HDTV

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Digital HDTV in Europe

Key issues in HDTV/ATV systems*

J. Forrest (NTL)

If broadcasters can find commercial or other justification for breaking away from the constraints imposed by compatibility with the existing analogue receiver base, digital technologies offer many interesting possibilities for new services which may – or may not – include HDTV.

Research is in progress in two projects, Spectre *and* HD-Divine, *which both draw on digital emission techniques developed initially for Digital Audio Broadcasting. They will offer rugged emission in the presence of multipath propagation, adaptability allowing control over interference to and from conventional television services in the same frequency band, and flexibility in terms of the programme signals conveyed.*

Past experience – especially in relation to the analogue enhanced systems – highlights the importance of the timely establishment of a standard for digital terrestrial television, preferably on a world-wide basis.

1. Introduction

The past few decades have seen enormous progress in new technology, introduced at an ever-increasing pace. *Fig.1* illustrates this by reference to some of the more significant milestones for television viewers.

The advent of satellite transmission has meant that television reception in some form is now possible virtually world-wide. Cable delivery systems in more populated areas have brought vast increase in the number of channels available to the viewer. Despite this progress, the evolution of television broadcasting technology has still been constrained by a very important characteristic of the broadcasting process: broadcasting requires all receivers, new and old, in the area of coverage to be compatible as regards the reception and processing of the broadcasting signals; it is a process in which by far the dominant investment in the broadcast chain is made by the public personally and is under their control. The television receiver is still a significant investment for many homes and one that is expected to provide good service for many years without obvious obsolescence. The expected life of a television receiver is at least ten years, although the purchase interval may now be closer to

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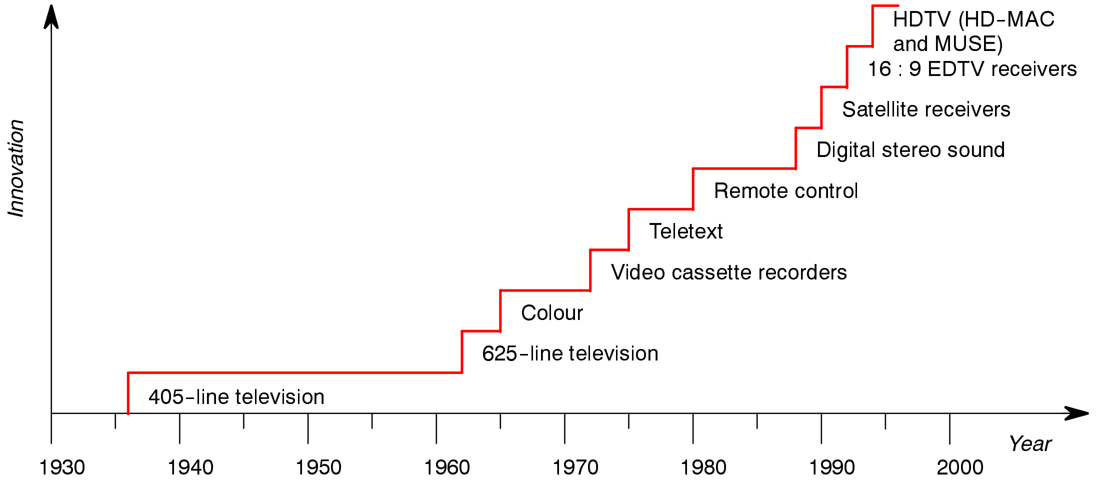

Figure 1
Milestones in United Kingdom television technology

five years because a large proportion of homes are increasing the number of receivers in the home. The receiver base and its lifetime are therefore the major constraining factors in the introduction of new technology.

A major technology change in a broadcast transmission service is long and costly. The change from VHF 405-line monochrome transmissions to UHF 625-line colour transmissions in the UK took some 15 years. Simulcasting of existing services was provided to avoid disadvantaging viewers, while at the same time new attractive programme services on the UHF transmissions were included to encourage viewers to invest in replacement receivers.

To gain insight into the key issues related to the introduction of new systems such as high-definition or advanced television, it is useful to look back at the introduction of new broadcasting technology in Europe in recent years. Certain lessons may be learned.

1.1. Evolutionary change

The most recent evolutionary change in some European countries has been the introduction of NICAM stereo sound to the television broadcast signal. The PAL signal format is such that two-channel digital sound could be added without affecting in any way the reception of the existing mono signal on current receivers. The result of the process in the UK has been a well-managed transition over a period of several years in which transmitters were modified to carry the signal, broadcasters gradually increased the amount of programme material with stereo sound, and the sales of NICAM television receivers and VCRs increased. The major driving force has come from the consumer electronics manufacturers, but assisted importantly by the fact that the whole broadcast chain was under the control of a unified body (eg the BBC or IBA in the UK) and by certain regulatory pressures on programme suppliers to provide stereo sound programming; this gave manufacturers confidence that a market for sets would be forthcoming. There were no commercial reasons for broadcasters to press for rapid introduction of stereo sound since the process involved cost rather than new revenue and there were no very obvious competitive forces to threaten market share if stereo sound were not introduced. Thus, the introduction of this new technology has been proceeding to a large extent on the same timescale as that of routine transmitter re-engineering and normal domestic receiver replacement.

1.2. Non-evolutionary change

The major non-evolutionary change has been the introduction of satellite-based transmission systems [1]. The limitations on spectrum availability for terrestrial transmissions have for some time placed a restriction on further expansion of the range of programme services, typically limited to about four channels in most European countries. When the feasibility of satellite delivery of programmes direct to the home was demonstrated, a complete system of new channels was planned. The WARC 77 conference allocated spectrum for the satellite channels in Europe on the very democratic basis of five channels per country (for even the most tiny countries), regardless of need and with no view overall of how channels would be used or the market for them. It was ten years after the 1977 WARC Conference before the challenge of providing a five-channel direct-to-home satellite service was taken up by British Satellite Broadcasting (BSB), a new private venture organisation.

By contrast with the rather primitive business thinking behind the launching of new channels, the technological planning was highly refined. Even as early as 1980 it was realised by some that the future would be one of digital transmission. A new transmission format for satellite broadcasting services, known as MAC, was developed. Digital technology at that time could not process the video signal components, so only the sound and data stream was encoded in digital form. The complete sound and vision signal was however put in a time-division multiplex so the video components could easily at a later stage be made digital. Evolution to widescreen format and HDTV was already foreseen and allowed for in the specification.

Sadly, the consumer electronics industry at that stage had little confidence in the DBS venture and in the early stages put inadequate resources into bringing the technology to market. An important factor in the lack of confidence was the battle over standards. C-MAC had been agreed by 1985 as the European standard for DBS, but there was at the time of this standardisation no identified market for DBS services. Technology and market thinking then evolved, leading to the development of D2-MAC, compatible with cable systems, but sacrificing performance, and then also D-MAC, which was a compromise solution. The industry prevaricated, wanting to wait for the resolution of a single standard.

A variety of delays, problems with single-sourced semiconductor chips and organisational problems for BSB occurred throughout this time. Criticism of the new technology was also launched by the media in general and by existing broadcasters who saw a considerable threat in BSB itself and in the capability it had to launch wide-screen and higher definition services in the future. BSB's launch date was one year late and although the technology was then very successful and programming of good quality, competition from services on telecommunication satellites such as Astra using existing PAL technology had become established. The market was inadequate for two satellite-based services and the inevitable merger of BSB and Sky Television occurred in 1990. Sky became the dominant partner with its larger installed base of dishes and use of a 16-channel satellite, giving greater potential for channel choice and also European coverage, but with the sad consequence that the older PAL technology was retained for the merged enterprise.

MAC is still the only available system in the world that offers compatible 4:3 and 16:9 enhanced or high-definition services by satellite. It may yet find some success, however, through the increasing number of D2-MAC services in Europe and the promotional efforts on HD-MAC.

1.3. Lessons for the future

There are useful lessons to be learned from this history:

- New technology will be more difficult to introduce if it does not provide reasonably balanced opportunity to the majority of those already in the market. A new service if based on new technology, outside the vertically integrated broadcasting organisational structures of the past, will face enormous funding and start-up challenges.
- The consumer electronics industry, although always enthusiastic at the research stage about new technology and the possibility of new products, must be adequately convinced that there is a business case for the programme services using new technology or systems; if not, they will not make the major investment at the critical point to bring development hardware into production.
- The consumer electronics industry will not wish to invest in production while a technology is still in a rapidly-evolving phase and before clearly-defined standards are agreed.
- A technical standard made any significant period of time before the market is ready for the introduction of a system will create confusion. Technology will evolve in the period between standardisation and implementation, bringing uncontrolled and increasing pressures to break away from the standard.

2. Key issues for digital HDTV/ATV

The key issues stem first from the need to understand the market for new services and any constraints faced by the new system. This can then lead to service definition and detailed system design, the latter having the very difficult challenge of needing to take account, in an evolutionary way, of the next twenty or thirty years' change in digital technology and associated software.

2.1. The market for HDTV/ATV systems

The identification of the market is the central issue which applies to these systems, whether analogue or digital. It is also the issue which is creating the most difficulty.

The modern PAL television receiver now available in much of the European environment, when fed with programme material originated and edited in component format, produces an excellent picture and accompanying stereo sound of compact disk quality. The limiting factor to increased performance is now the transmission path, both as regards its bandwidth, set by internationally-agreed channel spacing, and its susceptibility to multipath effects producing "ghosting". However, for receivers of around the 30-inch screen size or less, typical of the domestic environment, HDTV itself would yield relatively small benefits – a slight increase in picture quality and a wide-screen format allowing more complete rendition of movies. Until new display technology either of flat screen or projection type arrives, receivers larger than 30-inch are too cumbersome for many homes, thus denying to the domestic environment the obvious benefits HDTV has with large screens. It should be remembered also that much viewing at present is of prerecorded or self-recorded tapes, which do not even come close to utilising the full vision and sound quality capability of the modern receiver. Many studies have shown that the public are willing to pay only a small premium on the cost of a television set to have the features currently offered by HDTV [2]. As regards the viewer, therefore, it may fairly be said that HDTV at present is very much technology-led and still awaits a market justification, such as would be obtained through the convenience of large-area flat-screen televisions which hang on the wall, or the attraction of new and exclusive programming available only on HDTV services.

Broadcasters and production houses themselves, while strongly concerned about the costs associated with complete re-equipment for HDTV, can nevertheless see a certain number of potential cost benefits from HDTV technology. It is equally well suited to create a product for movie theatre and television markets. Editing and special effects are easier and less costly than with film. The European VISION 1250 project is a most important initiative in giving broadcasters the opportunity to understand and quantify these aspects.

HDTV over-air terrestrial transmission, if digital, has also the added benefit of greater reliability and reduced cost associated with the low-power transmission systems which would be used. Besides the aspect of capital cost, it is typically found, as shown in *Fig. 2*, that transmission system fault levels and associated maintenance costs are strongly related to power level. Payback periods associated with conversion from high-power analogue to low-power digital transmission could be surprisingly short.

Digital transmission, given an appropriately chosen modulation format and access to non-shared frequency bands, could also give much better mobile reception for portable receivers and in vehicles (e.g. cars, buses, trains), thereby increasing potential audiences or viewing hours.

The key factor in the introduction of HDTV will almost certainly be competition rather than its intrinsic consumer appeal. As can be seen, there is relatively weak justification for the existing broadcasters to move to this technology. New entrants to the broadcast business, if using terrestrial transmission, are constrained to use current transmission systems if they wish to access the existing base of receivers. To generate adequate revenue to service start-up costs otherwise is very difficult. New entrants using satellite transmission are not so constrained since new equipment is required at the viewers' premises in any case and they must overcome the hurdle of creating a new audience base. Cable broadcasters have a further difference in that they have control over the whole transmission path to the home in their area of operations and can therefore more quickly and easily modify and upgrade the transmission system to new standards such as HDTV if desired. However, satellite and cable broadcasters are showing greater interest in providing more channels and video-on-demand services than in HDTV at present.

The main competitive threat to existing broadcasters could come from the introduction of pre-recorded HDTV material which was also compatible with computer graphics, interactive television and multi-media workstations. In the author's view this is perhaps the most significant driving force which will influence traditional broadcasters.

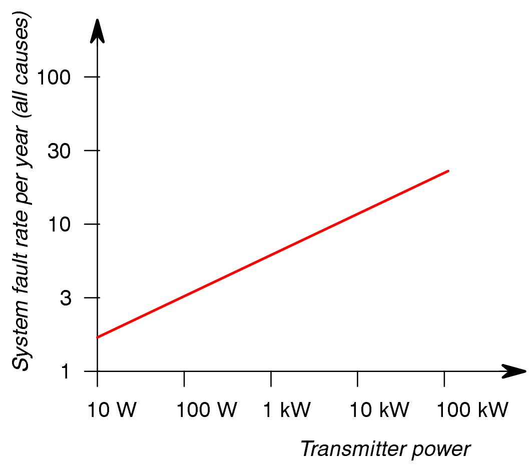

Figure 2
Transmitter system fault rate dependence on transmitter power

It would appear that until the market for HDTV/ATV technology becomes more clearly defined, the emphasis will be on all broadcasters, whether terrestrial, satellite or cable, attempting to try to identify a technological route and establish a preparedness for the introduction of HDTV/ATV, but having little desire to implement until maintenance of their competitive position requires it. These routes will, at least at this stage, not necessarily be common ones and in some cases may actually represent retrograde steps.

The consumer electronics industry meanwhile, having achieved high penetration of VCRs in homes, is desperately seeking to introduce a new product such as HDTV or ATV. To be successful in this though, it needs to have the commitment of broadcasters since it is access to programmes rather than technology itself which is the motivation behind the purchase of new consumer equipment.

2.2. System constraints

Much thought has been devoted to finding ways in which HDTV or ATV systems could be engineered to be compatible with existing PAL, SECAM and NTSC systems. Such approaches, usually based on providing digital assistance to improve picture quality, have an initial appeal in that they could avoid the need to simulcast programme material in the long period of introduction of the new technology and HDTV programme material. Ghost cancelling is a good example of where an enhancement technique can be most helpful, but to try to achieve HDTV or ATV performance by enhancing thirty-year-old techniques such as PAL, SECAM and NTSC seems fraught with difficulty. Even presently-envisaged enhanced-PAL and enhanced-NTSC ATV systems seem to bring as many disadvantages for viewers with existing sets [3] as advantages for those buying new widescreen sets. A new technology can be more effectively used if few compromises have to be made to past practices. Full digital transmission offers the opportunity to make a fundamental step forward.

An important first step in digital HDTV/ATV is to decide what are the key system design constraints. Bearing in mind earlier considerations, it must be assumed that simulcasting of a significant amount of existing services will be necessary. It is also important that the system should be capable of being used with any of the current transmission media, the most restrictive being the 6 MHz/7 MHz over-air terrestrial channels and some older cable systems. However, it would be unfortunate if system design was focussed exclusively on a 6MHz or 7MHz bandwidth constraint. A sensible approach would be to ensure that the system could be used with such channels, but that compatible system variants, maybe with less signal processing complexity, could be used on other wider bandwidth transmission media.

2.3. Service definition

A second step is to define clearly what services are to be carried by the new technology. Although it must be able to carry HDTV or ATV simulcasts of certain existing channels, it would be restrictive to assume that this is the only goal. Just as in MAC transmission the digital sound and data multiplex was designed to be able to carry any combination of sound and data channels, including full-field data, the digital multiplex for the new digital television transmission system should encompass applications across the full multi-media spectrum. In the UK, part of the usage of the VBI lines has been given over to business applications and, by analo-

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gy, some of the new digital channels could be made available to business users. The new channels should more properly be thought of as one–way communication pipes which have the capability of very inexpensive wideband signal delivery into all the homes, businesses and mobiles within the terrestrial transmitter area.

2.4. System architecture

The concept of the broadcast channel being a communication pipe focusses attention on the need to define early a hierarchy of bit rates for the digital transport structure. This has been common practice in telecommunications where the need for a range of related bit rates is caused by the different capacities of transmission links at the various levels of a network (eg trunk, inter–exchange, and local). The concept of a digital hierarchy for telecommunication links is now well established.

The classical communications system (and a digital broadcasting system is no exception) consists of an encoder, a modulator, a transmission channel, a demodulator and a decoder (*Fig. 3*). For a given application, all three are specified together, but it is common in digital systems that a given channel can convey a range of encoded material where any encoder/decoder pair will function and may be multiplexed together. This leads to the concept of so–called "embedded" coding whereby for a given channel a common structure can be used by a range of encoders and corresponding decoders to deliver a wide variety of services. By this means, common algorithms can be used across a range of bit rates and transmission media, bringing the particular advantage of common processing chip design. This yields the volume market for the electronic circuitry so necessary to achieve acceptable entry price in the market for the consumer product.

This line of approach can also lead in the future to the situation where the decoder is simply a non–specific hardware platform and its functionality is defined by special software which may easily be changed. This would alleviate in time the difficulty caused by the large consumer base of immutable receivers – their functionality could be altered by the simple process of reloading new software.

The step to digital television is one of those few occasions when there is an opportunity to break with the past incompatible mix of standards and achieve commonality, not only in the television domain, but across the whole multimedia environment. The television set is already used in the role of entertainment and news provision, data access, video games console and home computing or word processing. The move to digital television will serve to reinforce that multifunctionality and multi–media character.

The greatest obstacle to progress will be protectionist attitudes, either national or commercial, on the part of broadcasters who wish to set themselves apart from other media, or from the consumer electronics industry who likewise may wish to differentiate themselves from the computer industry.

It is vital that the coding structures and transport hierarchy for digital television systems is defined

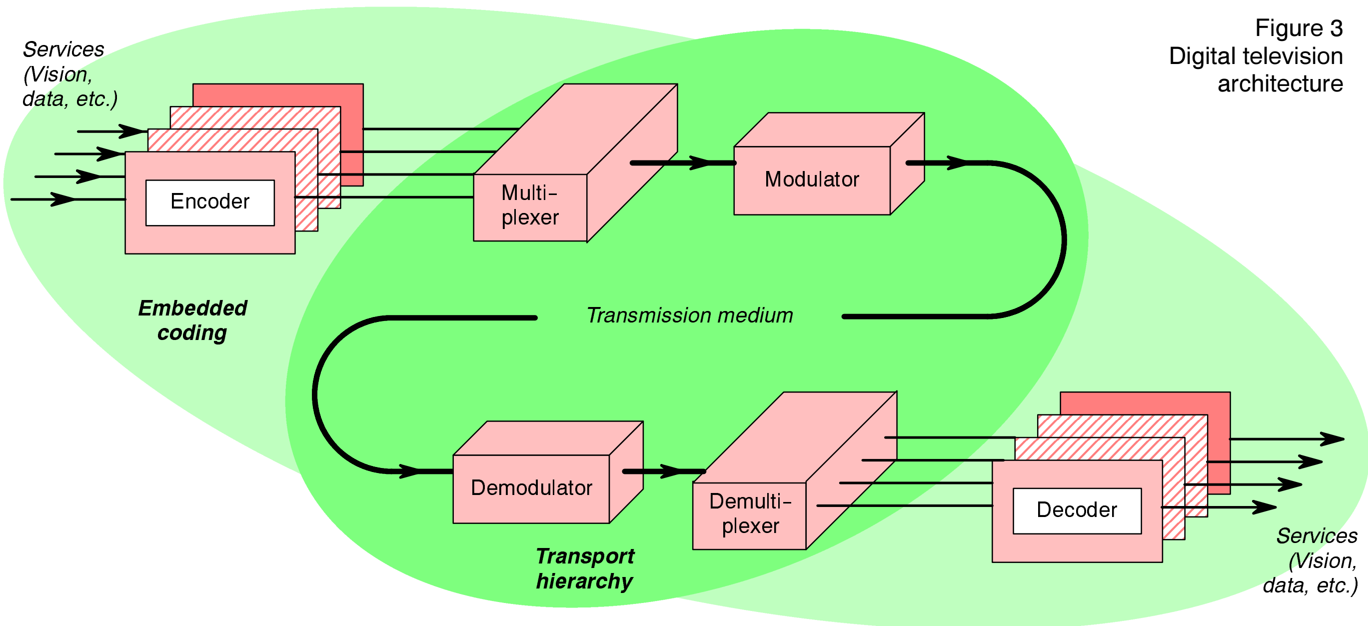

Figure 3
Digital television architecture

	64	kbit/s	Standard digital telephony Video-conference
	144	kbit/s	Narrow-band ISDN
	384	kbit/s	Mono broadcast audio Video-conference
	728	kbit/s	Stereo audio
	2048	kbit/s	Video-conference (1.544 Mbit/s in USA and Japan)
	4.4	Mbit/s	Compact Disc (audio) Interactive CD video?
Remain to be defined	5	Mbit/s	VHS quality TV
	10	Mbit/s	S-VHS quality TV
			Domestic digital VCR Terrestrial TV
	15	Mbit/s	Enhanced-def ATV domestic systems (Domestic HDTV in future?)
	34	Mbit/s	ATV distribution (Current studio quality distribution for PAL) (45 Mbit/s in USA, 32 Mbit/s in Japan?)
	140/155	Mbit/s	HDTV distribution
	1000	Mbit/s	HDTV studio

Figure 4
Digital bit-rate hierarchy

as quickly as possible, encompassing all levels of picture quality, not just ATV and HDTV systems. It is understood that this is a view strongly shared by the SMPTE in the USA. The structure should build on the basic relationships shown in *Fig. 4*. It would be folly also if the coding structures adopted did not build on the progress already achieved in international standardisation of picture coding through JPEG and MPEG activities.

It would be particularly beneficial if a coding structure could be developed with a similar approach to that of the videoconferencing standard H261 which is operable with 50Hz or 60Hz field rate and which uses a transport hierarchy in multiples of 64kbit/s. The goal for digital HDTV and ATV should be a coding structure which is not source parameter or display parameter dependent and which fits a transport hierarchy encompassing all media.

Given the ability to adopt a common coding and hierarchical transport structure, the choice of bit rate for a given application is dependent on the picture quality required, the data rate capacity of the channel and the complexity of bit-rate reduction processing that the application, for economic reasons, will support.

2.5. Modulation format

Since digital terrestrial television must share a frequency band with existing analogue services, great care must be taken in the design of a robust modulation format, but one that ensures that interference with the existing analogue television transmitters will not occur. This is particularly critical in national networks which use many low-power relay stations. The only way to be sure of avoiding such interference is to radiate the new digital service at very low power, at levels typically one thousand times (30 dB) less than those of the current analogue system and co-located with existing transmitters. Despite the large difference in transmitter power, it is possible to cover similar service areas because typical carrier-to-noise ratios (C/N) for digital signals are about 15dB whereas the analogue television system requires a C/N of greater than 40dB for a good quality picture.

A particular difficulty to be overcome arises from the reflected signals in multipath propagation which impair the received digital signals and introduce errors.

If bandwidth were the only consideration, a simple modulation system such as QPSK would allow the transmission of normal definition television at a bit rate of 12 Mbit/s in one of the standard 6 or 7 MHz channels allocated for UHF terrestrial television broadcasting.

At the expense of error performance, a higher bit-rate can be transmitted in such a channel by using a 16-level modulation scheme such as 16 QAM. This enables the data rate to be increased to 24 Mbit/s which appears to be necessary for a picture quality which could be described as ATV or HDTV. However, there are some disadvantages of QAM systems over PSK systems, such as more complex carrier recovery and increased susceptibility to non-linear distortions.

For all but very benign propagation environments it seems likely that particular attention will need to be paid to the multipath problem. This can be tackled in a variety of ways, such as the use of adaptive equalisation, the use of spread spectrum techniques or the use of parallel data transmission involving orthogonal frequency division multiplexing (OFDM). These techniques have been evaluated elsewhere [4] and there seems little doubt that OFDM is the most powerful and cost-effective. Tests of such a system by NTL and the ITC [5] have just started, but much yet remains to be done in the practical assessment of all possible systems. Trade-offs between signal robustness and picture quality, particularly as regards performance close to the service area edges, will need very careful consideration. Design will need to take particularly careful account of receiver cost, minimising decoding complexity at the expense of encoding complexity. Talk of standards for digital HDTV/ATV systems, therefore, is premature until such factors have been properly evaluated.

Attention must also be focussed on the development of a domestic digital video recorder since video recording and playback is an essential component of the domestic video environment. Both digital receiver and digital video recorder must have interfaces to standard computer buses and some capability for interface with existing analogue VCRs to handle the now substantial home archive of tapes and output from camcorders.

3. Conclusions

The key issues facing a digital HDTV/ATV system today are:

- the importance of a common view and commitment from broadcasters and the electronics industry on the market and introduction timescale for such a system;
- the need for a clear definition of the services which the system must be capable of delivering, taking into account the needs of the whole multi media environment;
- the development of a domestic digital video recording system, also compatible with multi-media requirements;
- agreement on a system design which trades on the growing international standardisation in picture coding through MPEG and which also sets in place a hierarchical transport structure compatible with that already established in the telecommunications field;
- the management of a technical standardisation process which builds on common goals and takes adequate account of market needs and timescales.

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A common worldwide standard for digital terrestrial television - dream or reality? *

D. Wood (EBU)

1. Introduction

A "Global Village" needs a Global Television System. However, agreeing durable common standards has proved frustrating and difficult. As world broadcasters begin to embrace the concept of digital terrestrial television systems, there is a new opportunity to seek success where, in the view of some observers, we have failed in the past.

In North America, the standardization of digital terrestrial television is much further advanced than in other parts of the world, including Europe. Viewed from the North American perspective, one might ask: "why bother with worldwide standardization for advanced television?" Agreement within North America alone will be difficult enough . . . There is a large enough internal market, so economies of scale can be achieved without

* Edited text of a paper delivered by the author at NAB HDTV World, Las Vegas, April 1992.

needing a larger market anyway. On top of that, worldwide standardization in broadcasting in the last few years, could hardly be called a runaway success story.

However true this may be, there is no question that single worldwide standard for advanced television would be a golden apple. We surely owe it to future generations of broadcasters and viewers at least to examine whether we can try to grasp it for them.

The traditionally cited benefits of worldwide standardization are lower costs and more choice for the public, and many other non-financial, cultural and morale-boosting benefits. But the other side of the same coin – what happens if you do *not* have a unique standard – is also worth looking at.

If we look at the evolution of new broadcasting systems over the past ten years, a pettern emerges which is rather surprising (except with hindsight).

Key milestones might be seen to be: first MAC in 1982, then MUSE in 1985, then HD-MAC in 1989, and now the soon-to-be-selected North American ATV system (1993). Let us assume hypothetically that the US-selected system will be a motion-compensated hybrid DCT system.

Each new system has arisen in a different part of the world, after a three-to-four year period following the last system.

MAC's novel feature was the use of time-compressed component coding. MUSE had all this plus a new idea, a four-field sequence for high-definition stationary (or panned) pictures. HD-MAC had the component coding, the four-field sequence, plus a new idea; block-based adaptation using a priori signaling, and motion compensation. The new digital ATV system may have all these (if it is motion-compensated hybrid DCT) plus a new idea: direct digital transmission of the prediction error, which allows transform coding and subsequent variable-length coding.

In each case, the new system is, to some extent, a more sophisticated version of the previous system.

As a engineer working during this entire period, the author was convinced, at each juncture, that the systems (MAC, MUSE, and HD-MAC) represented the last word in new broadcast technology. In each case, he was wrong. Unfortunately, providence has not given us the possibility of second sight.

However, it does seem reasonable not to make the same error of judgment four times in a row.

It does seem likely that if a system is developed today in North America, then later on in the 1990s, in another Region (which may be Japan or Europe or jointly) it will be possible to develop an improved variant.

Even if this proves to be the case, it may not have to lead to completely independent systems. It does make sense to examine what may be done in terms of common standards. At worst, the feedback may well be beneficial for the internal North America discussions.

Just because a new system uses a greater amount of digital processing than a previous system does not, unfortunately, mean that it is the last word or final technical solution. It may be just one more stage in technical evolution. It is probably a mistake to assume there is nothing over the horizon, just because we cannot see beyond it.

The intention of this article is not to provide the complete formula for worldwide commonality but, more modestly, to make a first excursion into the subject. Hopefully it will encourage reflection of the subject.

2. What lessons can be learned from the past?

The NTSC system was developed in the early 1950s. The European economic climate made the transition to colour conceivable about ten years later. By then it was possible to devise a more refined colour system, (ironically) using the experience gained with NTSC. Since the basic scanning standards in use in Europe and in the 60-Hz world were different, persuading Europe to adopt the NTSC colour system was a hard sell, and a 50Hz/60 Hz world split seemed inevitable. However, a single system within Europe was also not achieved, and that is more difficult to justify. Alas, in different parts of Europe, different selection criteria were used: degree of backwards compatibility, studio-signal processing capacity, national prestige, etc.

On balance, useful elements demonstrated by this story may include the following observations:

- unless everyone chooses a standard at the same time, it is quite likely that late-comers will be tempted by technological advances and refinements, which experience with the first system have shown to be valuable;
- the system selection criteria used by all those choosing a system must overlap to some degree, if common ground is to be found, and a single standard is to be agreed.

In the late 1970s and early 1980s, a digital studio standard which had only two variants was agreed; CCIR Recommendation 601. A totally unique system was not possible, but the standard was still seen as a major breakthrough. In principle, it allowed common 50 Hz/60 Hz switchable equipment to be made without difficulty. The agreement was the result of a concerted effort by the SMPTE and the EBU in pre-CCIR discussions. After a few years, further agreement was reached on a common tape format to carry the system. The standard however has not been universally used; the major reason seems to be that it is too expensive.

On balance, useful elements demonstrated by these events may include:

- basic agreement needs to be reached by all the key actors before a common standard is taken to the CCIR;
- whatever else is part of the selection process, the cost factor has to be brought into the equation. In the end, goodwill is not enough. The product has to be saleable.

In the mid 1980s, all the world's Broadcasting Unions agreed that efforts should be made to agree common HDTV production, point-to-point, and broadcasting standards.

Conceiving the first users of HDTV to be the motion-picture industry, attention was focused at the start on a common HDTV production standard.

Initially there was talk of a common 80-Hz interlace/40-Hz progressive system, but the 60-Hz world thought there would be little to be gained from this, and put forward the 1125/60/2:1 system as a unique worldwide standard.

The 50-Hz world was unable to accept. They argued that 60 Hz/50 Hz is nearly the most difficult standards conversion there can be, and there also seemed no major psycho-physical benefit to 60-Hz since, in both cases, up-conversion will be needed in the home receiver in the years ahead. European Administrations proposed a 50-Hz progressive standard as the single world standard. No agreement was reached, and this situation remains today. The discussion never really progressed to common point-to-point or broadcasting systems.

On balance, the elements shown by these developments may include:

- Common systems must offer more advantages that disadvantages to each side if they are to be agreed, and equal benefit/equal misery solutions are needed.
- A dominant consideration may be the influence of the existing infrastructure.

3. The dimension of commonality

It is not possible to cover all aspects of the common standards question. However, it may be helpful to have a brief map of part of the territory, so that at least we know which parts of the (standards) discussion we are in.

There are essentially *three* dimensions for potential commonality for image systems.

a) *The international dimension.* If all parts of the world (or large parts of it) used the same systems there could be well-known benefits to the user (lower costs, because of competition and the economies of scale) and to the receiver maker (large market size). The *international dimension* is that which is concerned with maximizing the use of a unique system in different countries.

b) *The application dimension:* Given that the number of products and systems which could use image coding is growing (broadcast, home disc and tape, still photography, facsimile, B-ISDN, etc.) there could be benefits if the same (or a related) system was used in each case. The *application dimension* is that which is concerned with maximizing the adoption of a unique system in different applications.

c) *The quality-level dimension.* Over the years, the possibilities for achievable picture quality have continued to rise; furthermore, picture quality requirements are linked with screen size and viewing distance. There is, and will continue to be, a need for systems operating at different quality levels. There could be benefits if the systems used at each quality level were related; for example, if images were always receivable in some form, or simply transcodable between levels. The *quality-level dimension* is that which is concerned with optimizing the relationship between the systems operating at different quality levels.

Overlaying all these dimensions is a new conception of the way that image systems should be developed in future. This is being discussed in many international forums and may be outlined as follows.

It is supposed that there will be a large number of uses for image systems. Bearing this in mind, the objective (according to some) should be to develop total systems as the combination of two elements:

- *Generic elements.* These are elements which can be common to all applications, such as (possibly) basic image coding, basic image format,
- *Application-specific elements.* These are elements which are tailored to the particular environment or use, such as forward error correction.

It is important to be aware of the maps that have been outlined, if only to be able to follow the discussions. However, for the purposes of this early review of the situation, we will concentrate here on the international standardization of a broadcast signal format.

4. Options for commonality in broadcast ATV

In broad terms, the ATV system (if digital) can be considered as comprising the elements in *Table 1*.

In the best circumstances, all of the elements would be common throughout the world. However, different planning and infrastructure environments exist in different parts of the world. Some of these may be summarised as follows.

In Europe the current terrestrial broadcasting plan operates with 7 or 8 MHz channels, and a similar situation applies with cable networks. In North America, the current terrestrial plan operates with 6-MHz channels.

The maximum bit-rate which can be transmitted in a given terrestrial channel depends on the type of modulation used, and the planning constraints (which define the potentially-available received eye-height, etc).

The planning circumstances which exist in North America are different to those in Europe. There is also a rather different broadcasting infrastructure. In the USA there are essentially a very large number of local stations, each serving a given community. In some senses they are usually independent entities. In Europe, the pattern is more usually of national broadcasters, each using a jigsaw puzzle of transmitters to achieve nationwide coverage.

Furthermore, the protection ratios which apply in Europe are generally more stringent than those used in North America, owing to the different requirements of the different systems.

For reasons such as the above, it well may be necessary to move our horizon to maximum commonality, rather than total uniqueness.

It may this be useful to study *Table 1* and establish which elements will have the most implications for receiver costs and quality. Furthermore, it may be possible to establish the degrees of potential difficulty in achieving commonality in the various elements.

In *Table 1*, the columns are not complete. Hopefully the reader will be stimulated to include his/her own ideas. The author consoles himself for his inadequacy with Plato’s maxim “The beginning is the most important part of the work”

To make a positive suggestion, one option, is to begin with discussion of a *common multiplexing system*. It should be possible to design a unique system which can cope flexibly with present and future requirements in all parts of the world. From this, progress may be easier with other elements.

5. Obstacles to standardization

There are certainly many obstacles to standardization in the other boxes of *Table 1*. Different countries and different regions will have different selection criteria for choosing a system. If we are to complete the table, we need to understand what these are. Two of the most critical factors may be timescales and quality/ruggedness criteria. These are briefly considered below, although by no means exhaustively.

ATV sub-systems			Ease of agreement	Priority
Modulation system				
Multiplexing system				
Baseband system	Vision	Error correction		
		Image coding algorithm		
	Sound	Error correction		
		Sound system		
		Sound coding algorithm		
	Data	Error correction		
		Teletext system		
		Programme delivery control system		
		Conditional access		
		Other		

Table 1
Elements of commonality in advanced television

5.1. Time scales

The current timescale for the internal standardization process and commencement of ATV services in North America is (understood to be) that a decision will be taken on a system in 1993, and that arrangements are also being made to encourage services to start within the years immediately following.

In Europe, there is no unique or formal position on standardization on introduction timescales for a digital terrestrial system. An enhanced PAL system has been developed, which could provide compatible wide-screen services terrestrially from about 1995. The studies of digital terrestrial systems are only just beginning, and effectively have begun several years after North America. This probably means that Europe will be some years behind North America in starting services.

Of course it would be for the Japanese to explain their own timetable if they wished to do so. It would seem, however, that their introduction scenarios are not too dis-similar to those in Europe.

This timescale difference between Europe and North America may well present a problem as far as appropriate technology is concerned. However, the best way forward now could be not to prejudge the matter before discussions have begun.

5.2. Quality and ruggedness objectives

5.2.1. The modulation system

In Europe, the Digital Audio Broadcasting system (DAB) has been developed over the last three years. One of its key novel features is the use of modulation system, COFDM (*C*oded *O*rthogonal *F*requency *D*ivision *M*ultiplex). The signal to be broadcast is shared in a defined way between a large number of simultaneously-transmitted closely-spaced carriers. When there is multi-path propagation, the effect in the frequency domain is that some of these carriers are reduced, and others are increased. The receiver processes the complete set of carriers, and the result is that the received signal quality is much less affected by the multi-path. This means that the requirements for receiver antennas are less stringent. This is a very attractive feature for in-car reception in DAB. It will also be attractive for a future European high-quality digital television service. We may need to ensure that noise or other impairments do not mask or remove the advantages of the extra-definition available. There is clear European interest in using techniques of the OFDM type for digital terrestrial television. This would need to be reconciled with North American criteria.

5.2.2. The baseband system

The picture-quality versus bit-rate curve is one which is notoriously difficult to define. It seems, to some extent, to be a moving target as technology evolves.

At the current time however, there is no evidence that it will be possible to develop a system with a better bit-rate to picture-quality ratio than hybrid DCT with motion compensation and variable-length coding (VLC), although systems which are more flexible or simpler may be possible.

Within this overall framework there are still "adjustables" which will affect picture quality, for example; motion vector accuracy, the type of VLC, etc. We cannot draw absolute conclusions at this stage, nevertheless, the following seems to be the general situation.

The laws of nature tell us that the lower the bit-rate, the poorer the picture quality. As the bit-rate is decreased, however, with this type of system, the predominant effect is to reduce the proportion of moving pictures which can be conveyed impairment-free, rather than to systematically impair all pictures. When a given information content is exceeded, mechanisms kick-in (albeit smoothly) which effectively add noise or lower the resolution. Lowering the bit-rate lowers the "kick-in" point and increases the extent of the impairment. If, however, you start from a lower quality source (i.e. a source with fewer samples) you arrive at the equivalent kick-in point later.

The design game is therefore to choose the best combination of systematic (i.e. source system) reduction and coding system algorithm parameters for the best balance of picture quality and receiver costs.

It is always necessary to have an open mind. The results of the FCC Advisory Committee evaluations may indeed confirm the optimism of the many respected engineers who anticipate that HDTV picture quality will be achieved with bit-rates as low as 14 Mbits/s. However, other recent evidence leaves many Europeans rather uneasy about this.

For example, the ISO/IEC JTC MPEG Phase 2 system evaluations in November 1991 examined a large number of digital codecs operating at about 4 Mbits/s and 9 Mbits/s. These simulations of codecs used a series of moving picture sequences from a 4:2:2 source. The test material was well chosen to explore the quality limits of the codecs.

What comes from the results is that 9 Mbits/s seems enough to give 4:2:2 picture quality with material which is "critical but not unduly so", with a well-designed hybrid DCT system. However, at 4 Mbits/s there is a perceptible loss in quality (with this kind of material). This would mean that normal programmes would occasionally be impaired.

A useful shorthand way to describe the way a codec operates is in terms of "bits/pel". This is the ratio of the codec's operating bit-rate to the active pixel-rate of the source. The active sample-rate of the 50-Hz 4:2:2 system is 20.7 Msamples/s. The bits/pel ratios at 4 Mbits/s and 9 Mbits/s are thus about 0.39 and 0.87 bits/pel respectively. If the results of the MPEG tests are taken as some sort of guideline, we may conclude, in a source-independent way, that about 0.8 bits/pel can be effectively transparent to the source but lower than 0.4 bits/pel cannot. This might be called an "occasionally-impaired" quality. The same kind of conclusions can, incidentally, be drawn from independent work made by the RAI and Retevisión. This is only a guide, however, because there will be some relationship between the degree of annoyance caused by an impairment and the total amount of information presented to the viewer.

We could use these data, however, for guidance to extrapolate the situation with digital terrestrial widescreen service.

For our digital terrestrial television system we could begin by examining the bit-rate needed for virtually transparent wide-screen 4:2:2 quality. This would be 1.3 x 9 Mbit/s = 12 Mbit/s.

Virtually transparent reproduction of a 1152/1920/50/2:1 studio source (with 110592 Msamples/s) would need 44 Mbit/s. A 1152/1440/50/2:1 source (82944 Msamples/s) would need 36 Mbit/s. If we drop to 0.4 bit/pel, and our "occasionally impaired" system, then the above bit-rates would be halved.

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David Wood has been particularly interested in image quality assessment for many years, and was until recently the Chairman of the CCIR Joint Interim Working Party 10-11/6 on this subject. He has recently been nominated to Chair a new Working Party on Conventional and Enhanced systems for CCIR Study Group 11A.

It seems likely therefore that, in the range of available bit-rates for digital terrestrial television, which is likely to be up to about 30 Mbit/s, at least in Europe, there will be a difficult choice. Which is likely to be more attractive to the viewer? A system which is always impairment free, but has lower resolution, or a system which has occasional impairments, but a higher resolution, provided the picture does not contain more than a given amount of information.

This is a far from easy question. To complicate the argument, it is possible to up-convert lower resolution signals in the receiver, and in certain types of programme material such as feature films, at anything more than 3H, the difference will probably be difficult for the normal viewer to see.

The FCC evaluations themselves will certainly add important evidence and information to this issue, of value not just to North America. However, this article was written before that evidence was available, and so for the time being we are not able to draw on it.

Another factor to be borne in mind is that there is interest in Europe in evaluating two or three-level hierarchical systems which can be received simulteneously on HDTV receivers and on (portable) receivers offering lower quality.

In the coming months it should be possible to put together a clearer picture of the relationship between picture quality and bit-rate.

6. Conclusions

Efforts to agree unique world standards in the past have met with varying amounts of success. It proves to be a very difficult business, complicated by different needs and requirements in different parts of the world. To complicate matters further, technology continues to increase its boundaries, making ever more sophisticated systems possible, at apparently regular intervals.

The histories of past standardization sagas may give us some clues about what to do, and what not to do, for the maximum likelihood of success.

The commonality discussions are wider than just the international dimension, and include commmonality across different applications and different quality levels. Initially, it may be more manageable to took at international standardization.

One way forward is to examine the various elements which will make up a digital television system, and to establish priorities for commonality etc. *Opening discussion on a common multiplex system may be a useful beginning.*

The obstacles to be overcome include potentially different conceptions about the type of modulation method to be used, and the degree of ruggedness needed. Furthermore, the optimum quality balance is not clear.

A major difficulty is also the different time scales which are sought for such systems in different parts of the world.

For all the difficulties and potential obstacles, standardisation is still worth the attempt. Thomas Jefferson, a founding father of the United States, said "I like the dreams of the future better than the history of the past". He would have tried.

Acknowledgements

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A rugged and flexible digital modulation scheme for terrestrial high definition television*

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1. Introduction

There is great interest at present in both Europe and the United States in transmitting digital television in the "taboo" channels of the UHF band. Digital television has been under study for some years in our SPECTRE project which was described at IBC'90 [1] and NAB'91. SPECTRE (*S*pecial *P*urpose *E*xtra *C*hannels for *T*errestrial *R*adiocommunication *E*nhancements) is concerned with all aspects of digital television – low bit-rate video coding, modulation and frequency planning. Field trials of the system are planned this year in the United Kingdom.

This paper focuses on the work we have been doing on modulation, and highlights how orthogonal frequency division multiplexing (OFDM) can be used to provide not only an extremely rugged transmission system but also one which is flexible and can be adapted to the needs of high-definition television.

The transmission of digital information in a band shared with existing broadcast television is not simple. In the UK we have to ensure that digital transmission will not interfere with the existing television relay network and, as this network operates at low power, it is very prone to interference. The only way to avoid interference into this network is to transmit on the opposite polarisation, and also radiate the new digital service at 30dB less power than the existing services. In some cases reducing the transmit aerial height and shaping the radiation pattern is also needed to eliminate interference to the PAL-I service. In spite of these constraints, our studies to-date have found that most of the existing transmitter sites were able to cover similar population sizes to the analogue service with four additional digital channels. The constraint of very low power digital transmission demands excellent rejection of co-channel interference (CCI) from the high power analogue service. Moreover, having to broadcast in adjacent channels from the same mast with different aerial radiation patterns for analogue and digital transmissions, places severe requirements on the adjacent channel interference performance of the digital system. This occurs because the digital service is not only 30dB lower in transmitted power, but the ratio can be made even larger by using different aerial radiation patterns.

Multipath propagation is also a difficult environment for digital signals since reflection from buildings can severely reduce the data "eyeheight". OFDM can be used to overcome multipath problems and can even permit operation in a mobile environment. The OFDM signal can be made to be very rugged to television interfering signals as the next section will show. Later in the paper we will describe how the OFDM signal can be used in a flexible way where it may be optimised to give a more graceful failure characteristic in the received digital video signal. This can be achieved if the modulation, channel coding and baseband source coding are carefully combined, resulting in the avoidance of the abrupt failure characteristic traditionally associated with digital services.

2. Properties of OFDM for system design

The OFDM multiplex consists of a large number of carriers equally spaced in frequency, where each carrier is modulated by some digital modulation method, e.g. QPSK or 16QAM. The spectrum of each modulated carrier is arranged to overlap the spectrum of its neighbouring carrier in such a way that the information content of each carrier is mutually orthogonal. It is in this way that the OFDM modulation scheme achieves its high spectral efficiency.

This orthogonality criterion is satisfied if the carriers form a set of orthogonal functions. In the case of sine and cosine waves this condition is met if the carrier frequencies are harmonically related. Under these conditions the orthogonal carrier set is a Fourier series. Other orthogonal function sets may be used for the carriers, however they may not always be easy to generate. Examples of possible orthogonal functions which are easily generated, are those associated with square waveforms. These include Walsh functions and maximal length binary pseudo-noise sequences (m-sequences). An m-sequence can be shown to be orthogonal with time-shifted versions of itself however, these

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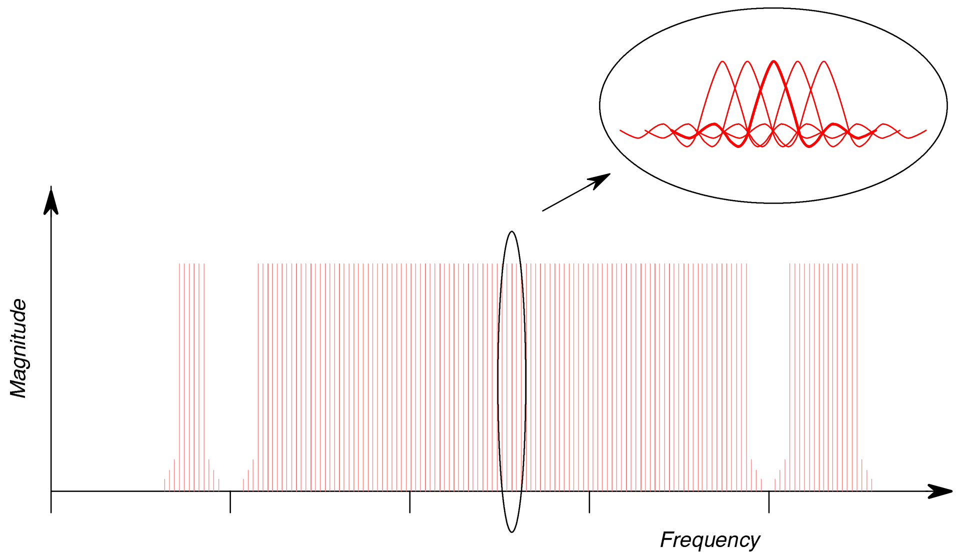

Figure 1
The conditioned OFDM spectrum

functions are only orthogonal when in square-wave form. In passing through a real channel their non-square form looses orthogonality, which can however be restored by re-sampling the waveform and converting it back to a square waveform. This process requires accurate synchronisation of the re-sampling clock with the incoming signal – which is not easy. Nevertheless, an OFDM system based on m-sequences would have the advantage of converting all interference to noise.

The system implemented by NTL uses sine and co-sine waves for the carriers. The OFDM signal is constructed by means of the inverse discrete Fourier transform and demultiplexed by means of the discrete Fourier transform (DFT) function. Other requirements of a practical receiving system are carrier recovery, and synchronisation to the DFT blocks, the details of these are described in [3].

2.1. OFDM television interference rejection

The OFDM spectrum is ideally suited for use in a hostile interference environment where the interference can be approximated as single tones of continuous waves (CW) at known positions in the spectrum. This property of OFDM arises because information need not be sent on the carriers affected by the CW interferers. Hence, provided the interference can be well defined, portions in the transmitted spectrum can be essentially cut out leaving a spectral template where bonafide information is transmitted. The receiver would naturally only look for information within the given template – hence it would ignore the interference.

The spectrum of a PAL television signal has two main components that represent continuous high power interfering elements, these are the vision carrier and the sound carrier. Although the colour sub-carrier and the digital sound sub-carrier are also present these are reduced in level by the dispersal effect of their modulating signals. In other words, these sub-carriers have a similar energy level to the vision modulation which has much less peak power than the vision and sound carrier levels. It then follows that a television signal may be approximated to a spectrum consisting of two continuous wave tones (CW), the vision carrier and the sound carrier.

Fig. 1 shows how the OFDM spectrum is tailored to reject the vision and sound carriers from co-channel interfering (CCI) television signals. Furthermore, since the spectrum is rectangular with steep sides it just fits the channel, making it spectrally very efficient. The exact width of the spectrum can also be adjusted by cutting out carriers at the edge of the channel, thereby optimising OFDM to give best adjacent channel interference (ACI) rejection as well. To achieve the very high levels of ACI rejection required (some 70dB), a good quality SAW filter is necessary at IF, with further filtering at both RF and baseband.

2.2. Reception in multipath - fixed, mobile and portable reception

The OFDM signal gives excellent performance in the presence of multipath propagation conditions because the symbol period of each carrier can be made much longer than the delay spread of typical multipath reflections. In this way the eyeheight of received symbols is not significantly reduced.

In the OFDM system, implemented by NTL, there are 432 carriers each with a symbol period of 64µs. The total data-rate amounts to 13.5 MBit/s using QPSK and fits into an 8-MHz television channel. A 500 ns reflection at -15dB causes only a 1-dB degradation in system performance.

This small degradation is mainly due to frequency-selective fading across the OFDM channel, caused by the reflection; it is not significantly due to intersymbol interference. The frequency selective fade causes some carriers to be received at a lower level than the mean signal power, creating a slightly higher bit error ratio on those carriers in the presence of noise.

For normal fixed reception using directional receiving aerials the delay spread of typical multipath is short. Hence, the standard OFDM system, without special error correction and without special measures taken to combat long delay echoes, should give excellent performance for fixed reception of digital television. OFDM, operated in this way, is at its most efficient since nearly all the available data capacity is used for information bits, and coherent demodulation of the carriers is possible [2].

For mobile reception with non-directional receiving aerials the multipath is very severe indeed. Often in built-up areas only reflected signals are present and no direct path to the transmitter exists. The receiver is constantly moving through a changing multipath environment and adaptive equalisation of digital signals is virtually impossible. OFDM however, correctly tailored to this environment, can be made to work well. This has been demonstrated many times in the Digital Audio Broadcasting application [3].

In order to cope with very long echo delays, time domain guard intervals are needed in the OFDM signal [3]. These are necessary to maintain orthogonality of the carrier when the delay time of the multipath becomes a significant fraction of the data symbol period. The guard interval has the disadvantage that it reduces the data-rate of the channel but allows orthogonality to be maintained by restricting the FFT to be taken over a shorter symbol time. The FFT block is shortened by the maximum foreseeable echo delay time, perhaps some 10µs in a 64µs symbol period. If the reflection were not omitted from the FFT process, the FFT would integrate over a discontinuous function and the orthogonality of the system would be lost. The effect would be to cause interference between the OFDM sub-channels, and each separate sub-channel would not be demultiplexed independently.

For mobile television reception to be possible, much heavier levels of error correction are required and coherent demodulation becomes less feasible. The additional overhead of the error correction, perhaps a factor of two, coupled with the loss of data capacity due to the guard intervals, will restrict the resolution of the picture obtainable. Enhancing the modulation from 4-level (such as QPSK) to 16-level (such as 16QAM or 16PSK), will probably not provide a workable means for achieving greater resolution. The 16-level modulation schemes have greater sensitivity to channel distortions, and schemes such as 16QAM will require coherent demodulation of the carrier which is difficult to perform in a mobile environment because reflection paths are continuously changing.

Since OFDM is a frequency multiplex, different carriers may be configured differently. It may not be possible to offer a mobile television service due to lack of data capacity, but a few carriers could be configured to give mobile reception of a low capacity data channel or even perhaps the television sound service. The carriers used for the mobile service would use a very rugged 4-level modulation scheme, contain guard intervals and use heavy error correction. Using the same OFDM multiplex, the carriers used for the television service could carry a higher order modulation, perhaps 16QAM with less overhead, to give high definition television to non-mobile receivers. Non-mobile might include portable receivers as well as fixed. It should be noted that if guard intervals are included they need to be applied to all carriers equally since this defines the FFT block length for the complete OFDM multiplex.

Portable reception is of great interest as many secondary television receivers in the home are of this type. The advantage of this is, of course, that each member of the household can operate their own personal receiver, without the constraint of having to connect it to the single roof-top aerial. This benefit however leads to the major difficulty of portable reception – that the receiver is only able to obtain a low signal strength due to lack of aerial gain and height.

In order to obtain satisfactory CCI performance in the portable receiver it may well be necessary to employ electrically-steerable aerials to null-out strong CCI signals. One might imagine that portable reception might be possible provided the receiver was located well within the normal service area. Moreover, since reception of high definition is unlikely to be necessary on small portable screens, the concept of a coded digital video signal which permits HDTV reception on fixed receivers and also lower definition reception on portable receivers appears very attractive.

The OFDM signal lends itself well to the flexibility of carrying different service qualities within the same multiplex. This convenience occurs because different carriers within the same OFDM signal can be modulated and error protected differently. If the source coding of an HDTV service is arranged to yield a structure which contains a lower resolution signal embedded within it, this basic service could be sent on OFDM carriers, using say QPSK, and the additional HDTV bits sent on separate carriers, using say 16QAM. The 16QAM carriers would be able to convey twice the bit-rate of the QPSK carriers but the QPSK carriers would have nearly 7 dB better noise and interference performance.

2.3. *Graceful degradation of the digital video signals*

In the same way that the flexibility of the OFDM system could be used to provide different failure points for portable and fixed reception, the same principle could be applied to achieve a more graceful degradation of the digital video signal at the edge of the service area [4]. The concept is shown diagrammatically in *Fig. 2*.

Pictures delivered by analogue means have a very graceful degradation with the picture becoming increasingly impaired as the receiver is moved away from the transmitter. The last part of the analogue signal to be lost is the synchronisation after the picture has become unwatchable. Pictures coded and delivered digitally have the same excellent quality up to a certain distance away from the transmitter and then might be expected to fail completely with a very sharp transition. This might cause an HDTV signal to fail much closer to the transmitter than is desirable, since the 16QAM modulation scheme necessary to carry HDTV, is less rugged than a QPSK scheme which might used for normal definition television.

The OFDM multiplex could be used in a flexible way in conjunction with the video source coding to achieve a graceful failure characteristic. Since different carriers can carry different modulation schemes we might imagine that the video signal could be divided into three parts. A first part representing the synchronisation, which needs to be very rugged. A second part which contains information representing a low definition picture,

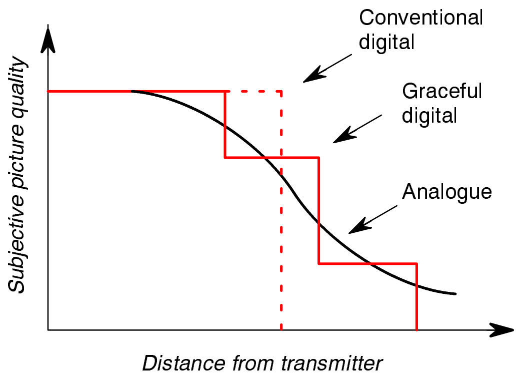

Figure 2
Graceful degradation of picture quality

and a third part which represents additional information to increase the definition of the picture to HDTV. The additional HDTV information could be sent using say 16QAM on one set of carriers, the low definition information could be sent on another set of carriers using say QPSK and the synchronisation information might travel on carriers using, say QPSK, with increased error protection. If this were practical it could lead to a three-step quality curve such as *Fig. 2*, which exhibits a more graceful degradation than the single-step traditional approach.

The video signal could still be watchable after the low definition mode had failed provided the synchronisation remains. This may be achievable if picture concealment techniques are applied whenever errors can be detected. This can be performed by simply copying samples from the previously received picture frame but improved results can be obtained by employing a motion- compensated picture concealment scheme. In this case the motion vectors need to be strongly protected with the synchronisation information.

2.4. *Single frequency networks*

As OFDM has excellent performance in the presence of interference and multipath it may be used in a single frequency network (SFN). This allows complete coverage of a country having a large number of terrestrial transmitters all on the same frequency. There are two ways OFDM can be used within an SFN and these have different properties.

A first method, when using directional receiving aerials, is to make use of the fact that QPSK-OFDM has a protection ratio for OFDM interfering into itself, which is lower than the front-to-back ratio of the receiving aerial. This means that an interfering signal arriving from behind the aerial can even have the same power as the wanted signal arriving at the front of the aerial. The same argument also applies to signals received at the sides of the aerial. Moreover, the path loss across the service area is also greater than this co-channel protection ratio, so an interfering signal arriving at the front of the aerial from the next transmitter in line will also be sufficiently attenuated. Hence each transmitter may use the same frequency without interference. Note that each transmitter may also radiate different programme material as the condition is independent of the data stream.

This SFN method breaks down when higher order modulation is used for HDTV because the OFDM-to-OFDM protection ratios are likely to exceed the front-to-back ratios of the receiving aerials. In practice, even with QPSK modulation, some outage due to interference is experienced at the edges of the service areas. This however, is often not too much of a problem if the viewing population is distributed well within the service area.

A second method of producing a single frequency network with OFDM is to make use of its enhanced multipath properties. Provided that all transmitters in the SFN are radiating the same programme material, *and this is a constraint*, the adjacent transmitter signal can be considered as a delayed version of the wanted transmitter signal. The interfering transmission resembles an active multipath reflection of the wanted signal – which is rejected by the OFDM system. Since the path length between transmitters is long, the OFDM signal will require the use of guard intervals to suppress the active reflection. Use of an SFN in this way may suit a national broadcaster, but the constraint of having to have the same programme material at each transmitter is likely to be unacceptable in regional broadcasting.

Provided the loss of data capacity caused by the guard intervals is acceptable, this second type of SFN may be useful for designing relays to fill in gaps in the main transmitter coverage area. Here the constraint on programme material does not present a problem because the same digital service is required in the relay coverage areas. Furthermore, this method of providing relay coverage is very efficient, because it would not need to use additional RF spectrum. The main practical problem likely to be encountered with an SFN relay provided by this second method, is the requirement for adequate site shielding. Since the relay trans-

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Mr. Mason acted as a consultant to theArthur Norwegian Telecom Administration on Conditional Access and gave many papers on this subject at international conferences. He now runs the Digital Television project called SPECTRE and is responsible for three teams of R&D engineers working on the digital modulation (OFDM), digital video coding and frequency planning aspects of SPECTRE. Arthur Mason first proposed the idea of Digital Terrestrial Television in the taboo channels of the UHF band in his IBC paper at Brighton, in September 1990. The IBC paper started the European debate on Digital Television and had been the result of some two years work studying the feasibility of the SPECTRE system in the UK.

He is presently group Leader of the Radio Frequency Laboratory R&D group and manager of the SPECTRE Digital Television project.

Nick Lodge *began his career with the Racal Group in 1979 after graduating from the University of Wales. Here he worked for two years on low bit-rate speech and speech encryption systems. In 1982 he joined the Video and Colour section of the Independent Broadcasting Authority (IBA), where he was a member of the MAC development team. Subsequently he was involved in the development of digital image processing techniques, with a special interest in digital television coding. After some years as Project Manager in the IBA Baseband Group, dealing with enhanced and high-definition television, he joined the new Independent Television Commission (ITC) in 1991 as R&D Coordinator. He is currently Head of Standards and Technology.*

Mr. Lodge is involved in the studies of the EBU and CCIR, as well as many European collaborative projects in the framework of Eureka, RACE and TIDE. He is currently completing a PhD degree as a student at Heriot-Watt University and is a member of EURASIP and the IEE where he is Hororary Editor of the technical journal "Communications, Speech and Vision".

mitter is basically a high gain amplifier, receiving and transmitting on the same frequency, there will be a tendency for the amplifier to oscillate. In order to prevent oscillation, it is likely to be necessary to position the receiving aerial well away from the relay transmitting aerial and also provide site shielding between the two. This practical constraint may require the two halves of the relay to be sited either side of a hill, rather than on top of the hill as at present.

3. Laboratory measurements on protection ratios

A modulator and demodulator which uses the OFDM principle has been constructed and laboratory measurements of its performance have been made. The measurements quoted below are for QPSK modulation of the carriers, however, the equipment is capable of a range of higher order modulations as well. The practical system performs extremely close to the theoretical performance. The values quoted in *Table 1* are suitable for frequency planning purposes in the UK and take into account implementation margins and effects due to picture dependency. They are therefore deliberately more pessimistic than the best measured performance of our system.

The measurements given were used for frequency planning studies, with PAL-I at grade 4.5 (when it is the "wanted" signal), and QPSK-OFDM at BER=10^{-4} (when it is the "wanted" signal).

4. Conclusions

This paper has explained how OFDM can be used in a very flexible way to meet most of the challenges posed by terrestrial digital television. OFDM is a very rugged signal and allows use of the taboo channels in the hostile interference environment in which digital HDTV would have to operate if simulcast with conventional analogue television signals.

Wanted signal	Interfering signal	Protection ratio (dB)
PAL-I	QPSK-OFDM	45
QPSK-ODFM	PAL-I	3
QPSK-OFDM	QPSK-OFDM	14
QPSK-OFDM	Noise	14

Table 1
System protection ratios

Acknowledgements

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HDTV

Development of a terrestrial digital HDTV system – The HD-Divine project

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1. Introduction

In the autumn of 1990 we were failing in our Swedish HDTV strategy. After 18 months of struggling to develop a PAL-compatible, 16:9, 1250-line/50-Hz system, we ended up with a complex system of poor picture quality compared to full HDTV. We realised that we were barking up the wrong tree. Analogue technology is becoming dated and will be obsolete by the time it is introduced. Furthermore, the idea of letter-boxing old television receivers did not fit well with our responsibility as a public broadcaster.

It may be wondered why a relatively small public broadcaster, such as *Sveriges Television* (SVT) should wish to engage itself on the highly infected issue of an HDTV broadcasting standard, on a collision course with leading European electronics manufacturers.

The answer was, and still is, that the European Eureka 95 project, in our opinion, took a rather narrow perspective regarding the possibilities of broadcasting HDTV signals. Any approach devoted solely to satellite distribution does not supply the answer to how we, as a public broadcaster, should handle certain elements of our public service function. As an example, we can consider our responsibility to provide regional broadcast services.

So back in 1990 we understood that HD-PAL was not the answer to tomorrow's television, and, furthermore, that none of the satellite-based systems were either.

2. Digital technology

Digital technology is not a goal in itself. However, tendencies in television production technology and telecommunications point in this direction. This is important because it implies that the environment in which television systems will be used in the future will be digital. Considerable synergistic benefits would be gained, in terms of circuit development and exchangeability between different carriers, if the next television system were also digital. The difficulty is that the data rate needed to convey an HDTV signal is well over the limit for terrestrial broadcasting.

If we look back a few years, it is clear that the RAI/ Telettra Eureka 256 project was a pioneering achievement of the first order. During the World Football championships in the summer of 1990, the 70 Mbit/s satellite HDTV broadcasts were very impressive and they represented an aggressive and foresighted effort. They served as an eye-opener to many of the research teams active in the field of HDTV. What they demonstrated was that the complexity of a digital codec was far less than that of a codec for a comparable hybrid system and the picture quality at this relatively low bit-rate was better.

The concept of digital terrestrial HDTV first presented by General Instruments was a real brainwave. It combined the attractive features of the Eureka 256 system with the possibility of terrestrial broadcasting.

3. Route to a new television standard

The first question to answer when considering changing the broadcasting standard is “Why?”. Is it because the public is longing for a digital receivers? Or is it to alleviate the frustration of film producers over our inability to show their Cinemascope films? Would we like to stimulate European households into buying new television sets? Do broadcasters feel that we need to brighten up our now rather old and somewhat drab pictures? Or is it because certain Japanese companies have developed a new technology, which represents a thrust we must parry?

To change a television system, i.e. to start a new service and to abandon a system that involves the greater part of the public, is a dramatic step; it is expensive for the viewer as well as for the broadcaster. A comparable step in the short history of televi-

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sion is the changeover from black-and-white to colour television.

That brought about a dramatic improvement for the audience. So must the next move, which must be a change to a stable system for the future, which has the potential to survive and improve.

It appears that Europe has now decided on a changeover and we feel that, in SVT, we must take a single major step. This would mean the least expensive, enhanced-television future for everyone involved – the audiences and the broadcasters.

To do this in stages would erode the interest of the audience, and the public broadcasters would lose credibility. When introduced, the new television system should have an expected life cycle of at least 40 years.

Furthermore, a new system cannot be limited to satellite and cable. It must be suitable for *all* media, including terrestrial, B-ISDN and consumer recording equipment.

The reality of the operators of all expensive public networks (such as for television, radio, telecommunications and electricity) is such that we are stuck with what we already have and any change must take current installations into account. However, at certain points in the development of our resources we are compelled to do something incompatible, to break through the limitations. Just imagine the number of telephone poles in the landscape if the telecommunications administrations insisted on using overhead lines instead of optical fibres to carry all the information required in modern telecommunications.

The priorities for HD-DIVINE are HDTV quality, low-cost terminal electronics and rugged terrestrial services before the year 2000 – in that order.

4. The video coding algorithm

There are many vital building blocks in a terrestrial digital HDTV system, one of which is the video coding algorithm. The algorithm used in HD-DIVINE should demonstrate that acceptable image quality is achievable in the narrow terrestrial channel.

Early simulations indicated that the available bit-rate on the channel is about 27 Mbit/s. In HD-DIVINE 4 x 128 kbit/s are set aside for audio, 64 kbit/s for data and 2 Mbit/s for forward-error correction. This leaves about 24 Mbit/s for the video data. The four mono audio channels are coded according to ISO/IEC layer II.

The source video signal has 1250 lines/frame and 25 frames/s. This signal is sampled at 54 MHz for the luminance and 13.5 MHz for the chrominance. This gives the following net bit-rate for the video signal:

		pixels
luminance:		
1440 pixels x 1152 active lines	=	1658880
chrominance:		
2 x 360 pixels x 1152 active lines	=	829440
pixels/frame:		2488320

There are 25 frames/s and each pixel is represented by 8 bits, which gives about 0.5 Gbit/s (497664000 bit/s). To squeeze this signal into 24 Mbit/s is a formidable task.

The algorithm used in the HD-DIVINE project is of the hybrid-DCT type. As the name "hybrid DCT" implies, the algorithm used is a hybrid (i.e. a combination) of other methods; in our case the most important tecdhniques are DPCM (differential pulse code modulation) and transform coding.

4.1. DPCM

When using DPCM, a difference signal is sent over the channel. This difference signal is formed by subtracting a prediction from the original signal. A good prediction will give a difference signal (also called "error signal" or "residual signal") with a very skewed distribution. A perfect predictor would give a difference signal that is equal to zero, whereas a real predictor yields a signal which is not equal to zero. A usable predictor will, however, give a residual signal that can be compressed by subjecting it to variable-length coding.

Fixed-length coding of values from a signal with a skewed distribution is not the best (most compact) representation. A more efficient method is to give short code-words to values of high probability and long code-words to values of low probability; this is known as "variable-length coding". There are a number of methods that construct code-books according to this principle, and the method used by HD-DIVINE (and most other video coding schemes) is Huffman coding.

A good predictor for moving images can use the previous image in the sequence as basis for the prediction. As the greater part of an image in a sequence does not change from one frame to the next, the residual image will be mainly zero or close to zero. This results in a skewed distribution of the residual image, which can be efficiently compressed by variable-length coding. By using movement-compensated prediction the result of the prediction can be even better. This is done by first estimating the apparent movement of each part of the image, between successive images. The predictor will then use this information to make a better prediction for the next image in the sequence. The coder function that does this is known as "motion vector estimation". It must be remembered that there is a cost associated with this type of prediction. The movement vectors must be sent over the channel to the decoder. The algorithm must be designed so that the gain from coding the residual image is bigger then the loss due to sending the movement vectors. The vital parameters are the number of movement vectors, the magnitudes of the movement vectors and the quality of the movement vector field.

4.2 Transform coding

If the DPCM part in a hybrid-DCT coder reduces mainly the temporal redundancy of the moving sequence, the transform-coding part is aimed at reducing the spatial redundancy and exploiting the characteristics of the human visual system.

Images are usually easier to describe in the transform domain than in the time domain. This is due to the fact that the DCT concentrates the energy into a small number of coefficients. For most images, the DCT is very close to the optimal transform (Kahrunen-Loeve) in this respect, but it is much easier to compute. HD-DIVINE uses a 8x8 pixel transform and, for many blocks, just a few (from two to four) coefficients are transmitted out of the total 64.

Another advantage of a DCT coder is that it is easy to include the frequency response of the human visual system. This is done in the quantising step. Every coefficient in the transform domain represents a spatial frequency (not exactly but closely enough), and is quantised according to the frequency response of the human visual system. Typically, high spatial frequencies are quantised with larger steps than low frequencies. Furthermore, the thresholding of the quantised coefficients results in local adaptation according to the image content. The combination of the concentration of energy into a small number of coefficients, the quantisation of the coefficients and the thresholding of the quantised coefficients results in a signal which is well-suited to variable-length coding.

The quantising operation is also used to control the resulting bit-rate of the coder. This is done by controlling the level of quantisation according to the degree of output buffer filling.

4.3 Combination

HD-DIVINE makes the standard combination of DCT and DPCM, i.e. it applies a discrete cosine transform, quantization and variable-length cod-

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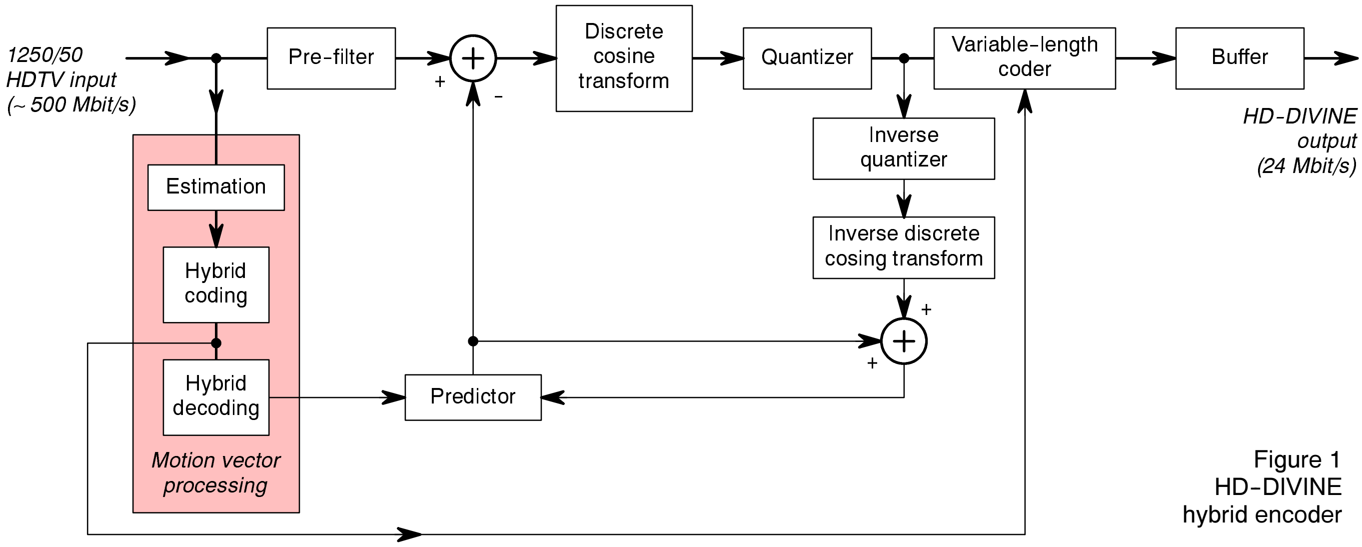


Figure 1
HD-DIVINE hybrid encoder

ing to the output of a DPCM loop (*Figs. 1* and *2*). It is important that all predictions are made on the basis of previously-transmitted information. If this were not the case, the coder and decoder would not be able to make matching predictions and this is central to the operation of a hybrid-DCT system.

The decoder receives the residual image and movement vectors which are to be used in the prediction. The movement vectors are used in the decoder to movement-compensate the decoded image and this predicted mage is then added to the residual image after variable-length decoding, inverse quantisation and inverse transformation. This sum forms the output of the decoder.

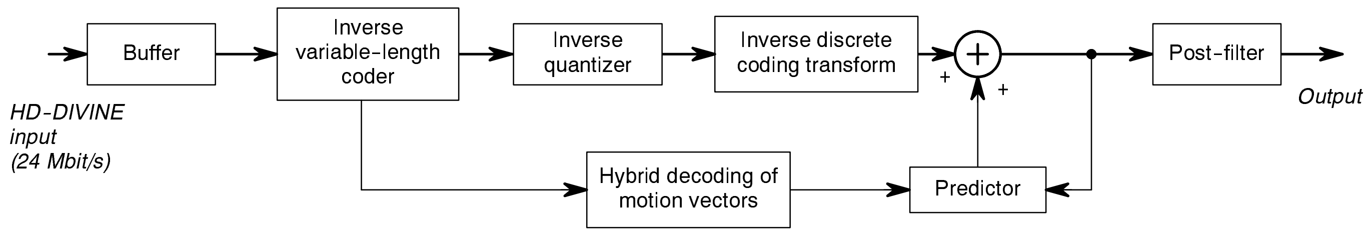
There is one problem in this scheme: how is the process started? The first image after start-up cannot be predicted from a previous image, so this image must be treated in a special way known as "intracoding". Intracoding does not use the predictor at all; the image is coded as if it were a still image, using only the transform coding part of the hybrid-DCT coder. This is also done at regular intervals to prevent the propagation of errors in the decoder. The use of intracoding at regular intervals is also known as "refresh" and is usually done a few times (once to five times) every second. The normal mode of the coder, using the predictor and transmitting the residual image together with the movement information, is known as "intercoding". Usually the number of bits used for a intracoded image is much higher than the number of bits used for an intercoded image. There are rare cases where it is more efficient to transmit an intracoded image, typically when there has been a scene change or when the movement estimator has been unsuccessful in finding good movement vectors. The coder has the ability to choose locdally between inter/intra coding and it always use the most efficient method.

How does HD-DIVINE differ from other hybrid-DCT coders? The most important differences are:

- the format of the movement vector field;
- the coding of the movement vector field;
- adaptive pre- and post-filtering of the signal.

As can be understood from the above description of a hybrid-DCT coder, the quality of the predicted image is of vital importance. The better the prediction the smaller the number of bits expended on the residual image. However, there is a cost associated with sending the movement vectors to the decoder. It is a delicate task to balance the gain in coding the

Figure 2
HD-DIVINE hybrid decoder



residual image against the cost of coding the movement field. The trend in modern image coding is to spend more bits on prediction and less on the residual image.

The magnitude of the movement vectors is also important. There are extremely large excursions between successive images in a video signal. If the quality of the prediction is to be high, it is vital that the movement field can describe such large excursions. But, again, there is a trade-off between the magnitude of the vectors and the coding gain. Large vectors require the transmission of more bits to the decoder.

A very dense movement field is used in HD-DIVINE. There is a movement vector for every 4x2 pixel block in the image. This makes very precise prediction possible compared to older systems that use only a single movement vector for a 8x8 pixel block or for a 32x16 pixel block. Furthermore, the magnitude of the movement vectors is large, ± 32 pixels (horizontal) and ± 16 pixels (vertical). Furthermore, the movement estimation algorithm used gives half-pixel accuracy. Estimation and compensation is done on a field basis and is done only between fields of the same parity.

The type of movement vector field used in HD-DIVINE needs efficient coding in order to leave some bits for the residual image. Due to the movement estimation algorithm used, the movement field is very precise, it describes the movement correctly and is noise free. One possibility for coding the movement field is to use DPCM, but the high quality of the movement fields is such that it is more suitable for hybrid-DCT. Accordingly, the movement vectors are subjected to the same treatment as the image data, in a hybrid-DCT loop, but with one exception: there is no movement compensation of the movement field. During this coding some minor distortion of the movement field occurs but, in spite of this, the quality of the prediction remains very high.

It is not always possible to reduce the amount of data in a video sequence by 95% without introducing visible distortion. Some scenes will have perceptible distortion and artifacts. When the images in a sequence are difficult to code the quantisation of high-frequency components is very coarse. This may result in visible ringing around edges and the image may also contain noise and artifacts (such as blocking effects). One way to make images easier to code is to lower their spatial-frequency content. This results in fuzziness. However, it may be a good idea to exchange the type of distortion introduced by the hybrid coder with fuzziness. An adaptive pre-filtering process analyses the images and, in areas where the hybrid-DCT coder risks introducing distortion, such filtering reduces the resolution marginally.

Adaptive pre- and post-filtering has another very significant effect on image quality. The filters used are very efficient in removing noise. In the pre-filter this is used to reduce source noise. Noise is not only unpleasant to look at: it also costs bits to code. Consequently, the noise-reduction properties of the pre-filter are doubly important. The post-filter reduces the quantising noise that is introduced in the coding loop. The post-filter can also perform aperture correction but this has not yet been tested.

5. Modulation

Perhaps the most interesting part of the HD-DIVINE project is the modulation scheme. The technique is not new and is currently also used in digital audio broadcasting (DAB). The actual implementation, however, differs in the choice of modulation parameters.

The terrestrial channel is a difficult one, particularly due to multipath propagation. It can be questioned whether a single-carrier system can be robust enough in such an environment. One way to obtain the desired capacity in the channel is to use coded orthogonal frequency division multiplexing (COFDM). COFDM is a multi-carrier system and it combines modern forward-error protection algorithms with very efficient implementation.

In a COFDM system a large number of low symbol-rate carriers are used, as opposed to single-carrier systems with one high symbol-rate carrier. HD-DIVINE is a 512-carrier system in which only 448 carriers are actually used. The reason for not using all 512 carriers is the need to shape the spectrum of the COFDM signal to match the PAL spectrum and to eliminate adjacent-channel interference. In an environment where PAL and COFDM have to coexist it is desirable to minimize the interference between the two types of signals. The main problem is the large image and sound carriers in PAL. The solution is to open up slots in the HD-DIVINE spectrum and thus prevent destructive interference. Most of the 64 unused carriers (about 40) form the slots in the COFDM spectrum. Some are left unused on each flank of the spectrum, due to adjacent-channel interference (*Fig. 3*). The experimental modem is programmable in respect of the number of unused carriers and their positions in the channel.

Quite apart from the slots and flanks mentioned above, the COFDM spectrum is optimally shaped.

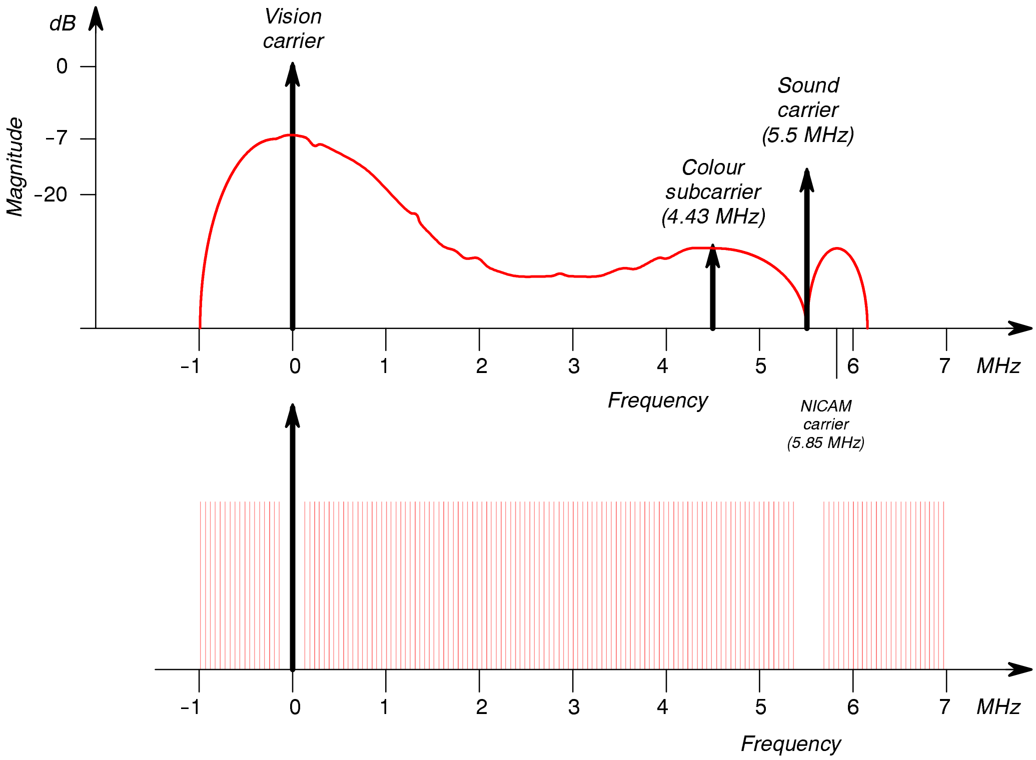


Figure 3
Spectrum of PAL and OFDM signals

The spectrum of each closely-spaced carrier overlaps that of its neighbours and which results in a very flat spectrum for the total signal and an efficient use of the available bandwidth. Demodulation of the carriers is possible if they are mutually orthogonal during the symbol time. This is valid if the frequency spacing between successive carriers is $\Delta f = 1/T_S$. In HD-DIVINE the symbol time T_s is 64 µs (*Fig. 4*).

To make the modulation system even more robust against inter-symbol interference, another method combined with the long symbol time is used. The symbol time T_S is stretched to cover a small additional period ΔT where no information is sent. The period ΔT is known as the "guard interval" and, if given a proper value, this totally eliminates the inter-symbol interference. In HD-DIVINE a guard interval with ΔT = 2 µs is optional (*Fig. 5*).

The use of a guard interval will avoid inter-symbol interference but the phase and magnitude of the received signal will still be affected. This problem is solved by dynamic equalization. A pre-determinated signal with a known phase and amplitude is sent regularly, and the receiver uses this signal to measure the influence of the channel. An equalization characteristic for each carrier is calculated on the basis of this measurement. In this way the receiver can, theoretically, compensate for the channel perfectly. The method used requires that the channel is stationary, i.e is stable over a period of time, which should be the normal case for HDTV reception. As the channel is impaired by noise an averaging procedure is done in order to get a more accurate measurement; this also demands a stationary channel.

Each single carrier in the prototype system is modulated using 16-state quadrature amplitude modulation (16-QAM), i.e. each symbol transmits four bits. As the total length of a symbol T is $T_s + \Delta T = 66 \mu s$ and the total number of carriers used is 448, the useable bit-rate is $448 \times \dfrac{1}{T_s + \Delta T} \simeq 27$ Mbit/s. The error-correction code is a shortened Reed-Solomon code (208,224) which leaves a net bit-rate of $27 \times \dfrac{208}{224} \simeq 25$ Mbit/s. The modem is, strictly speaking, not COFDM but OFDM, in the sense

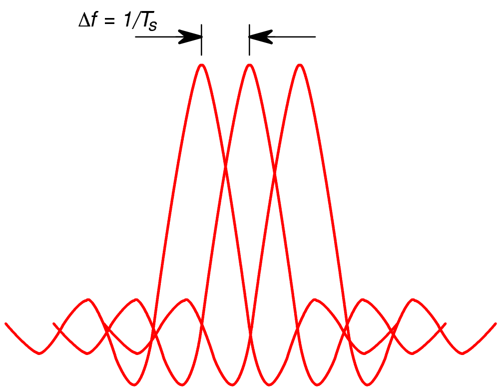


Figure 4
Overlapping spectra of three closely-spaced carriers in an OFDM system

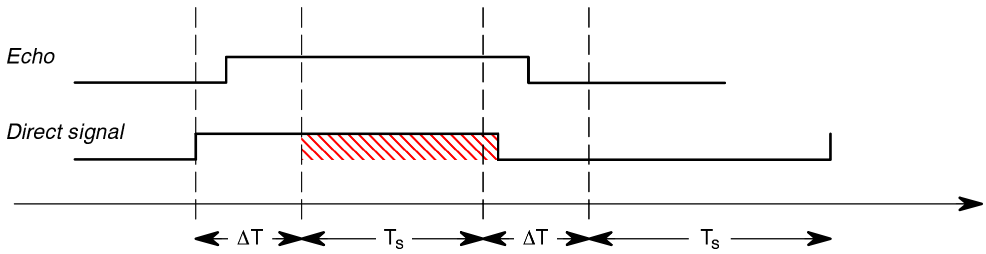


Figure 5
Use of the guard interval, ΔT, to eliminate inter-symbol interference

that the forward-error correction is not incorporated in the modem. However the overall system implements COFDM as the forward-error protection is incorporated in the video source coder/decoder.

The modulated carriers are generated using a 1024-point inverse discrete Fourier transform (IDFT) implemented using a fast Fourier transform. With the use of modern integrated circuit technology the modem has a very small physical size (the modulator has just three boards, each measuring 25 x 63 cm).

6. Network planning

The network planning studies conducted in the HD-DIVINE project are based on the assumption that directional receiving antennas will be used. This simplifies frequency planning considerably for conventional as well as single-frequency networks. This makes it possible to use the same channel for two different programmes, with a minimum of separation between the two. This is a vital difference compared to the situation in DAB, where non-directional antennas are used. The protection ratio for OFDM versus OFDM (16-QAM) is virtually the same as that which can be expected from directional receiving installations. The guard interval completely eliminates the effect of inter-symbol interference when the time difference between the OFDM signal and its echoes is less than the length of the guard interval. The negative effect of selective fading can be eliminated by proper channel coding.

Good reception may require a carrier-to-noise ratio (C/N) of less than 20 dB; this is an improvement of more than 20 dB compared to analogue PAL. Hence, the transmitted power for a given coverage area can be reduced significantly. With techniques for integrated coding and modulation (e.g. trellis-coded modulation) the required C/N ratio will be even lower. Planning is greatly simplified because the protection ratio between the wanted OFDM signal and an unwanted OFDM signal is about an order of magnitude (i.e. 20 dB) better than the best protection ratios obtained using precision offset in PAL channels. When the time difference between the direct and delayed paths is within the guard interval, the orders of magnitude of the signals on each path may be equal, without any risk of inter-symbol interference. As the time difference increases the magnitude of the delayed signal decreases and thus reduces the effect of inter-symbol interference.

One attractive way of using the single-frequency option is in the form of single-frequency coverage extenders, or gap fillers, in connection with in-band networks using conventional frequency planning. In the same way, a regional power profile can be designed to fit the desired coverage area. The basic idea is to increase the number of transmitter sites and to reduce the total emitted power. The lack of overspill reduces the frequency reuse distance to a minimum. This power profiling technique will facilitate the introduction of singlefrequency services, with a minimum of blocks available for singlefrequency networks throughout Europe. Thus the flexibility in planning networks for single-frequency operation opens up the possibility of a combination of national, regional and local programmes, without adversely affecting frequency economy.

During a transition period, analogue television and digital HDTV must use the same part of spectrum, possibly in the form of simulcasting. In this period the coverage of digital HDTV will be limited more by interference from analogue television transmitters than from digital television or noise. An important measure to reduce the effect of interference from analogue television is to leave unused the OFDM carriers that are subject to interference from the vision and sound carriers of the analogue system, as described above.

Planning exercises suggest that the simultaneous broadcasting of digital HDTV and current analogue services is possible, even in areas with intense use of the spectrum, such as the Öresund region between Sweden and Denmark. This is made possible by the low power used to transmit digital HDTV, the use of directional antennas and the use of different polarizations.

7. Conclusions

HD-DIVINE aims at attaining a balanced solution for broadcasters, audiences and the electronics industry for the next generation of television broadcasting standards. It is our hope that the main principles of HD-DIVINE will guide the process of international standardization. The system as it stands today is not complete. It is the first working prototype. During the next two years, efforts within the project will focus on a final system. It is our belief that, to be a success, a new television broadcasting standard must offer something to all parties concerned.

First International Symposium on Digital Audio Broadcasting
Montreux, 8 and 9 June 1992

Since 1985, the EBU Members have been playing a major role in the design, laboratory tests, field trials, public demonstrations and world-wide promotion of DAB. Cooperation with the Eureka 147 Consortium has resulted in the world's most-advanced technical development in the field of sound broadcasting. The achievements have been widely recognized, for example by the ITU which, at the WARC-92, allocated a new frequency band (1452-1492 MHz) on a world-wide basis (with the exception of the USA) to be used for both satellite and complementary terrestrial DAB services. Then the 7th World Conference of Regional Broadcasting Unions (Mexico, April 1992) made a further step by adopting a resolution encouraging world broadcasters to align their choices both in terms of a unique DAB system standard implementation and a common frequency band.

Recognizing the need for a concerted and coherent introduction of DAB services in Europe and world-wide, the EBU Members organized the **First International Symposium on DAB** to bring together all the major parties involved in the development and implementation of DAB services in various countries. The Symposium, whose Organizing Committee was chaired by Dr. Ian Childs (BBC), was conceived as a forum for discussion on the impact of DAB technology on the economic viability and programming of future sound broadcasting services, and on new regulatory frameworks.

EBU

The Symposium was structured in four main sessions, during which 31 speakers covered a range of technical, operational, regulatory, economic and programming issues related to DAB. The first session, entitled *Sound broadcasting for the 21st century* gave wide-ranging background information on DAB. The second session *Technical background of future sound broadcasting* explained the latest technical developments. The third session concerned *DAB implementation prospects*, and the last session returned to a more-general discussion on *DAB global issues*. The Symposium was closed with a panel discussion on convergence in DAB implementation.

Different views were expressed on the future strategy for the introduction of DAB services in different parts of the world. In Europe, broadcasters are agreed that DAB services should start experimentally in 1995/96 using terrestrial transmitters operating at VHF. In Canada, it is likely that DAB will start in the 1.5-GHz band allocated by WARC-92. Following extensive evaluations, both Europe and Canada have agreed to use the Eureka 147 system. In the USA, no exclusive frequency allocation is currently available for terrestrial DAB services, so investigations are in hand to determine the possibility of developing a DAB system which could work in the FM band in parallel with the existing sound broadcasting services. Many developing countries are interested in satellite delivery of DAB, using a low-cost receiver which would not necessarily deliver the full compact-disc quality of the Eureka 147 DAB system. Several world broadcasters providing international sound broadcasting services were talking about DAB as a medium- to long-term replacement for short-wave transmissions.

A number of European broadcasters highlighted the fact that the Eureka 147 system can potentially provide noise-and interference-free reception in highly-congested areas, in particular to mobile and portable radio receivers which at present suffer poor reception. They stressed the fact that the Eureka system offers significantly better use of the spectrum and will allow additional sound services to be provided: in particular local commercial and community services which may at present be unable to go "on-air" because of a shortage of frequencies. Many broadcasters were enthusiastic about the huge

(continued on p. 85)