European perspectives on digital television broadcasting – Quality objectives and prospects for commonality

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In Europe, a series of collaborative projects are developing elements of digital terrestrial and satellite broadcasting systems. Efforts are being made to encourage these projects to work towards a common standard for Europe.

The article outlines some of the proposals already made for an initial target system. Particular explanations are given of the current quality goals, and how they were established.

Other issues considered are coverage problems, commonality of terrestrial with satellite, common multiplexing, and conditional access.

1. Introduction

In the field of digital television broadcasting, North America has been some years ahead of the rest of the world in its faith in what could be done with very powerful image compression systems. The open decision–making process which has taken place in the United States for advanced television (ATV) is a considerable achievement, and a great credit to the many individuals involved.

In Europe, considerable expertise has been accumulated in image compression and digital modulation, but a range of factors and circumstances have influenced the profile given, until recently, to studies of digital terrestrial television broadcasting. These have included pessimism that the planning environment in Europe would allow the development of digital high definition terrestrial television with reasonable coverage, and pessimism that sufficiently attractive picture quality could be achieved with the bit–rates that are possible in terrestrial networks.

Today there is clear recognition in Europe that we must pursue digital television broadcasting, undaunted by the problems, and explore the potential solutions, because the prize for success will be considerable.

An international committee, the European Launching Group (ELG), has been established to try to coordinate the various projects which are developing digital terrestrial television broadcasting, or indeed related systems, in Europe. This committee has a technical subcommittee, the Working Group on Digital Television Broadcasting (WGDTB).

Current projects in Europe include those listed in *Table 1*.

The WGDTB has examined the aims of the current collaborative projects, and their timescales, and looked at the potential uses of digital television broadcasting. They arrived, at the end of 1992, at a work plan, intended to make it possible for Europe to achieve common standards for digital television broadcasting within the next few years. The

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Project	Country (ies)	Objectives
RACE dTTb	multi–national	centred on the development of modulation systems appropriate for digital terrestrial television
RACE HD–SAT	multi–national	centred on the development of modulation systems for 20 GHz digital satellite television
RACE FLASHTV	multi–national	centred on the development of digital HDTV satellite point–to–point systems
HD–DIVINE	Scandinavia	developing all aspects of digital terrestrial television
HDTV–T	Germany	developing all aspects of digital terrestrial television
EUREKA–VADIS	multi–national	developing baseband coding systems
EBU – Working Parties R and V	pan–European	continuing studies of terrestrial and satellite planning, requirements and testing

Table 1
A selection of European digital television broadcasting projects.

present article will outline some features of this plan, and give the background to the conclusions reached. What the WGDTB has done is to develop a first scenario which needs now to be taken up by experimental work.

A fundamental limitation on the quality and ruggedness of terrestrial television services will be the terrestrial channel capacity. In Europe, the VHF/UHF broadcast television bands use either 7 or 8 MHz channels. The working assumption has been that the system should have a bandwidth of about 7.5 MHz. The prospect of using more than one channel in a contiguous way for a single broadcast service seem remote, and the prospects of obtaining new frequency allocations with a wider channel spacing, even more so. Given a 7.5 MHz channel, it seems that the upper bound on gross bit rate is likely to be about 30 Mbit/s.

The first task the WGDTB undertook was to evaluate the options which seemed most likely to be attractive and salable to the European consumer in the next century, in the light of what could be seen, or predicted, as general trends in society.

There is no doubt that the quality expectations of viewers are rising, and that the long–term future of television lies with HDTV. Nevertheless, the Group was also conscious that viewing habits are changing as society evolves. Therefore, when setting system goals there are dimensions other than quality which need to be taken into account. It is not sufficient to ask what the public may want, we also need to ask when and where they will want it. Furthermore, the practical large flat–screen HDTV display, for many years regarded as the key to HDTV acceptability in the domestic environment, seems nearly as far away as ever.

One underlying trend in society is toward individual activity, rather than group activity. A second element to consider is mobility. Essentially sound–radio has migrated from a group experience in the home, to a near–individual activity in the car. We could reasonably ask if some of the same evolution will apply to television to any degree, or at least whether television will also have to cope with a mobile environment.

There seemed to be four options, essentially linked to different viewing environments, which were worthy of most attention. These were as follows:

– HDTV (high definition television) services to viewers with very large screen receivers, using *fixed roof–top aerials*.

– EDTV (extended definition television) services to viewers with medium to large screen receivers using *fixed roof–top aerials*.

– SDTV (standard definition television) services to viewers with portable televisions using *set–top aerials*.

– LDTV (limited definition television) services to viewers with small screen receivers using *whip/stub aerials* in a *mobile* situation (e.g. in a car).

In order to translate these concepts to practical systems, it is necessary to decide what is meant precisely by the quality in each case, and what is meant precisely by each of the receiving environments.

Picture quality is difficult to quantify in absolute terms, because it is the net effect of a series of factors such as resolution, sharpness, noise, artefacts, etc. It is by no means only related to the scanning standard. The picture quality that is achieved will also be related to the source quality, the sophistication of the compression algorithm, and the bit–rate used.

The receiving environment can be defined somewhat more easily. It is related to the bit–error distribution in which the system is required to work.

In other words, it is associated with the ruggedness necessary to achieve impairment–free pictures of the intended quality. As a first assumption in the WGDTB, the roof–top environment is considered to be associated with a spectral efficiency of 4 bits/s/Hz. The portable environment is considered to need 1–2 bits/s/Hz, and the mobile environment is considered to need 1 bit/s/Hz.

2. The dimensions of picture quality

2.1. HDTV

High definition television is defined rather loosely by the International Telecommunication Union (ITU) as a system which has about twice the horizonal and vertical definition of conventional television. This still leaves open the amount of noise or artefacts that are permitted, and which affect the picture quality just as much as definition. Furthermore, there is a relatively wide range of definitions available within the term "conventional television". In addition, interlaced systems have a triangular vertical–temporal response, so it is difficult to know where the concept of "twice resolution" applies.

To pin down HDTV, we have to look at the combined effect of all the quality factors on the picture; and, to some extent, make up new rules.

When deciding on a required picture quality we have to bear in mind the target viewing distance, and the need to ask, responsibly, for no more than is necessary.

Digital compression systems all work in a similar way. The information content of the source picture varies from scene to scene. The system reproduces the content of the input picture essentially intact, until the point is reached where the transmission bit–rate will be exceeded if nothing is done. At this point, a series of approximations are made to parts of the scene. The output scene can thus have (apparently) added noise or loss of resolution, to an extent depending on the original scene content.

For any practical system there will always be scenes which are reproduced perfectly, and others which are impaired. The system designer's intention is to make the impairments occur as infrequently as possible, and be as unobtrusive as possible.

The main approach examined by the WGDTB to specify the quality needed is termed the "scene–content failure characteristic". This is a logical and scientific method, but it is also relatively expensive to use.

The basic element to be specified is the proportion of total programme time which should be free of artefacts. "Freedom from artefacts" is considered to be associated with a minimum mean score of 12% in a double–stimulus continuous–quality scale (DSCQS) subjective evaluation. This is somewhat arbitrary figure, but much experience shows it to be a good rule of thumb for virtual transparency.

The challenges are then, first, to decide what constitutes a sensible proportion of time for which impairment free pictures should be demanded. The second challenge is to assemble statistical evidence about the relative occurrence of different kinds of scene content, so that it can be verified that the requirements are met.

In choosing the proportion of time for which impairment–free pictures could be expected, we can look to the other "statistical" domain of picture quality, which is the propagation failure characteristic, used as a planning criterion. For example, in broadcasting satellite systems (BSS), quality is required to be maintained for a defined percentage of the worst month of the year. If this kind of guideline is acceptable for satellite systems, would it also be acceptable for terrestrial television broadcasting?

Unfortunately, the answer is "not quite". In satellite broadcasting, the "outage time" is used up in rain–fades, which occur over a period of, say, half–an–hour. The quantization–noise artefacts that are introduced by digital coding will probably be more spaced out than this, and their effects will therefore be less severe on the viewers overall perception of quality (this is sometimes called the "forgiveness effect"). However, it may be appropriate to adopt a value similar to that for the BSS as a starting point for fixing the scene content failure characteristic requirement.

The WGDTB has tentatively begun by taking 99.7% transparency as the requirement for the digital terrestrial HDTV service. Coupled with this, it is assumed that the reference quality is a 1250/50/2:1 HDTV studio signal, with 1440 samples/line.

We do not yet have a catalogue of HDTV picture sequences and their places on a codec "criticality table", but we do have some experience from former 4:2:2 codec studies. These suggest that to achieve the target transparency, the codec would

need to pass, unimpaired, *almost all* the test pictures so far devised, including the second most–stringent CCIR sequence "mobile and calendar" (critical, but even so only in the area of 80%–90% criticality).

The quality target is very high, and may not be achievable at the available bit–rate. But it certainly is worth aiming high at the start. It is known from past experience that HDTV source and display equipment quality will improve, and a system which will last well into the next century would be valuable.

The next key question is "what quality can be achieved with 20–30 Mbit/s?" Initial tests may be possible in autumn 1993 with the HD–DIVINE system, and these will provide first clues.

2.2. EDTV

The second quality level targeted is termed EDTV, extended definition television. This is not a particularly appropriate name, because the scanning standard for the system would be the normal 625–line system.

The level is included because large–screen HDTV receivers, which have an HDTV dot pitch, will be very unwieldy and very expensive for many years to come. An EDTV level would fulfill a need for a lower–cost and lighter receiver. Having probably a screen size less than about 30 inches, it would not be dramatically inferior to an HDTV display in perceived quality. There may also be living rooms which are not large enough to take a true HDTV receiver.

The source format for EDTV is assumed to be a signal conforming to CCIR Recommendation 601, with 720 samples per line and a 16:9 aspect ratio.

The codec transparency required, in terms of the percentage of programme time unimpaired, would be roughly the same as for the HDTV level (although in this case with respect to the 4:2:2 source).

The best information available at the present time is that in order to achieve this level of transparency, a bit–rate of about 9–11 Mbit/s is probably needed for a motion–compensated hybrid DCT system.

2.3. SDTV

The third quality level considered is SDTV, standard definition television. This is specifically intended to be a matched to the quality needs of portable receivers.

On small–to–medium screen sizes, even today's PAL/SECAM quality is very good. Thus, for the SDTV level, we need a system which has a 625–line scanning format, but we can accept some artefacts, as is the case for PAL and SECAM.

The kinds of artefacts associated with PAL/SECAM and with a digital motion–compensated hybrid DCT system will be different, but we believe that to achieve, globally, about the same overall quality, a data rate of about 5–6 Mbit/s is needed.

2.4. LDTV

The fourth quality level is LDTV, limited definition television. This is intended to match the needs of very small screen receivers, which might be used in cars.

It has to be said that broadcasters among the WGDTB membership are not yet convinced that there would be a need for such a level, but it has certainly been included in the discussion. The quality requirements of this level would be about the same as the MPEG 1 codec or about VHS level. This means about one–quarter of the resolution potential of CCIR Recommendation 601.

Specifying the quality requirements, and evaluating the systems in terms of their scene–content failure characteristics will be a major technical challenge, principally because of the need to establish how often scenes of a particular type of content are likely to occur. There may be alternative simpler approaches which will also help to understand and quantify the systems' behaviour. One such approach is outlined in the next section.

2.5. The "quality space" concept

Another potential quality evaluation criterion, which the WGDTB has been asked to consider, is associated with the concept of "quality space".

Our perception of the picture quality of a given system is directly influenced by the viewing distance. The further from the screen, or the narrower the viewing angle, the less discriminating we are in terms of resolution or artefacts.

One way, therefore, to see the various quality levels, is by imagining that there is a "quality space", which is a graphical representation of picture quality–versus–viewing distance. For the picture quality axis, we use the same axis as for DSCQS evalu-

ations. This is five contiguous and equal intervals characterised by the quality descriptors: excellent, good, fair, poor, bad. For the viewing distance axis, we used multiples of picture height as markers 3H, 4H, 5H, 6H, 7H, and 8H.

In this quality space we assume an unimpaired reference in each case, and define an HDTV system as one for which the mean results of all assessments must fall within the "excellent" band at 3H. Similarly, we specify an EDTV system as one for which the results of assessments must fall in the excellent band at 4H. SDTV systems are those for which the results must fall in the excellent band at 6H, and an LDTV system as one for which the results must fall in the excellent band at 8H.

This seems a relatively clear means of defining and distinguishing between the quality levels, but experimental work remains to be done to establish its viability in practice.

2.6. The impact of source scanning parameters on overall quality

Another interesting dimension to this question of picture quality concerns the impact of source quality on final picture quality under high compression.

Compression systems may show a characteristic such that it could be considered (in a simplified way) that their characteristics of quality–versus–bit–rate have two regions. In the first region, which extends down to a given bit–rate, the codec is essentially transparent. In the second region, beyond a kind of knee in the quality/bit–rate curve, there is a progressive increase in artefacts as the bit–rate is reduced.

The point at which the knee begins is related to the "overload" level of picture detail.

If there were two systems, one 1250–line and the other 625–line, the quality associated with the flat region of the characteristic for the 1250–line system would be a grade or so above the flat region of the 625–line system. However, the knee of the 625–line system would arrive later, at a lower bit rate, because there is less picture detail to handle. Since the roll–off of the 1250–line system curve is relatively steep, it is possible that the two will cross, making the quality achievable with the 625–line system higher than with the 1250–line system, over a given range of (low) bit–rates.

With very powerful compression systems, which are actually operating in their quality roll–off region, there may thus, surprisingly, be better results with lower resolution sources that with higher resolution sources. The loss in resolution may be less annoying than the artefacts that are introduced by the compression. This issue needs to be resolved when experimental systems are available.

3. Multi–layer systems

3.1. The concept

Having established the desired individual quality criteria, the WGDTB moved forward to develop the concept of a multi–layer system.

Bearing in mind the potential of modern compression methods, the Group asked if it is possible to devise a system that will allow the reception of several quality layers simultaneously. Is this were possible, there would be considerable benefits in the size of the market attainable by a given service.

There are, in theory, two approaches to multi–layer systems. The first, and simplest, is to broadcast the services separately side–byside. This is termed "multi–cast", in the WGDTB vocabulary. The second is to embed one layer in a second, and this is termed "hierarchical coding" in the Group's vocabulary.

Each of the layers has to be arranged to have its own baseband coding elements and its own modulation elements, which give the required ruggedness or spectral efficiency.

Preliminary calculations suggest that, taken overall, the multi–cast and hierarchical approaches will be about equally efficient for a two–layer system, but for a three–layer system, the hierarchical approach will be more efficient. This remains to be verified experimentally.

It would be foolish to deny that, if it going to be difficult to achieve the high quality asked in a stand–alone system, it will be even more difficult in a multi–layer environment. When all the evidence is available we will have to weigh up all the trade–offs involved.

3.2. The WGDTB terrestrial "strawmen"

The WGDTB has drawn up a set of "strawman" multi–layer systems which it proposes should form the basis of studies for the projects associated

with digital terrestrial broadcasting. These are explained more fully in [1].

The first proposal is a three–level multi–layer system which would simultaneously allow reception at HDTV, EDTV, and SDTV, and be reconfigurable to carry two EDTV services. If the three–level multilayer system proves impractical, a two–level system should be investigated. The second proposal is a three–level multi–layer system which would simultaneously allow reception of EDTV, SDTV, and LDTV.

4. Coverage

It would a mistake to minimize the problems and uncertainties associated with terrestrial planning in Europe. Transmitter density is massive, and traditionally, broadcasters have achieved national coverage for their channels. It appears from a first analysis that only in countries on the periphery of Europe (geographically speaking only) will it be possible to repeat the kind of coverage achieved today with PAL and SECAM with a digital HDTV service.

Critical studies still need to be made, based on hard data for protection ratios, and it seems possible that we may be faced with a difficult choice of providing HDTV coverage to a part of the population, or perhaps lower quality services to a greater part of the population, or some compromise.

The difficult planning situation is one of the main reasons why the use of COFDM as a modulation scheme for terrestrial services seems very important for Europe. It will make reception more immune from multipath propagation, and it will allow the development of single frequency networks.

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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.

5. Considerations of commonality

5.1. Commonality with satellite systems

The CCIR agreed in 1992 that it was even more important to achieve common standards between satellites and terrestrial services in a given country, than to achieve international standardization of terrestrial or satellite systems in isolation.

In the end, what matters most is how many pieces of equipment the consumer needs, to allow him to receive the available services. International viewing is important, as are the economies of scale which an international system would bring. But more important, at the level of an individual European household, is having only one receiver for all the national services.

This is very much recognised by the members of the WGDTB, although everyone realizes that there may be difficult commercial hurdles to be overcome before a common system for satellites and for terrestrial systems can be achieved. The WGDTB is nonetheless intent on pursuing all relevant options.

There is considerable interest in Europe in bringing into service digital multi–channel satellites at frequencies around 12 GHz. A number of programme providers are studying systems rather like the DIRECTtv concept developed in North America. The ideal solution would be to bring such systems into a family which encompasses terrestrial digital systems and future HDTV services by satellite. This would be in the best interest of the public.

The WGDTB has prepared a further “strawman” which would provide a compatible bridge between digital satellite and digital terrestrial services. This is a satellite system which would be developed from the same tool–kit as the terrestrial system.

In the satellite case, there would be two key differences. First, the useable system bit–rate would be about 45 Mbit/s, and this could be used with any of the currently foreseen transponder bandwidths. Second, no attempt would be made to use systems with very low spectral efficiency, to help portable or mobile receivers, because the propagation conditions from satellites in the 12 GHz region or higher would probably rule them out in any event.

5.2. Multiplexing

A major step forward to achieving common systems both between different types of transport and

internationally would be to develop a common multiplex system. This prospect is being seriously investigated in the WGDTB group. An analysis of the options available for a common multiplex is currently being made.

There seem to be a number of potential candidates for a common multiplex, and particular attention is focussed on the MPEG proposals and the DAB system. A unique system for DAB and DTVB seems particularly attractive.

5.3. Conditional access

It is clear that the only way to finance many of the new digital services will be by pay–TV or conditional access. Standardization of conditional access systems has proved very difficult in the past. Some operators see the use of a proprietary conditional access system as a means to secure a market advantage. Whilst this is true, the greater public good can be argued. It is unfair and unreasonable to ask the public to use a multiplicity of different decoders, all of which do very much the same thing in the same way. A more reasonable course may be to call for a common decoder system with a smart card interface. To use different services the viewer would just change smart cards, which would be obtainable from the programme provider, and could include proprietary software etc. This may be a way to balance the interest of the public, and the needs of the programme provider. Competition between programme providers on the basis of their programme content is the way to raise standards for everybody. Using technology differences to prevent people seeing the competition will not raise programme standards and certainly will raise costs for the viewer.

6. Conclusions

The European ELG and WGDTB have tried to commence their task – the coordination of digital television standards in Europe – with imagination.

The "strawmen" proposed are extremely ambitious, but it is right to begin the development of a television system for the next millennium in such a way. If however, the work continues as it has begun, with good–will, cooperation, and pragmatism, it has every chance of succeeding.

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The development explained in this article was undertaken by the members of the Working Group on Digital Television Broadcasting. Their work, under the Chairmanship of Prof. Ulrich Reimers, is acknowledged.

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