



Multichannel audio

— in the Digital Home

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A story of witches and wizards (with just the occasional wicked one).

Chapter 1 — in which stereo gramophone records first appear

Once upon a time (for that is surely how the best stories start), stereo gramophone records arrived in our lands. It seemed that life was going to become – acoustically – very exciting.

Even at that point in time, the recording technology used to make these records was already more than 25 years old. What is more, the whole spatial (stereo) effect depended on performing a difficult “magical spell” to establish *virtual* sound images in the listeners’ minds. In fact, for most listeners in their homes, acoustical or electrical shortcomings meant that they would never hear the full stereo effects, as intended. Indeed for a few people (including some honest Record Producers), a belief in the magic of stereo was simply not enough. In their case, their sensory or perceptual hearing simply prevented them from hearing the full “stereo” effects.

However, even when the virtual images didn’t fully work, there were audible benefits in having two reproduction channels. So everyone (well, the young men anyway) flocked to buy, or often build, huge “hi-fi” systems in order to worship these new stereo records.

Then years later in the early 1980s, just as it seemed that this form of magic might be fading away, along came the digital Compact Disc.

The source material used for CD production was exactly the same two-channel material as had been used for making gramophone records. In one sense this was odd, because the Cinema industry had realized some 40 years previously that you really needed more than two channels to reproduce “stereo” audio. Indeed, films like “Star Wars” – with discrete multichannel sound tracks – were just then (early 1980s) about to draw us all back to their own brand of Cinema magic.

In reality, there were two reasons why two-channel stereo was to remain king in the home for another twenty years. Firstly, libraries of music formed the main sales market for the record companies, and it was not music – but dialogue – that benefits most from discrete multichannel audio recordings. Secondly, there was only just enough data storage on one CD for a full concert recording in two-channel Pulse Code Modulated (PCM) form. Low data-rate audio encoding, or larger capacity discs were years away. As it was, the magic of digital technology was stretched to its limits to make digital source recordings in those days, and that legacy still remains in the CD audio sampling rate of 44.1 kHz. This strange number (44.1 kHz) came about because U-Matic video recorders were used in those days to record CD source material in the form of three digital audio samples on each of 588 lines in a simulated 625-line/25 fps video picture:

$$3 \times 588 \times 25 = 44,100$$

Chapter 2 – in which the Digital Witch starts to work in our homes

During the 1980s, the cost of CD players – with their complex optical mechanisms – was high whilst, after 50 years of development, radio receivers and record players had reached an almost trivial low cost in the shops. Was it therefore going to take another 50 years for digital audio in the home to come down to a similar low price? Well, maybe it would have done, had it not been for a surprise trick or two, involving Kodak and a few million personal computers.

Twenty years ago, 650 Megabytes of data stored on an easily-duplicated, fast-access, consumer-priced disc was just what the fast-expanding computer companies were looking for. The growing size of computer programs was becoming obvious with the expanding number of “floppy” disks required to install them, and the huge paper manuals contained in even bigger packaging boxes. So in 1984, the International Standards Organization (ISO) set about standardizing a data-carrying (read-only) version of the CD. This standard was to be eventually published as ISO-9660 in 1988, and groups such as OSTA soon improved on it, eventually creating the Universal Disk Format (UDF) that we use both at home and professionally today.

In exchange for the entry of the CD into the land of industry (computers were ten years away from most homes then), the cost of the basic CD optical mechanism dropped. Indeed the costs of CD hardware fell by so much that the cost of audio CD players took only ten years to follow the costs of basic radio receivers to a really low level. What is more, the same cost reduction happened to digital audio items that we use professionally. Here, it was more a case that costly precision mechanical engineering was replaced by precision electronics. The electronic parts in turn used the same circuits as the consumer industry.

There was clearly going to be no such thing as a professional digit in the future, and there was certainly a possibility that no more dedicated professional audio formats would ever again be developed. The home CD had set the audio quality level for all.

Chapter 3 – in which Broadcasting tries to catch up with the digital home

Stereo Radio came late to most of our lands, mainly because that magic spell of stereo imaging demanded not only well-matched loudspeakers, but well-matched broadcast delivery channels as well. For the programme providers, that was an awkward detail that denied them long-distance contribution and distribution of stereo programmes for many years, at least until digital landline transmission (e.g. PCM) became established during the late 1970s.

For many years, we were told that television would never benefit from stereo sound. It therefore came as a surprise to many that there was a big increase in the sale of new televisions after the digital NICAM stereo system was introduced in the late 1980s. Obviously that particular magic worked well in the home.

Many years later, it came as no surprise when it was said that **multichannel audio** would never have any big applications in the home. Yet, today, multichannel audio in the home seems to have such a promising future. The reason behind this later success lies as much in the area of DVD player developments, as in broadcasting itself.

And onwards to the DVD ...

Physically, the jump from the CD to the DVD ¹ was a small one – because the same physical recording techniques were used, with the dimensions tightened up as better optical mechanisms were developed. However, the “streaming” form of audio data used on the audio CD was no longer seen to be the best format arrangement

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1. Some say that DVD stands for “Digital Versatile Disc”, but the author has never seen any real evidence that the DVD Forum ever referred to them as anything but “DVDs”. What is more, no one seems to really know how you pronounce DVD-R. Is it a dash, a minus sign, or do you just ignore the sign? Mind you, what did the “VHS” letters stand for, and who cared anyway?

Abbreviations

AES	Audio Engineering Society	MPEG	(ISO/IEC) Moving Picture Experts Group
AOB	(DVD) Audio Object	NICAM	Near-Instantaneous Companding And Multiplexing
ATSC	Advanced Television Systems Committee (USA)	PAL	Phase Alternation Line
BUP	(DVD) Back-UP of IFO files	PCM	Pulse Code Modulation
CSS	(DVD) Content Scrambling System	PVR	Personal Video Recorder
DTS	Digital Theatre Systems	RGB	Red-Green-Blue colour model
IEC	International Electrotechnical Commission	VGA	Video Graphics Array
IFO	(DVD) Information for Formatting VOB files	VOB	(DVD) Video Object
ISO	International Organization for Standardization	UDF	Universal Disk Format

for the DVD medium. The computer experience with CDs had shown that better data arrangements and better error protection could be found – the file arrangement of the data on CDs was awkward to use in the wider applications that were obviously destined for DVDs.

This jump in thinking separated the different *physical formats* (such as DVD-ROM and DVD-R) from the *application formats* (such as DVD-Video and DVD-Audio) – and the confusion of compatibilities is by no means over yet.

DVD-ROM – including recordable variations such as DVD-R/RW, DVD-RAM and DVD+R/RW – is the base format that holds data, whilst **DVD-Video** (often simply called DVD) defines how video programmes (such as movies) are stored on the disc and played in a DVD-Video player or on a DVD-equipped computer. Current application formats include DVD-Video, DVD-Video Recording (DVD-VR), DVD+RW Video Recording (DVD+VR), DVD-Audio Recording (DVD-AR), DVD Stream Recording (DVD-SR), DVD-Audio (DVD-A), and Super Audio CD (SACD) – not to mention application formats for game consoles such as the Sony PlayStation 2 and the Microsoft Xbox.

Chapter 4 – in which Broadcasting, DVD players and an Interface become friends

It looks therefore as if our homes will become the battleground for yet more commercial wars between audio manufacturers – or rather, wars between groupings of “licensees” for systems, or even interfaces. We have, so far, not mentioned many of these past and possible future battles ... for this is really the story of how we came to have – quite suddenly (and as much by luck, as by any good marketing) – the slightly unexpected capability to receive and replay multichannel audio in our homes.

In reality, digital broadcasting systems have always had some potential to carry multichannel audio, even though it may never have entered into the economic models for most of the systems. As a result, multichannel audio still has to win a fight to justify the raw bitrate needed to transmit it on a day-to-day basis. The battle to reduce this multichannel bitrate for broadcasting has received immense help from the digital systems first developed for Cinema soundtracks, and then adapted for the DVD movie releases. In turn, the computer-industry adoption of the CD many years ago has directly contributed to the amazing affordability of DVD players.

To complete the set of items needed, low-frequency effects channels (with sub-woofer loudspeakers) were first introduced in the Cinema in order to hide the low-frequency noise that was present on analogue soundtracks. These loudspeakers may have been introduced for a simple and almost crude purpose but, as an addition to home audio systems, they sound quite sexy. This has led to the design of “Home Cinema” 5.1 loudspeaker systems that are quickly replacing (or at least augmenting) the “Hi-Fi” stereo loudspeakers in our homes. It is also true that digital audio processing within DVD players contributes something to the performance of these tiny loudspeakers, but that equally makes it difficult to upgrade the loudspeakers if you wish to do so.

Two vital pieces of equipment are therefore to be found in many homes – **set-top boxes** (STBs) with a digital audio output and, surprisingly, low-cost **DVD players** with the necessary multichannel audio decoders and the set of loudspeakers included.

The final piece of this puzzle is the **interface** needed to join them together.

The AES/EBU audio interface was first used to carry bitrate-reduced multichannel audio in a packet form, by those ever-practical development engineers who selected the most usable physical interface that was around at the time. It was first standardized as IEC 61937 in 1998 and, at first, it only enabled Home Cinema enthusiasts to link from the early DVD players to Dolby Digital or DTS decoders. Multiple *analogue* cables then led onwards from this equipment to their audio amplifiers and loudspeakers.

In a suitably-equipped home, this single wire or fibre link now enables the whole multichannel audio broadcast chain to be completed.

So is it worth it? Well, if the equipment is already largely in place in the home, then the obstacles to try out multichannel audio are fairly low. What is more, anyone who attended the EBU demonstration of 5.1 multichannel audio for Radio and Television at IBC-2003 in Amsterdam may have been pleasantly surprised with the *range* of programmes that can benefit from multichannel audio.

Chapter 5 – will the Interface be the final battle between good and evil in the Digital Home?

Where a programme-recording device (e.g. personal video recorder or PVR) is integrated within a domain that remains under the control of the broadcaster, (typically inside a set-top box or receiver), then complete control over the recording rights and time-shift limitations can be applied. The vital home interface will therefore be the one from such a PVR to the video display device (possibly including the audio signal) and it is clear that the demands for a high-quality picture will drive the industry towards simple high-bitrate digital connections, similar to the DVI computer monitor interface

If such an interface is in a format that is compatible with the display (say, full-bitrate RGB representation), then it is unlikely to be compatible with equipment used for external home-recording purposes, and vice-versa. Not contented with this simple protection mechanism, the industry's fear of digital home recording may well extend to **encryption of the display interface**, in much the same way that the files on a DVD movie are encrypted. One possible result of the standardization work currently underway on this subject, would be for a display to show only a poor-quality (VGA, PAL?) representation of the input signal, unless the correct "keys" were in place inside the display for an HD picture.

That then is the end of our story for now, but if you haven't gone to sleep yet, some of the technical details of the DVD family may well interest you ...

So where did Kodak come into this? And what about all those DVD recordable formats?

The Kodak involvement was connected with the recordable CD. The technological jump from the pressed CD to a recordable version was actually a much bigger piece of technical magic than was the jump from the CD format to the DVD format. Not only was a lot of technical magic needed in order to make recordable CDs available to us all ... it looked for a long time as if the companies involved in the development of the audio CD were going to make the recordable CD too costly for us to use at home – for a totally different reason. These companies thought that the main use of the recordable CD in the home was going to be for *copying* commercial audio recordings.

Kodak, on the other hand, saw a much bigger application area for recordable CDs, particularly as a *storage medium* for home photographs. Therefore, in order to reduce the basic costs down to a level at which they could sell the photograph storage idea to the public, Kodak fought the music taxes on blank recordable discs. In most countries, we have all benefited from this – not only at home, but at work as well.

The recordable CD – CD-R(W) – uses a pre-recorded spiral groove, which the recording laser follows. First though, it makes a practice recording in the inner area of the disc reserved for this (*Fig. 1*). Then, to help

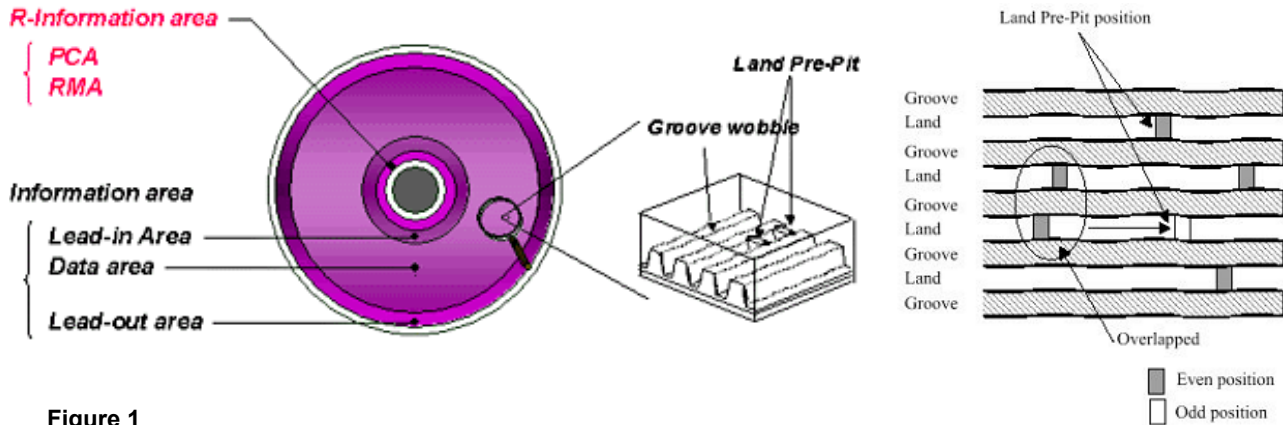


Figure 1
Layout of a DVD-R(W) recordable disc

speed up access to any part of the disc, the blank discs are made with a slight wobble in this groove. This wobble is detected electrically as an AC signal from the servo which follows the groove, and this signal can tell the writer or reader the speed it is running at. Also the address can be read from a frequency modulation of this wobble, called the ATIP data (Absolute Time In Pre-groove).

The similar DVD-R(W) format (*Fig. 2*) uses a slow wobble (140.6 kHz) for tracking and speed, and the address and additional information is carried in pre-recorded pits between the grooves.

On the other hand, the DVD+R(W) format uses a much faster wobble (817.4 kHz), and the addressing (and additional) information is carried by ADIP (ADress In Pre-groove) phase modulation.

This is the only major difference between the DVD-R and DVD+R formats. However, something else to beware of when buying DVD recordable discs are those sold as “Mastering” format discs.

Mastering DVDs are not high-quality recordable DVDs, but are designed for a different application in dedicated Mastering writers. These Mastering writers use powerful short-wavelength lasers and, although you may succeed in recording on these discs with a normal writer, it will not be as good as a normal disc and will put a strain on the writing laser.

So, how is the data on a DVD organized? Put any DVD movie or DVD-Audio disc into a computer drive, and you should be able to see just two “folders” of data, one containing the Video (Video_ts) and the other, the Audio (Audio_ts).

If you click on the Video_ts folder, you will find .VOB, .BUP and .IFO files. The VOB files are MPEG-2 encoded. These files contain basic MPEG video and audio, the subtitles and multiple camera angles. The IFO files are the information files used by your DVD playing device. It gives the DVD player information on what VOB files to load and when (e.g., when to start a new chapter). The BUP files are simply a backup of the IFO files and will only be used if any IFO files become unreadable. The Audio folder (Audio_ts) contains .IFO and .BUP files, as well as .AOB audio files.

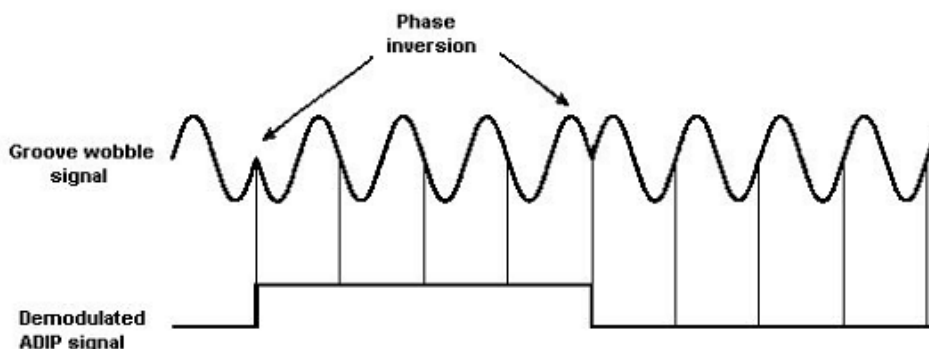


Figure 2
The Address-in-Pre-groove (ADIP) modulation on a DVD+R(W) disc

You might think it would be easy to copy these files to a folder on your hard disk and then burn them to a recordable DVD, but almost all movies are encrypted with CSS copy protection. Decryption keys are stored in the normally inaccessible lead-in area of the disc. You will usually get an error message from your computer if you try to copy

Table 1
Some key differences between the CD and DVD formats

Specification	DVD-Audio	CD-Audio
Audio Format	PCM	PCM
Disk capacity	4.7 GB – Single layer 8.5 GB – Dual Layer 17 GB – Double-Sided Dual Layer	650 MB
Number of audio channels	Up to 6	2 (stereo)
Analogue frequency response	0 - 96 kHz (max)	5Hz - 20kHz
Maximum dynamic range	144db	96 dB
Sampling rate – 2 channels	44.1, 88.2, 176.4 kHz or 48, 96, 192 kHz	44.1 kHz
Sampling rate – multichannel	44.1, 88.2 kHz or 48, 96 kHz	n/a
Sample size (quantization)	12, 16, 20 or 24 bit	16 bit
Maximum data rate	9.6 Mbit/s.	1.4 Mbit/s

the contents of an encrypted DVD to a hard drive. However, if you have used a software player to play the movie, it will have authenticated the disc in the drive, allowing you to copy without error, but the encryption keys will not be copied. If you try to play the copied VOB files, the decoder will request the keys from the DVD-ROM drive and you will again fail at this stage. You may get the message “Cannot play copy-protected files”.

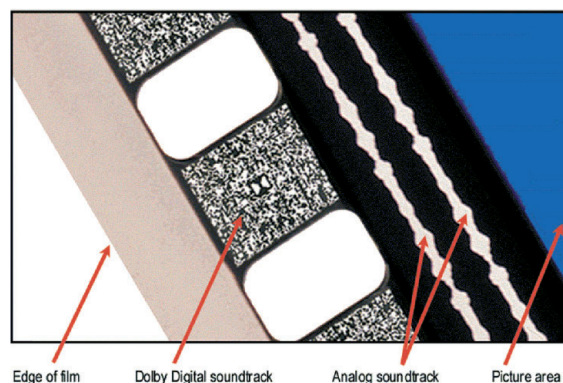
Multichannel audio formats for the home

The Cinema came to multichannel audio via those “spectacular” display formats such as 70mm, Cinerama, and IMAX. These formats used the best quality sound that analogue audio could offer, and that eventually involved multitrack audio carried on separate magnetic film, running in mechanical synchronism with the projector. No sooner had this grand system become established, than the costs of making the distribution prints rose, and audience audio expectations grew as a result of the arrival of the CD into the home.

Dolby, and others, looked at just about every possibility for putting digital audio into the Cinema. Today, just two of those early contenders remain – the Dolby Digital format and that of Digital Theatre Systems (DTS).

The DTS format uses an optical timecode track on the film, to lock to an external CD (or computer-based server), which carries multichannel audio at the same bitrate (approximately 1.4 Mbit/s) as that found on a normal two-channel CD. On the other hand, the Dolby Digital coding system uses an amazingly low combined bitrate of 384 kbit/s for 5.1 channels, which it manages to print directly onto the film in the space between the sprockets, even including a little DD logo in the middle of each patch (*see the accompanying photo*).

The Dolby Digital system, with a few enhancements, became the basis for the AC-3 audio stream used for the



Edge of film Dolby Digital soundtrack Analog soundtrack Picture area



Dr John Emmett joined the Engineering Department of Thames Television in London after gaining a Ph.D. at Durham University, and after starting the UK audio equipment manufacturer, EMO Systems. Whilst at Thames Television, he worked on subjects as diverse as film archive formats and psychoacoustics and, along the way, gained six international patents as sole inventor. Jointly with Lee Lighting, he received a Technical Oscar for developing the flicker-free Lighting Ballast.

John Emmett continued as R&D Manager with Pearson Television, and is currently Technical Director and Chief Executive of Broadcast Project Research, a new independent studio-based research group. He represents UK Independent Television at the EBU as Project Leader for the new P/AGA (Advisory Group on Audio) project, following on from leading the P/AFT project that created the BWF audio file format.

ATSC digital television system in the USA. Meanwhile, the higher combined bitrate that can be carried by the DTS method has gained favour where extreme bitrate reduction is not so necessary, and low latency (signal delay) is important.

In the DVD-Audio format, which is an audio-rich form of the DVD-Video format, you will find the options for audio coding are fairly open and, importantly, these include full-bitrate PCM multichannel. Indeed, the DVD-Audio specification requires PCM audio, while the Dolby Digital, DTS and MPEG audio formats are optional. The full list of PCM options for DVD-Audio is presented in *Table 1*, compared with the single specification which we find for CD-Audio.

And looking into the crystal ball at the future of audio in the home

Cinema presentations are tending towards more playback channels, especially to fill a perceived “hole” at the centre-rear effects area. This may not be so important for Television, where the sound “picture” is more front-centred. However, Radio is an interesting case as the sound pictures in this medium remain free of any visual limitations.

The important thing seems to be that the present 5.1 standard will be stable enough to form a platform for broadcasters to experiment upon – and that is what consumers would like to know when planning their AV purchases. Aside from broadcasting however, the overall DVD system is likely to continue suffering incompatibilities in the home (optical as well as format), as different versions make an inroad into our lives.

Professionally, we have learned to take a simple view of this; **it is, for instance, more economical now to give a multichannel audio recording sample to a client on a recorded DVD ... along with a suitable player ... than it is to make a multichannel audio tape!**