Ready for digital audio? It might arrive sooner than you think

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By the end of this year, you might be buying hour-long stereo records that fit in your pocket. Not only will these disks be small, but their manufacturers claim they will offer lower distortion, wider dynamic range and flatter frequency response than conventional LPs.

You won't be able to play the records on your present turntable, though—these first commercial products of the digital-audio revolution will have no grooves and will spin much faster than 33⅓ rpm.

Although the digital-audio technology behind such devices isn't new, the high cost and complexity of the required conversion and storage have confined its application primarily to professional equipment. Now, however, as data converters' prices drop as fast as their accuracies improve and as practical high-density storage media become available, you'll see a proliferation of low-cost consumer-oriented digital-audio products. The development of these devices will not only radically change the audio industry, but will also affect general data acquisition and signal processing.

Only 4.7 in. across, *the Sony Compact Disk (CD) holds as much as 1 hr of digital stereo audio. CD players should be available in the US by the end of this year.*

Still no standards

One of the biggest problems now confronting digital-audio-equipment designers is a lack of industry standardization. Committees in Japan, Europe and the US are discussing the subject, but none has yet made a satisfactory recommendation. Hardware manufacturers expect that the first system to gain widespread consumer acceptance will establish a de-facto standard—one the industry is forced to adopt.

This approach, however, results in the classic chicken-or-egg problem: Manufacturers won't sell enough machines for a standard to develop unless sufficient software exists, but record companies will be reluctant to invest in expensive digital-disk or tape-production facilities that they feel might become obsolete. Furthermore, operators of recording studios, where audio signals are first digitized and mixed, will delay spending the $200,000 to $300,000 to equip their setups until a standard is developed.

To circumvent this problem, some equipment manufacturers are entering cooperative agreements with record producers. The first such venture, between Sony (Tokyo) and CBS/Japan (Tokyo), entails a joint commitment to produce the Compact Disk (CD) system developed by Sony and NV Philips (Eindhoven, Netherlands). Both Sony and Philips will manufacture players, and CBS will release a limited catalog of disks. The two equipment makers hope that availability of the CBS disks will establish the feasibility of the CD system and that other record companies will join the fold.

The CD system, which Sony expects to release in the US by the end of this year, is based on a 4.7-in. (12-cm) optically encoded disk. Similar to the larger Sony videodisk, the CD record contains a 2.5-mi-long helical track of 0.6-μm-wide pits and flats spaced 1.2 μm apart—allowing 8×10^9 active bits per record. As it's scanned, the disk alternately reflects and disperses a solid-state-laser beam.

The Sony/Philips system uses a 16-bit linear-encoded pulse-code-modulation (PCM) format with a 44.3-kHz sampling rate. Sony claims the system achieves more than 90-dB dynamic range and channel separation with less than 0.05% total harmonic distortion (THD). It compares these specs with the 35-dB channel separation, 55-dB dynamic range and 0.2% THD typical of an analog LP record (see **box,** "Are digital specs as good as they look?").

The CD player eliminates wow and flutter by servoing the disk's speed to maintain a constant data rate. The player compares incoming data with an internal crystal reference, and the resulting error signal controls the unit's motor. The optical bit length remains constant throughout the record's track; thus, the player must maintain constant linear velocity by decreasing disk rotation speed as the laser scans outward from the record's center.

Car CD system coming

Sony has stopped development of its previously demonstrated 12-in. digital-audio-disk player, capable of generating 5 hrs of programming on two sides. It feels that the smaller system, which plays for 1 hr using only one side, represents a better choice because it's cheaper and matches the analog LP's programming format. Moreover, the CD system is small enough for use in cars, and Sony promises an automotive system soon.

Not to be outdone by Sony and Philips, other Japanese companies have developed digital-audio-disk players. Of the 16 that demonstrated machines at the recent Tokyo Audio Fair, most use the CD format. A few, however, are experimenting with systems of their own.

JVC, for example, is working on an audio adapter, termed AHD, for its VHD Series videodisk systems. An AHD/VHD combination can

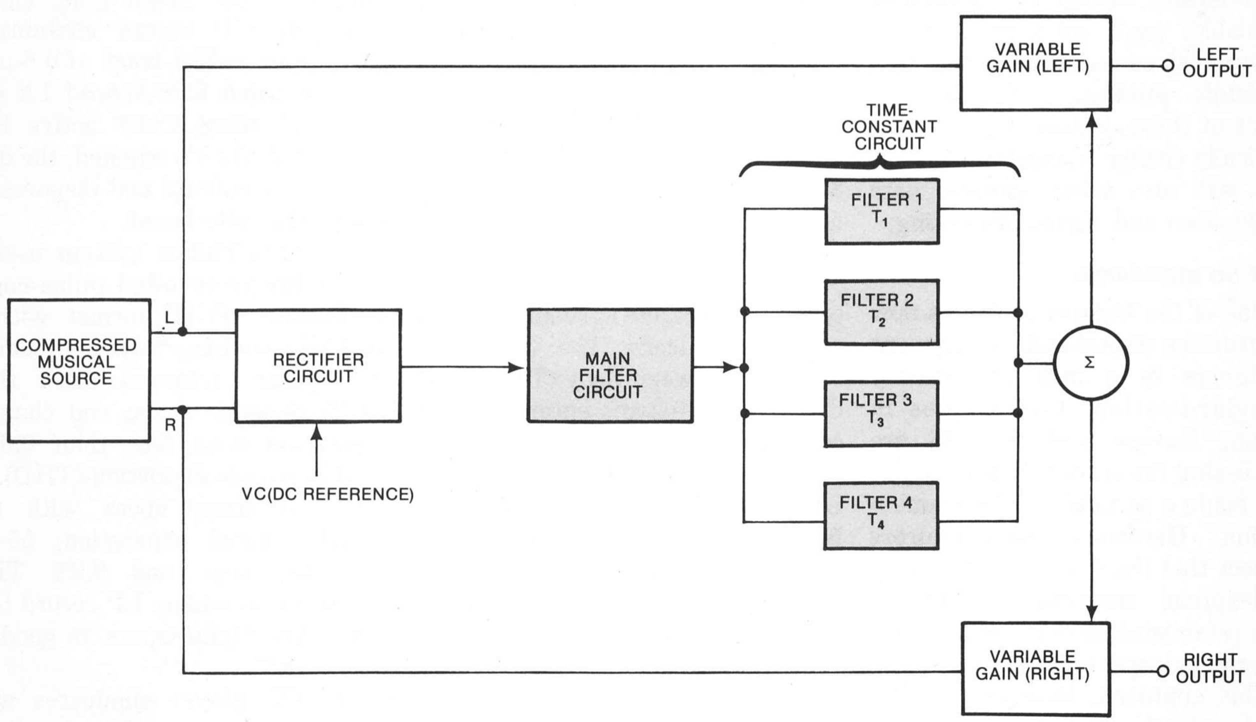
Until digital audio takes over...

Digital audio is coming, but don't throw away your present gear—you'll have to convert it gradually.

First, you'll need to invest about $800 to $1000 in a digital-audio-disk player. Manufacturers hope that these units will become less expensive, although they feel that even the costlier early units will be no more expensive than analog turntables *of comparable quality.*

Second, you won't see too many digital records soon. Optical disks require totally different manufacturing processes than analog LPs, so to produce them, record companies will have to make large investments in plants and equipment. Furthermore, the digital records are similar to videodisks, which, although simple in concept, have proven very difficult to produce. As a result, record companies will be slow in issuing digital disks, and these records initially will be 50 to 100% more expensive.

But while you're waiting for digital audio to take over, you can benefit from analog-audio innovations. Two companies, for example, have introduced analog signal-processing systems that allow conventionally manufactured LPs to offer—at lower cost—the same dynamic range as the digital disks. Both firms' techniques involve compressing a signal's dynamic range as a record is cut and then restoring the signal's original characteristics during playback. Instead of requiring a completely new player, listening to these records demands only that you buy an inexpensive processor that connects to your current



A 4-filter array *provides the time constants in CBS's CX decoder. A deadband in the rectifier circuit prevents expansion of very-low-level signals. Encoders are formed by putting the decoder in an op amp's feedback loop.*

display still video pictures as well as provide stereo audio. No marketing plans for the unit have yet been announced.

Sources within the industry also expect RCA to introduce some type of audio device for its CED Series videodisk players, but no specifics are available.

Fixed record, moving reader

Digital Recording Corp (Salt Lake City, UT) has also proposed a different type of digital-audio player. Its system employs a moving optical scanner that reads a stationary record. The fixed-record design, the firm claims, results in a less complicated and potentially cheaper system than the Japanese spinning-disk units.

Digital Recording says that its unit packs as many as 3×10^8 bits/in.^{2} on silver-halide film, allowing a 3×3-in. record to hold as much as 1 hr of stereo audio. Moreover, because high-resolution film processing is a well-established art and photographic materials are inexpensive, a record for the firm's machine could be made for only $1. This low cost, coupled with simple processing, should make the system attractive to low-volume record producers, according to the system's designers.

preamp or receiver.

The CX system, recently developed at CBS Technology Center (Stamford, CT), allows record companies to make analog LPs from digital master tapes with no loss of dynamic range. When played through a CX decoder, the encoded records offer a 20-dB higher signal-to-noise ratio than conventional LPs. In addition, CBS claims most listeners notice only a minor loss of sound quality when playing back the CX disks without a decoder.

The CX encoder compresses by 2:1 the dynamic range of all signals except those more than 40 dB below a reference level; the compression slope converts rapidly to 1:1 below −40 dB. CBS claims that by leaving very low signals unaltered, the system prevents master-tape hiss from becoming louder than record-surface noise.

To minimize the effects of CX compression on records played back without a decoder, the encoder maintains flat frequency response. Besides providing adequate audio quality for undecoded records, CBS claims that a wide-band process best suits the requirements of record-noise reduction. Although record noise increases at the audible frequency extremes, human-hearing sensitivity to low levels decreases at low and high frequencies, so the perceived disk noise spectrum is flat.

Unlike conventional compression/expansion schemes, the CX system doesn't merely detect a signal's rms level. Instead, the processor full-wave-rectifies and peak-detects the input signal and passes the resulting amplitude-dependent voltage through four parallel filters **(figure)**. Each filter provides a specific attack or decay time constant. The system's designers claim that the 4-filter array allows fast response to musical-level changes while avoiding the audible noise pumping common to other audio companders. To ensure that the encoder's filter characteristics exactly match those of the decoder, the encoder is constructed by placing the decoder circuit in the op-amp feedback loop.

CBS licenses the decoder circuitry to equipment manufacturers for a small fee and provides encoders to interested record producers. A few companies have already signed licensing agreements, so CBS anticipates that CX decoders and records will soon be available.

Until the system gains widespread acceptance, its developers predict, some existing records will be reissued in the CX format, and new releases will be available in both normal and encoded form. Additionally some Japanese manufacturers have expressed interest in incorporating CX circuitry into their receivers, and to make these plans economically feasible, three semiconductor houses are reported working on decoder ICs.

A second analog-disk-enhancement system, offered by DBX Inc (Newton, MA), also employs a compression/expansion technique. In this system, though, all signals are compressed 2:1 regardless of level. Input signals are rms-detected and processed with a single time constant. In addition to signal compression, the encoder provides 12-dB pre-emphasis, which, according to DBX, helps reduce record tic-and-pop noise.

DBX claims that any encoding process that audibly changes a musical signal requires the use of a companion decoder. Unlike CBS, then, it expects its records to be played back only through a decoder and thus isn't concerned with the undecoded sound of encoded-only disks. This approach, DBX explains, enables its system to provide greater noise reduction with simpler circuitry than the CX system.

To get the system off the ground, DBX is manufacturing and selling encoded records. Its catalog currently includes more than 200 titles, including works purchased from 40 record companies. To play these disks, you can use DBX's Model 21 decoder (approximately $110) or the firm's tape-noise-reduction systems. DBX predicts that as the system catches on, receiver manufacturers will integrate disk-decoding capability into their products.

Digital Recording's engineers also suggest that their player is well suited to such automated audio applications as Musak and preprogrammed radio broadcasting. The square records suit stacking in a sliding cube, allowing either sequential or random access.

Although no definite plans for the fixed-record player have yet been announced, Digital Recording says it's currently building six engineering prototypes, and full-scale production could begin within 2 yrs. Because the records are easily produced, the firm doesn't see software as a big problem. It has already established relations with a large German record manufacturer and is ready to make and market records itself if necessary.

Impact on industry

Although home disk players are not the only digital-audio products on the way, they are the ones most likely to have the greatest impact on other areas of electronics. For instance, the use of 16-bit DACs is currently confined to a small segment of the data-acquisition field. These devices are usually designed into high-accuracy industrial and commercial instruments, where their relatively high prices have not posed a problem.

But the DACs employed in home digital-audio players must cost only a few dollars each and be available in considerable volume. To this end, Sony claims that its Semiconductor Div has developed an inexpensive 3-chip set that performs all of the 16-bit linear PCM encoding and decoding functions. It has no plans to offer the devices on an OEM basis but expects it will have to supply them to other audio-disk manufacturers to spread digital technology.

Analog Devices (Norwood, MA) already offers its Model AD7546, a CMOS monolithic 16-bit DAC, which it says suits the needs of digital audio. Realizing that the part's

Are digital specs as good as they look?

Judging by specs alone, digital audio looks terrific: Designers of 16-bit systems with 44- to 50-kHz clocking rates claim flat frequency response from 20 Hz to 20 kHz, 90-dB dynamic range and −80-dB harmonic distortion. However, some audio experts dispute these claims.

For instance, P B Fellgett, writing for *Studio Sound* (November 1981), points out that the dynamic range of an N-bit digital system is $20\log(2^N-1)$, or approximately 96 dB for N=16 bits. This ratio is usually compared to 70 dB typ for a 15-ips analog tape recorder. But the figures can be misleading—the digital spec reflects the difference between a system's largest and smallest possible words, while the audio spec indicates the ratio of tape noise to 0 Vu, an rms-sine-wave reference level.

To make a true comparison, Fellgett contends, you must consider realistic conditions. A sine wave's rms level is about 9 dB below its peak-to-peak value. A 16-bit digital system, then, which produces 1-LSB noise, actually provides only 87-dB dynamic range.

Fellgett further explains that the human hearing mechanism can discern signals that lie below the wide-band noise level. Psychoacoustic experiments have demonstrated that the ear acts as a wave analyzer, comparing signal level only to the noise that surrounds it in a narrow band. Unlike digital systems, in which no signals can lie below the noise, analog recordings contain discernible information buried in the noise floor. The ability of the hearing mechanism to recognize these signals, Fellgett contends, adds 16 to 20 dB to an analog system's dynamic range.

Tape-saturation levels also affect an analog system's dynamic capability. A digital system's maximum signal level depends solely on its word size, but an analog recorder's peak amplitude capability depends on recording-head and tape-saturation characteristics. Good analog tape decks offer more than 10-dB headroom above the 0-Vu reference level. Les Tyler of DBX Inc (Newton, MA) claims that these factors, plus the use of noise-reduction techniques, allow analog recorders to exhibit almost 110-dB usable dynamic range.

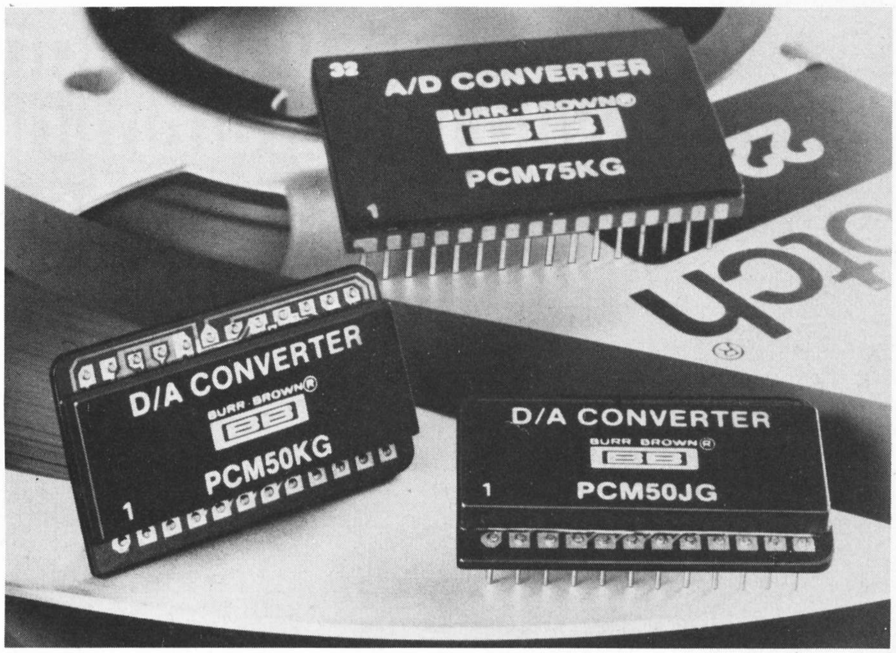
Digital distortion figures, too, are subject to debate. The lowest THD in a digital system occurs at the highest signal level, and distortion increases as the signal amplitude is reduced. By contrast, analog systems distort large signals most, and THD at low levels disappears into the noise. Thus, comparisons made between digital and analog systems at 0-Vu signal levels are misleading. Additionally, Fellgett claims that at low levels the step discontinuities that digital systems produce are similar to the undesirable crossover notches that Class B amplifiers generate.

John Curl of JC Designs (San Francisco, CA) argues that the introduction of digital audio is reminiscent of the development of solid-state systems in the mid-'60s. Then, transistor amplifiers appeared to achieve much better performance than tube designs, but they generated a completely new set of distortion problems. Curl contends that it has taken more than a decade to identify some of the more subtle effects of "transistor sound," and digital audio will most likely undergo the same scrutiny.

Of course, where audio is concerned, the truth is in the listening, and it won't be long before you'll be able to decide for yourself.

initial price of \$20 (100) is still a bit too high for mass-market home players, the firm is working on increasing production efficiency. Higher demand for 16-bit DACs, it explains, should bring prices down.

Burr-Brown (Tucson, AZ) has also introduced converters aimed specifically at the audio market. Its recently announced PCM50 16-bit DAC is the companion to the PCM75 17-μsec 16-bit ADC. This voltage-output DAC offers an internal reference and starts at \$50 (100). Steve Harwood, Burr-Brown's converter-products marketing manager, claims that the extremely rapid development of digital-disk players has caused his company to accelerate the evolution of its DAC line, and the converters it plans to introduce shortly will bear much lower price tags.



Intended for digital-audio use, *these Burr-Brown converters offer 16-bit accuracy and short conversion times. Non-audio users of parts like these will benefit from digital-audio technology by being able to take advantage of the improved performance and reduced prices of high-resolution A/D and D/A converters.*

Although DAC prices are already dropping in anticipation of increased demand, though, converter manufacturers expect digital audio to have only a small effect on ADCs. As Dave Kress, new-products marketing manager at Analog Devices, points out, early home digital-audio systems will offer playback capability only, so audio ADCs will be used primarily in professional recorders. Therefore, a single ADC will feed tens of thousands of DACs. ADC users then will benefit from the improved performance of the audio converters, but prices of these parts will not change as rapidly.

Computer and industrial mass-storage applications should also benefit from the development of digital-audio devices. Unlike videotape and videodisk systems, audio records store unformatted data, free from the constraints of line and frame synchronization. An optical disk capable of holding 10^{10} bits thus offers an excellent alternative to magnetic media in read-only applications. For example, some software vendors hope to eventually market home-computer programs in optical-disk form.

Production of records for home digital players requires that recording studios finally switch to a digital format. Although studio-quality digital tape decks have been offered by a few companies since the mid-'70s, their high cost and the lack of adequate digital-editing facilities have slowed acceptance.

Indeed, Tom Stockham of Soundstream Inc (a subsidiary of Digital Recording Corp) suggests that recording studios have had limited incentive to upgrade to digital gear. He claims that although digital recorders offer far better sound quality than analog machines, the improvements gained by upgrading to the digital decks are masked by the deficiencies of analog LP records. Now that data on digital master tapes can be transferred directly to digital disks, though, Stockham feels that studio operators will be more anxious to invest in new equipment.

To simplify the production of digital tapes, Soundstream has introduced what Stockham claims is the first practical digital-audio editor. Programs to be edited are loaded into the editor in digital form and stored on hard magnetic disk. The editor holds as much as 34 min of stereo audio and can accommodate any clock rate from 44 to 50 kHz with words to 16 bits.

Unlike conventional analog editors, which require that splices be made in order from a tape's beginning to its end, the Soundstream device allows editing passages in any sequence. The editor's operator can assign labels to specific words within the stored data, and these labels, or timed offsets from them, define splice locations.

As a program gets edited, the Soundstream machine stores all splice information in a playback map. The original data never gets altered, allowing simultaneous generation of multiple maps. Thus, a recording engineer can easily compare different edited versions of a stored musical passage.

Stockham claims that by allowing such ease of operation, audio devices such as the Soundstream editor will not only provide improved sound quality, but will also help record producers perfect their art. **EDN**