contact printing" process to transfer the magnetic pattern from a master tape to DAT duplicates. Still, while CDs now cost only a buck apiece to press, blank DAT cassettes cost about $5 in large quantities. Each DAT is a miniature videocassette, with a hinged door and a dozen internal parts, and the tape is a metal-powder formulation that is expensive to manufacture.

The bottom line is that prerecorded DATs (if record companies were willing to produce them) would always cost substantially more than the equivalent CD. That's enough to limit their appeal and probably rules out R-DAT as the digital successor to the analog cassette.

Philips concluded that the digital replacement for the analog cassette would have to be cheap enough to be a true mass-market product, be amenable to economical high-speed duplication, be supported by major record companies, and be readily adaptable to various physical forms (headphone portables, slot-load car players, and AC-powered home decks). So, rather than designing new mechanisms from the ground up, Philips decided to base the design of the DCC on analog cassette mechanisms that manufacturers around the world already produce in vast quantities at very low cost—from the $20 headphone portable made of plastic parts to the slot-load car player and the high-performance dual-capstan home deck. Many analog cassette mechanisms can be converted to DCC use by substituting a different head and adding a few small parts.

The DCC cassette has the same exterior dimensions as the analog cassette, runs at the same 1 7/8ips tape speed, and has the same 90-minute running time (45 minutes per side). 120-minute tapes will also be produced, mainly to offer home recordists the same 2-hour capacity as R-DAT. But home recording is a relatively minor part of the product concept. More importantly, DCC cassettes have the same playing time as the CD (80-plus minutes), so prerecorded DCC tapes can be mass-produced from the same masters that CDs are cut from.

As a bonus, the DCC offers the mass market a painless transition to the digital age: DCC machines will also play the dozens of analog cassettes that every home already possesses. (Compatibility and worldwide standards have always been high priorities at Philips.) The idea is that when your present cassette machine wears out and you go to buy a new one, you'll be tempted to upgrade to a DCC machine that will play all your old tapes and also provide CD-quality sound from new tapes. The analog playback will include Dolby-B since that is the world standard for prerecorded cassettes. Other manufacturers may include Dolby-S decoding, but Philips is reluctant because Type S is not a major factor in the prerecorded cassette market. (That may change by the time DCC decks arrive in 1992. Two large US tape duplicators recently converted their machines to Dolby-S encoding, which is said to be playback-compatible with Dolby-B.)

Of course, there are important differences between analog and digital cassettes. Analog cassettes have a bulge along one edge to accept the heads; DCC cassettes are uniformly slim, so it is easy to carry several in a shirt pocket. Analog cassettes are symmetrical, since in many machines you flip the cassette over to access the Side B tracks. All DCC machines will use dual-capstan auto-reverse mechanisms, so the DCC cassette is never turned over. It has reel hubs and access holes only on the bottom; the flat top face is covered by a big label.

A standard DCC machine will record and play digital tapes but won't record analog cassettes; it is playback-only. Reason: it is bidirectional, and adding dual erase and record heads for both directions would be expensive for a capability that few people would use. For those who still want to record analog cassettes (for friends, or to play in the car), Philips suggested that the most cost-effective solution would be a dual-well dubbing deck, DCC in one well and analog record/play in the other.

Several years ago, when Apple introduced the first Macintosh computers, Steve Jobs began a presentation to the Boston Computer Society by tossing a handful of then-new 3.5" mini-floppy disks into the audience. Computer buffs, familiar with the vulnerability of conventional floppies, were startled and impressed by this cavalier behavior—especially when Jobs demonstrated that the mini-disk didn't need a protective envelope but could be carried bare in a shirt pocket. The plastic disk housing contains a sliding shutter that seals the case shut when not in use, protecting the disk from fingerprints and dust.

Philips borrowed the same great idea for the DCC. Unlike analog cassettes, which are open along one edge and vulnerable, the digital cassette has a sliding metal shutter that protects the tape when it's not in the machine—forever eliminating awkward and easily broken "jewel box" carriers. Prerecorded DCC tapes will come in a transparent sleeve with program notes, but away from the living room you'll carry only the self-protected cassette. This fumble-free convenience is enough to make DCC the digital medium "for the rest of us." The sliding shutter doesn't add much to the cost of the DCC cassette; I paid only 39 cents for the 3.5" disks I use in my computer.

According to Philips, the metal-powder tape required for R-DAT is costly, not amenable to conventional high-speed duplication, and unstable at the high temperatures that may occur in a closed car on a summer day. So the DCC was designed from the ground up to use low-cost tape, specifically video-format chromium dioxide, which is produced in vast quantities for VCRs. A Philips spokesman mentioned that with CrO2 tape and a housing that is not much more complex than an analog cassette, blank DCC cassettes may be priced only slightly higher than premium-grade analog tapes, around $5. (For comparison, blank R-DATs cost $8 to $15 at retail.)

CrO2 tape can reliably record wavelengths as short as one micron (1;um or one-thousandth of a millimeter). At a tape speed of 4.75cm/s, this is equivalent to a maximum frequency of 47.5kHz. Since each cycle corresponds to two bits (a 1 followed by a 0), the corresponding data rate per track is 95,000 bits per second (bps). By recording on eight narrow tracks, the DCC records a total of about 760,000bps. About half (384,000bps) are audio data; the rest are used for error-correction coding. For comparison, the data rate in the CD is 1,408,000bps (44,000 samples/s x 16 bits/sample x 2 channels). Thus the data rate in the DCC is about one-fourth that of the CD. Since the sampling rate is the same, the DCC records an average of only four bits per sample. Low-level noise is added to "dither" the signal and thereby minimize any quantizing distortion.

In addition to the eight tracks of digital data, a ninth track will contain subcodes, timing codes, a table of contents, and (optionally) up to 400 characters per second of text, which may be shown either on a built-in display or a separate video screen. The text could be used for song lyrics, program notes (synchronized with the music), multilingual opera librettos, background stories about the recording sessions, etc. Philips proposed a similar text display nine years ago for the CD, but the idea was ignored by record companies and most manufacturers, perhaps because it would require extra work to prepare the text for encoding with the signal when the master recording is cut. (Most CDs don't even have indexing of the sections of a symphonic movement, which takes relatively little effort to implement.)

By monitoring the subcode track during fast-wind, a DCC player can cue quickly to the beginning of a song, display timings, play songs in any order, and generally provide the same operating conveniences as a CD or R-DAT. Cueing to another song may require a few seconds, as with R-DAT, instead of the near-instant cueing that CD provides. Since all DCC tapes will be recorded in auto-reverse format, the last song on Side B will be in the same section of tape as the first song on Side A, requiring only an auto-reverse maneuver (reverse the direction of tape motion and rotate the head 180°) to access it. If you're making your own recordings you'll have to plan ahead so that the automatic reverse at the end of the tape won't leave a two-second gap in the middle of a movement. (In this respect R-DAT is superior, with up to two hours of continuous, uninterrupted recording time.)

The DCC combo head has gaps for the nine digital tracks in its upper half, plus two gaps for analog tracks in its lower half. When recording or playing Side B, the head is flipped to place the digital gaps on the bottom (fig.2). When you load an analog cassette, sensing pins automatically flip the head to put the analog gaps on top for side A. (Incidentally, since DCC tapes don't turn over, Philips wants to call the two tape directions the A and B "sectors" rather than "sides.")

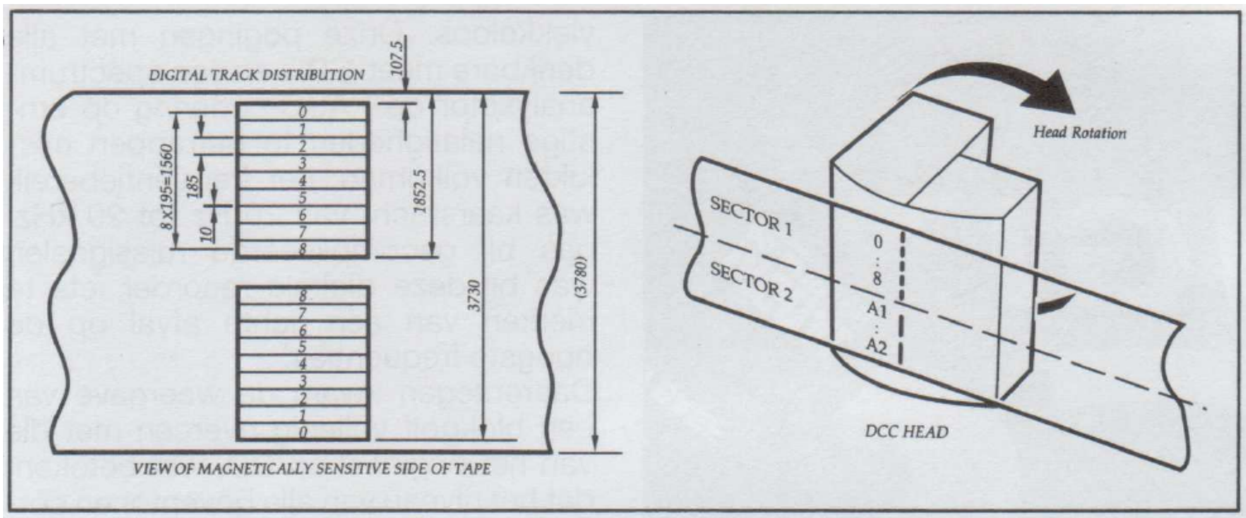

Fig.2 The DCC digital/analog tape head, showing the reversible disposition of digital heads 0–8 and analog heads A1 and A2.

The tiny head gaps are formed by a lithographic thin-film process similar to that used to create microscopic layered circuits and conductive paths in silicon IC chips. Philips took advantage of this to devise a clever trick. First, the nine digital recording gaps are formed in a row, each 0.19mm high so that tracks of that width will be recorded on the tape. A thin insulating layer is added, and digital playback gaps are formed on top. Each is aligned with the center of the corresponding record gap but is only 0.07mm high.

Result: since the short playback gaps read less than half of each recorded track, the tape can be misaligned relative to the head by as much as 0.12mm (plus or minus 0.06mm) and still play correctly. With this much tolerance for slop, DCC machines can use ordinary cassette mechanisms; costly machined parts and precise alignment won't be needed. (Incidentally, although the recording and playback gaps are separate, you can't use them to monitor the signal off the tape while making a recording. The gaps are so close together that magnetic coupling occurs between them.)

A DCC machine communicates with the outside world through a standard Sony/Philips digital interface (S/PDIF), using the same 16-bit PCM codes as a CD player or R-DAT. Thus its digital input accepts 16-bit data from a CD player, and its digital output produces normal 16-bit data that can be fed to an outboard D/A converter or may be recorded on any conventional digital device (R-DAT, recordable CD, et al). In principle, you could even record live music on a DCC deck and use its digital output to master a CD.

As in consumer R-DAT decks, digital dubbing is regulated by an SCMS circuit that allows any CD to be copied digitally onto tape but codes the copy so that it cannot be further copied. The analog input of a DCC deck is converted to PCM code by a normal 16-bit A/D converter, and the playback stage uses a conventional 16-bit D/A to generate its analog output. The choice of A/D and D/A circuits (conventional multibit, MASH, Bitstream, or whatever) will be up to each manufacturer of DCC machines.

The heart of the DCC is a complicated block of circuitry called the PASC (Precision Adaptive Sub-band Coding), which a few years ago would have required a roomful of computer power and hours of processing time to do its job—which is to compress the incoming 16-bit digital data to an average of 4 bits per sample for recording and, during playback, to re-expand the 4-bit data to 16-bit output codes. As explained in the January 1991 issue, the encoding is done by a microprocessor programmed with information about the psychoacoustic limits of human hearing. The goal is to provide accurate coding of sounds we hear but not to waste bits coding information that we can't hear.

The incoming 16-bit data stream is fed to a digital filter that divides the audio frequency range into 32 sub-bands, analyzes the signal content in each band, and uses only enough bits to encode the portions of the signal that are above the human threshold of hearing. The threshold varies with frequency (the Fletcher-Munson effect). A person with normal hearing can hear 2kHz at a very low 0dB sound-pressure level, but at 30Hz you can't hear anything softer than about 60dB spl anyway.

More important, the threshold at each frequency varies from moment to moment according to the strength of sounds at neighboring frequencies ("masking"). Thus when an 80dB tone is present at 1kHz, your hearing threshold at 2kHz rises temporarily from 0 to about 50dB spl. Then, as long as the 1kHz tone is present, the system can safely discard any information below the 50dB level in the 2kHz sub-band—which may include the second harmonic of the 1kHz tone. If you wouldn't have heard it anyway, you won't notice its absence.

Music, unlike noise, usually contains energy at only a few harmonically related frequencies. So at any given moment many of the 32 bands are likely to contain little or no energy. That frees many unused bits that can be assigned to provide more accurate coding in the bands that contain strong signals. This dynamic reallocation of bits between sub-bands plays a large role in the reduction of the overall bit rate.

When fed a pure tone at a single frequency, nearly all of the available bits can be assigned to the sub-band containing this frequency, coding it with very low distortion. Conversely, when tested with pink noise, which contains equal energy in every band, all bands are active and only a few bits can be used for each; but since it is noise, high accuracy at each frequency isn't important. The most challenging test signal might be music of moderate complexity, exercising enough bands to use up the system's bit capacity while leaving enough "open space" in the sound that any faults could be heard.

Final development

According to Philips, the basic engineering design of the DCC system was completed in 1989. With a normal product the engineers would then measure a prototype to certify its performance with test signals, and would listen to it to make sure there was nothing obviously wrong. But since the DCC's encoding varies dynamically according to masking thresholds and other psychoacoustic criteria, its performance cannot be judged with conventional test signals. In the final analysis its sound quality can only be judged by ear. It sounded OK to the engineers, but masking thresholds may vary, and it is well known that some people hear sonic faults more acutely than others do. Moreover, golden-eared listeners aren't just born; they are trained (or train themselves), learning what to listen for and improving their skill with long practice.

So, to evaluate whether the DCC could match the sound of CD, the designers turned to the trained listeners who are employed by the quality-control ~department at Philips Records (footnote 4). Listening to test signals and music, they did hear differences. So for the past two years Philips has been refining the PASC encoder, submitting it to listening panels, computer-analyzing the listening data with statistical programs to distinguish real differences from random chance and delusion, and fine-tuning the encoder again. Reportedly, after the latest round of refinements even the company's most golden-eared listeners can no longer distinguish the DCC from a CD source.

Thus one of the largest electronics companies in the world found itself in the unusual position of fine-tuning the performance of an important new product in the same way the smallest cottage-industry audiophile designers do—by listening to it, with recorded music. And the company's engineers found themselves in the slightly humbling position of having to improve a product's design because non-engineers said it didn't sound quite right.

The digital compression scheme has an interesting consequence. A DCC recorder accepts 16-bit PCM codes from a CD player, shrinks the bitstream to an average of four bits per sample for recording, then in playback regenerates 16-bit PCM output codes. The playback may sound the same as the original input signal, but the codes are not the same: the playback is a "cleaned up" version of the signal. The PASC processing puts the signal on a diet, stripping away the low-level musical harmonics that were below the dynamic masking threshold. Thus the playback signal, no matter how faithfully it may duplicate the original sound, is not a clone of the original code.

You may recall that when the record industry launched its legal war to prevent the R-DAT from being sold in the US, one of its alleged concerns was that, if consumers acquired an unlimited ability to make "clone" copies of the digital code in a CD, record companies would effectively lose control of their expensively produced digital master recordings. Hypothetically, pirates with R-DATs could swamp the market with perfect clone duplicates of master tapes, depriving the record companies of their economic base. Of course, this idea contained more paranoia than reality; anyway, for what it's worth, the DCC doesn't make digital clone copies. That may help to explain why some record companies, at least, have expressed support for the DCC and will be mass-producing prerecorded DCC tapes for sale.

Of course, the strongest support for DCC came from Philips's own PolyGram group of companies (Philips, DG, Archiv, Decca/London, L'Oiseau-Lyre, ECM, and Polydor), promptly followed by the EMI group (Capitol/Angel). BMG (RCA, Ariola, Arista) expressed interest in DCC but, like the rest of the record industry, wants Congress to impose a royalty tax on blank tape before the company will support any new recording medium. However, the momentum that seemed to be building in Congress to consider a royalty law was aborted by the Iraq war. Congress intends to devote itself to matters deemed more important than a squabble between branches of the entertainment industry.

Philips has acquired two major partners in the DCC project. In the US, Tandy Corp. announced last fall its intent to be the first licensed manufacturer of DCC machines and tapes. Tandy is already North America's largest electronics manufacturer and, through its 7000 Radio Shack stores, our biggest retailer of consumer electronics. The company is expanding its role still further by launching new store chains (Video Concepts, The Edge in Electronics) and by being first with new technologies like notebook computers and the DCC. The decks and their digital circuits will be produced at Tandy's computer factory in Texas, while the tapes will come from Tandy's (formerly Memorex's) magnetic media plant in California, a major producer of computer disks as well as audio and video tapes.

In Japan, Matsushita (parent of Technics and Panasonic), which has had a technology-sharing agreement with Philips for over a half-century, has also signed up for DCC. In fact, according to a Philips executive, Philips and Matsushita will be "co-licensors" of the DCC, in the same way that Sony and Philips are co-licensors of the CD. Companies that want to make DCC decks or tapes will have to get a license, pay royalties to Philips or Matsushita, and make sure that their products conform to the official design standard.

In contrast, standards for R-DAT were developed by agreement among several manufacturers and are unenforceable. Example: since Congress failed to pass an SCMS/DRM law last year, the inclusion of SCMS in R-DAT decks is essentially voluntary, enforced only by Japan's Ministry of Trade and Industry. Companies in Korea and Taiwan are free to make R-DAT decks without SCMS if they wish. But in the case of DCC the SCMS circuit is mandatory; it is a condition of the license.

All in all, the introduction of the DCC was the most impressive product launch since the CD, nine years earlier. If record companies get behind it—a crucial if—the DCC has a very good chance of knocking off both the R-DAT and the home-recordable CD as consumer products. Philips appears to have met its goal of combining CD-quality sound with the recordability, convenience, and compact size of the cassette.

The first DCC machines probably will be AC-powered home decks and may be priced in the $600 range when they appear next year. By that time R-DAT decks may also be selling for $600, so we could see a brief format war between the two digital tape systems. But it won't last long; second- and third-generation DCC machines, notably play-only portables, car decks, and DCC boomboxes, could drop to the $200 level within a few years. Audiophiles and tape recording hobbyists may continue to prefer R-DAT, if only for its longer uninterrupted recording time, but DCC is likely to prove the true successor to the analog cassette. It's what my sister—and everyone else—will want.

The largest remaining uncertainty is whether enough record companies will produce prerecorded DCC tapes to make it a mass-market success. At the moment the record companies that have committed to the DCC are all European. If the Recording Industry Association of America were to decide that the SCMS offers no protection and all digital recording formats must be fought until a royalty tax is passed, the US launch of DCC could be nearly as slow and painful as that of R-DAT.

If DCC gets the support of major record companies, and cuts the ground out from under R-DAT, Sony still has an alternative up its corporate sleeve: the tiny Digital Memo Recorder (DMR), a simpler and cheaper mini-DAT that uses stamp-size cassettes. The truly interesting format war between digital tape systems may feature DCC vs DMR. Stay tuned.—Peter W. Mitchell

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