Digital Terrestrial Broadcasting — Issues for Successful Implementation

By M. D. Windram and A. G. Mason

In considering the issues for successful implementation of digital terrestrial television broadcasting, we can draw on a foundation of National Transcommunications Ltd.'s (NTL's) experience as the provider of the NTL 2000 digital video-compression system worldwide, and over five years of study on the SPECTRE project in the U.K.

SPECTRE is concerned with all aspects of digital television including the low-bit-rate video coding, modulation, frequency planning, and perhaps most important, practical field trials. The work was initiated under the Independent Broadcasting Authority, but since the IBA was abolished in 1990, it has been carried out by NTL, under contract from the Independent Television Commission in the U.K.

For success in digital terrestrial broadcasting (DTB), it is necessary to resolve a range of commercial, technical, and standards issues. It is also particularly important to draw on the practical experience gained in the U.K. in field trials.

Some Commercial Issues

In Europe, the Group on Digital Video Broadcasting has established not only technical groups, but also commercial groups, to identify the features that systems must include in order to ensure viability. Typical issues to be resolved for digital terrestrial broadcasting include:

- What method of reception is desired? It is necessary to decide whether to have reception on rooftop antennas, or whether reception must also be possible on set-top antennas. Do we want reception on portable TVs or mobile TVs? To clarify definitions, a portable TV set is one that can be placed at any location and uses only a set-top or internal antenna. Mobile TV is essentially TV used in a car, train, or other vehicle.
- What services must be provided? Is high-definition television or extended-definition television necessary, or is standard-definition television adequate?
- What level of interworking with other services on cable or satellite is required?
- What form of conditional access system is required? Access control to permanent installations is straightforward in comparison to the difficulties associated with portable or mobile sets.
- How will the service be introduced?

The Broadcast Environment at the Introduction of DTB

The overall environment into which a DTB system must be successfully introduced is shown in Fig. 1. New services not yet introduced in Europe have been highlighted. In Europe, the existing analog terrestrial and cable services are well established. Digital satellite services are expected to become established in Europe sometime in 1995, which is at least two years ahead of the earliest time scale for digital terrestrial services. Therefore, in Europe, DTB will be introduced into an environment that has existing analog terrestrial and digital satellite services.

Interworking with cable systems is a more complex issue that is beyond the scope of this article, other than to note that cable and master antenna systems must be able to carry the digital terrestrial signal in some form if a large viewer base is not to be lost.

In an environment with competition for a range of media, particularly where these other media will be available sooner, why consider digital terrestrial broadcasting? Cable and satellite are suited to reception of TV at fixed locations, but they do not work for portable and mobile situations. The

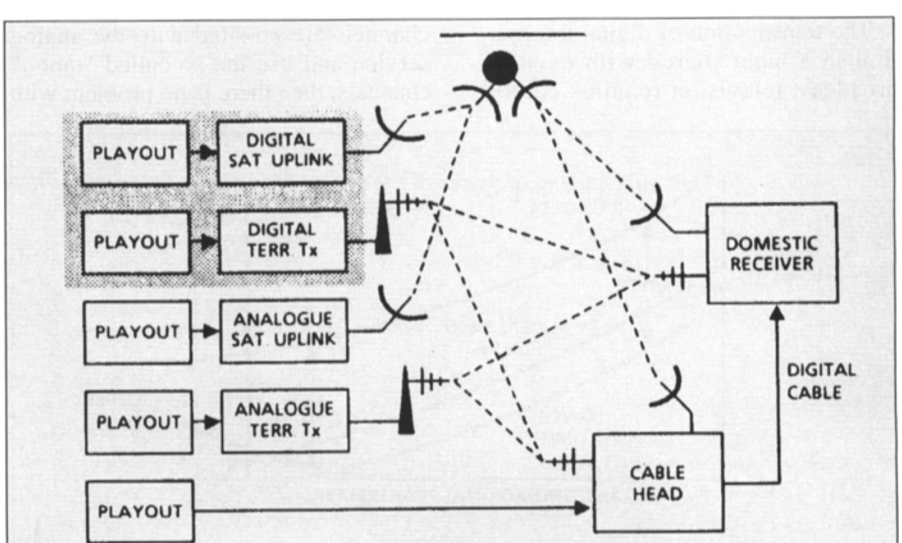

Figure 1. The broadcast environment.

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VHF and UHF bands are particularly well suited to reception not only at fixed sites, but at locations where no cable or satellite downlead connection can be available. The concept of a car, train, or plane attached to a fiber is just not practical. Such reception has been described in Europe as "plug-free," and imposes additional constraints on the choices of bit-rate, modulation, and frequency planning criteria.

DTB — Technical Issues for Successful Implementation

The issues of frequency availability, digital service power levels, and coverage are critical to the success of DTB. These frequency plans must be based on the types of services required and that are possible. The type of modulation scheme used is particularly important to give optimum coverage coupled with low costs in the receiver implementation. Transmission issues are of interest in the U.K., where relatively low powers are proposed for digital transmission, but are of particular importance in the U.S., where higher transmitted powers are contemplated. Practical field trials are important in establishing the accuracy of the technical and planning assumptions and in creating confidence among future service providers. A particularly difficult issue is the degree of commonality between terrestrial, satellite, and cable systems.

Frequency Planning, Power Levels, and Coverage

The transmission of digital information in a band shared with existing broadcast television requires careful planning. In the U.K., it must be ensured that digital transmission not interfere with the existing television relay network, which operates at low power. For each TV service, there are 50 main transmitters and around 1,000 relays.

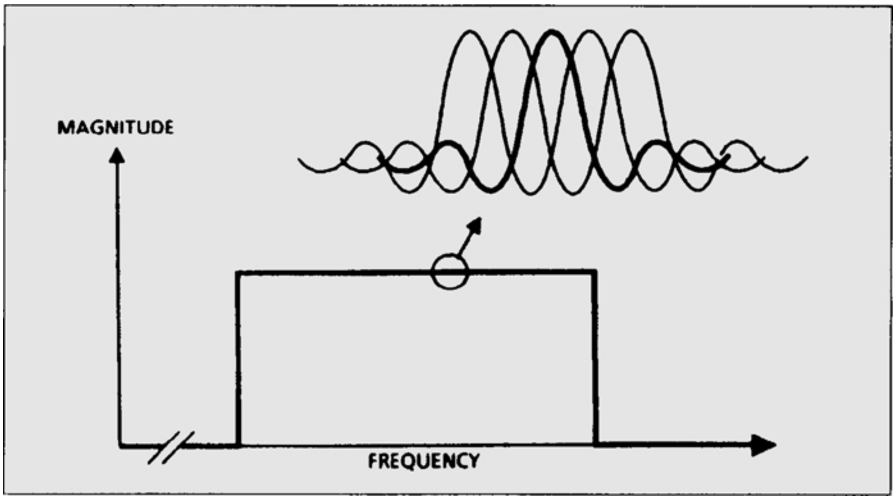

Figure 3. The OFDM spectrum.

The only way to avoid interference into this relay network is to transmit on the opposite polarization from the relays and also radiate the new digital service at a significantly lower power than the existing services. In the U.K., the UHF band is used for TV transmission. The main transmitters operate on horizontal polarization, and the relays use vertical polarization.

Figure 2 illustrates the basic principles used to derive the permitted radiated power level for a digital service in the U.K. Essentially, if the digital channels are co-sited with the analog service and use the so-called "taboo" channels, then there is no problem with relays within the digital service area, as such relays are not normally operated on the "taboo" channels. However, the relays of the adjacent main transmitters can be co-channels with the digital signal. For these relays, the digital signal must be 40 to 45 dB down to avoid degradation of the existing analog relay service. In the U.K., main transmitters use horizontal polarization, and relays use vertical polarization. Therefore, the digital service must use horizontal polarization to give maximum protection to the relays. Assuming that this protection is 15 dB, then the digital signal must be a further 25 to 30 dB down to give the required protection to the relays. If the digital signal is too low in power, then the digital receiver will have a problem, particularly if the co-sited analog service is high power on an adjacent channel. This leads to the ideal digital radiated power being around 25 to 30 dB down.

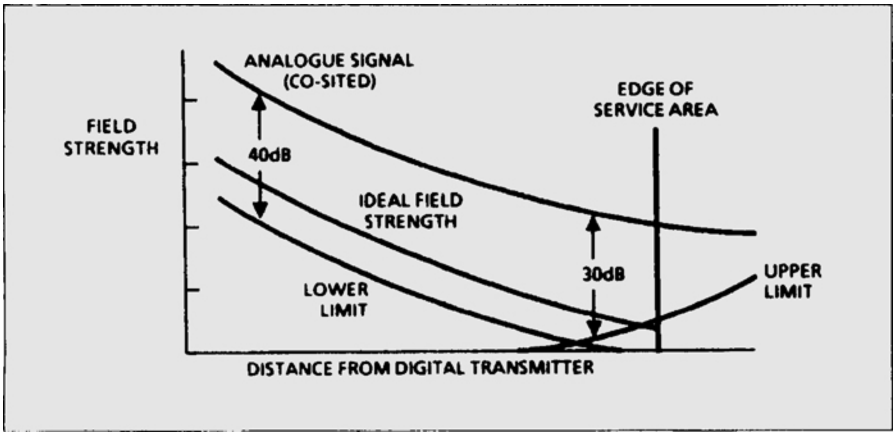

Figure 2. The choice of radiated power.

In the U.K., the practical situations have been modeled in far more detail, but the results are very similar. Based on co-sited digital services transmitted at around 30 dB down, it has been found that most of the existing transmitter sites were able to cover similar population sizes to the analog service with, on average, four additional 8-MHz bandwidth digital channels. The constraint of very low power digital transmission demands excellent rejection of co-channel interference from the high-power analog service. Moreover, broadcasting in adjacent channels from the same mast, with different aerial radiation patterns and height for analog and digital transmissions, places additional requirements on the adjacent channel interference performance of the digital system. This occurs because the digital service is not only 30 dB lower in transmitted power, but the ratio can be made even larger by the different aerial radiation patterns and antenna height.

In the U.K., it has been concluded that the digital services must be co-sited with the high-power analog services and must be low power, at around 25 to 30 dB down on the existing analog services. This is based on the assumption that significant degradation of the existing service in relay service areas for large numbers of viewers would not be acceptable. In this context, it should be noted that the broadcaster losing viewers may not necessarily be the operator of the new services. It has been assumed in the planning that serious degradation of service for existing viewers would not be considered acceptable.

For the U.K., the ITC has reported the results of the studies, that typically four 8-MHz bandwidth digital channels are available in each area. There are, in fact, more in some areas but fewer in other key areas. For Europe as a whole, the indications are that, in some countries, frequency availability may be limited by the increased use in analog services of the so-called "taboo channels."

Orthogonal Frequency Division Multiplexing, Modulation, and Error Protection

The key to the development of successful digital terrestrial broadcasting of TV or HDTV is to identify a digital modulation system that permits sharing of the UHF spectrum between the existing analog UHF services and the new digital services, as indicated earlier. To be suitable, such modulation should permit adjacent channel analog signals at up to 40 dB higher on the desired digital signal, should have excellent resilience to analog co-channel signals at a comparable level, and should be rugged and tolerant to multipath.

One of the most effective modulation techniques for dealing with hostile propagation and interference environments is a digital modulation scheme that spreads the signal energy over a wider spectrum. This conflicts with the limited spectrum available in the terrestrial UHF band. Nevertheless, the technique of orthogonal frequency division multiplexing (OFDM), also proposed for digital audio broadcasting (DAB) in Europe, is particularly suited to the difficult environment of sharing with the existing analog PAL, SECAM, or NTSC services. The basic principle is illustrated in Fig. 3. In essence, OFDM is an extreme case of a frequency division multiplex (FDM) system, in which several hundred carriers are spaced equally within the UHF 8-MHz channel. The data rate on each carrier is low at typically 15 ksymbols/sec, a characteristic that gives OFDM excellent multipath properties.

OFDM offers a rugged transmission system. Unlike single-carrier systems such as those used in satellite broadcasting, OFDM can handle multipath without the need for complex and expensive echo-correction systems. OFDM can offer flexibility in terms of order of modulation. Detailed studies with the QPSK, 8-PSK, and 16-QAM versions of OFDM have already been carried out, offering gross bit rates of around 13, 18, and 25 Mbits/sec in an 8-MHz channel. Sixteen-QAM OFDM offers adequate capacity for HDTV, as illustrated in the Scandinavian HD-DIVINE project, which is also based on the OFDM technique. OFDM also permits the use of single-frequency networks, that is, transmitter networks in which more than one transmitter uses the same frequency, modulation, and data, giving efficient use of spectrum and good digital coverage.

WANTED SIGNAL		INTERFERENCE			
		CO-CHANNEL INTERFERENCE		ADJ CHANNEL INTERFERENCE	NOISE
		PAL-I	OFDM	PAL-I	
PAL-I		40dB(C) 30DB(T)	45dB(C) 38dB(T)	+ 6dB(C) - 6dB(T)	45dB
OFDM	4-PSK	- 3dB	11.5dB	- 45dB	12.5dB
	8-PSK	2dB	17dB	- 41dB	18.5dB
	16-QAM	5dB	19 5dB	- 39dB	21dB

Figure 4. Interference protection ratios and noise performance.

Interference Protection Ratios and Noise Performance

Figure 4 illustrates the protection margins of the different types of OFDM with only a basic level of error protection. Significant improvements are possible in the performance margins where OFDM is the wanted signal, by the use of more sophisticated error-protection systems.

PAL is not very tolerant of adjacent channel interference, with a limit of 6 dB down on the wanted signal being set for continuous interference (the C is continuous interference, and the T is tropospheric, or intermittent, interference). On the other hand, OFDM tolerates PAL interference at 40 or more dB up, an adequate margin, as defined earlier. Unlike PAL or NTSC, which is sensitive to noise at 45 dB down, OFDM will tolerate noise levels some 25 to 30 dB higher.

Analog systems are sensitive to interference, and, for PAL, the maximum level of co-channel interference from another PAL signal must be 40 dB down for continuous interference. It might be noted here that OFDM, along with other digital systems, causes a slightly higher level of interference than analog systems. In the case of PAL, this results from the use of an offset of the carrier frequencies by 5/3 of the line frequency.

OFDM, particularly as designed with digital carriers omitted and not decoded in the region of the vision, sound, and color subcarriers, is very rugged and tolerates co-channel PAL of compara-

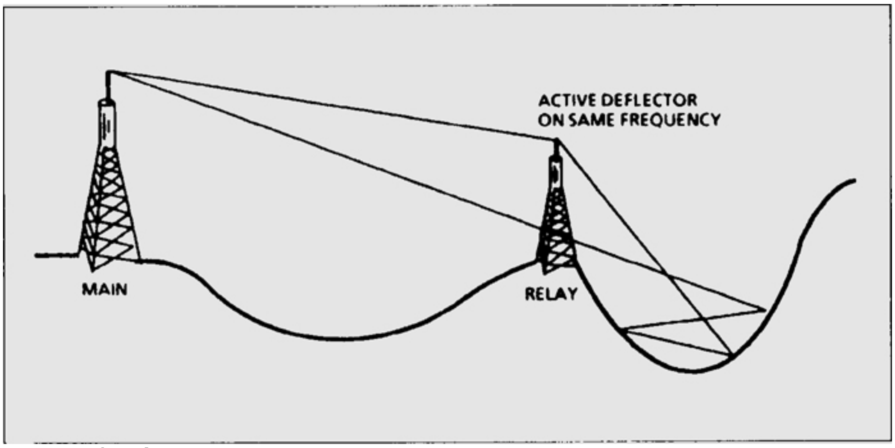

Figure 5. SPECTRE single-frequency relays.

ble level. As indicated earlier, this is with only modest error protection. With increased error protection, significantly higher levels of interference and noise can be tolerated, perhaps 5 to 10 dB higher. The performance described here has been a key assumption in the U.K. frequency plan.

Single-Frequency Relays

In the context of single-frequency networks, one specific subset that is of particular interest is the single-frequency relay (Fig. 5). With OFDM it should be possible to use relays on the same frequency as the main transmitter to provide fill-in coverage of low signal areas. This can, in principle, permit very efficient use of frequencies and good coverage without the use of high power from the main transmitter.

Transmission Issues

The transmission power required for the digital signal, as measured at the antenna, is 25 to 30 dB down on the 1-MW effective radiated power (ERP) of a typical analog high-power U.K. transmitting station. This corresponds to a typical power at the digital transmitter output of less than 1 kW and, for many sites, no more than 100 W, depending on the feeder loss and antenna gain. With such lower power levels, there is quite a different trade-off between feeder and combiner losses, antenna performance, and transmitter power than would be necessary on very high power analog sites.

Like noise, OFDM modulation in principle has an approximately Gaussian amplitude distribution, and it would be expected, therefore, to operate the transmitter with a significant level of power back-off. In practice, tests have shown that, with a hard limiter, a 6-dB back-off is required to reduce digital performance degradation to an insignificant level, and that a 3-dB back-off is all that is necessary on the older valve-type amplifiers currently in use in the field trials. For modern solid-state transmitters, a prudent back-off level would be around 6 dB.

If OFDM is to be placed into the channel adjacent to high-power analog transmitters, then care must be taken to reduce the transmitted lower sideband of the analog vision carrier to a level below that of the digital signal. This is, in principle, a very significant constraint and does require additional filters to be put in the outputs of the existing high-power analog transmitters. In practice, such tests and modifications have been featured in the field trials.

Ideally, the digital transmit aerials should be co-located with the high-power analog antennas. However, there are practical limitations in trying to combine multiple sets of high-power signals 30 dB different in level, without introducing power losses into the analog output. If the digital antennas are fitted slightly lower down the mast, then an advantage can be gained due to the reduced aerial height in putting out a slightly higher signal level. The risk is that, at the edges of the service area, regions covered by the analog transmissions may not be included due to terrain shading for the digital signals radiated from lower down on the tower.

In studies for the ITC, NTL has carried out the frequency planning for practicable antenna heights and has chosen powers and antenna patterns to give the best coverage while minimizing interference into existing services. The patterns have, in many cases, needed to be shaped to protect these services, especially relays.

SPECTRE Field Trials

The SPECTRE project has been in field trial for a year and a half from NTL's high-power analog transmitter sites in the South West of England at Stockland Hill and Beacon Hill. These two sites are separated by around 50 km, as shown in Figs. 6 and 7. NTL has the option to transmit digitally from both sites on each of four channels, including channels that are adjacent to the high-power channels, and channels that are common at the two sites. The digital power levels are typically 25 to 30 dB below those of the analog UHF services.

In the trials, one transmitter normally broadcasts the full digital signal and the other acts as the OFDM interferer. By choosing sites that have at least one common channel available, it is possible to carry out experiments on the sharing of a single frequency between adjacent sites, and, in principle, to study aspects of a single-frequency network. In practice, the choice of site

Figure 6. SPECTRE field trial transmitter sites.

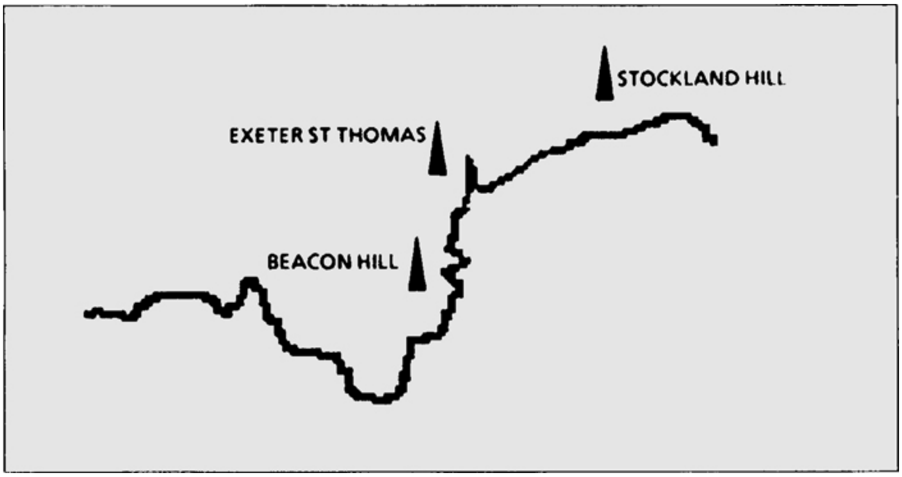

Figure 7. SPECTRE field trial transmitter and reception sites.

permits even more interesting and important tests to be carried out. The city of Exeter sits in a valley midway between Stockland Hill and Beacon Hill. Exeter is partly served by Stockland Hill, partly by Beacon Hill, and partly by a relay to the north of the city at Exeter St. Thomas.

In February 1994, the ITC carried out the first demonstration in the U.K. of off-air reception of digital television, at a site chosen in Exeter for its marginal reception of analog television. In these trials, 16:9 material was used that originated from HDTV via a downconverter and was upconverted after digital reception for final display on a 40-in. television.

The choice of this site in Devon permits evaluation of many technical issues, and such trials are ongoing. The relay at Exeter St. Thomas will allow NTL to test the concept of the single-frequency relay and identify the implementation difficulties.

The SPECTRE field trials have used digital transmissions, mainly from Stockland Hill and Beacon Hill, and reception in a mobile survey vehicle equipped with a digital receiver and decoder. This is shown diagrammatically in Fig. 8. At Stockland Hill, there is a coder compressing the 216 Mbits/sec of video to around 10 Mbits/sec, accompanied by stereo sound compressed to 256 kbits/sec.

The survey vehicle has a log periodic antenna for field strength measurements, as well as a digital receiver. With this equipment, NTL can monitor and record bit error performance, including the performance of individual carriers of the OFDM, and also monitor and record the analog or digital TV signals. Measurements have been carried out at many sites, and these provide confirmation of the planning assumptions, which is very encouraging for the planning work that has been carried out for the rest of the U.K.

One experiment was to put both Stockland Hill and Beacon Hill digital transmitters on the same channel: in Exeter, to point the antennas to Stockland Hill to get perfect reception of these signals; and by turning the antenna towards Beacon Hill, to also get perfect reception of the Beacon Hill signals. Unlike analog systems, in digital systems where the margins are far smaller, the antenna can provide sufficient discrimination between the desired and interfering signals.

It has been shown that the interference performance is as expected. More rugged error protection may well be useful to offer better protection against manmade interference effects, such as ignition interference, and to permit reception under more difficult conditions that could arise in portable sets with set-top antennas.

Interworking with Satellite and Cable Systems

In considering implementation issues for digital terrestrial TV, we must consider the requirements for interworking with satellite and cable systems. In Europe, we expect digital satellite broadcasting to start in 1995. Here in the U.S., the time frame is even more aggressive, with 1994 being quoted for DirecTV. In Europe, we can expect digital services on cable soon after the start of the digital satellite service, and again, the time frames in the U.S. look a little more aggressive. However, even if all commercial, regulatory, and technical issues are resolved, we cannot expect implementation of European digital terrestrial broadcasting before 1997. A key issue in implementation, therefore, would be the extent to which the digital terrestrial system is forced to be compatible with the satellite and cable systems so as to gain access to

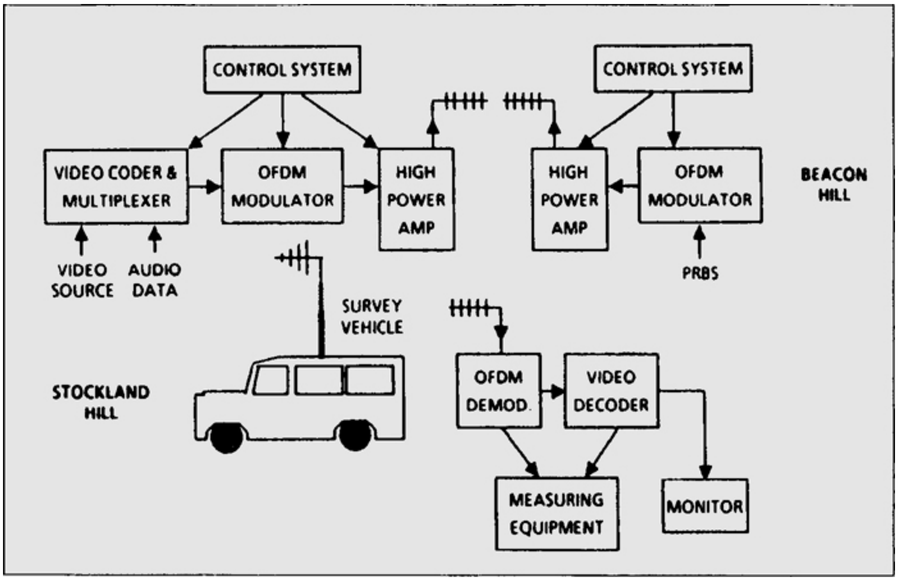

Figure 8. Equipment configuration for field trial.

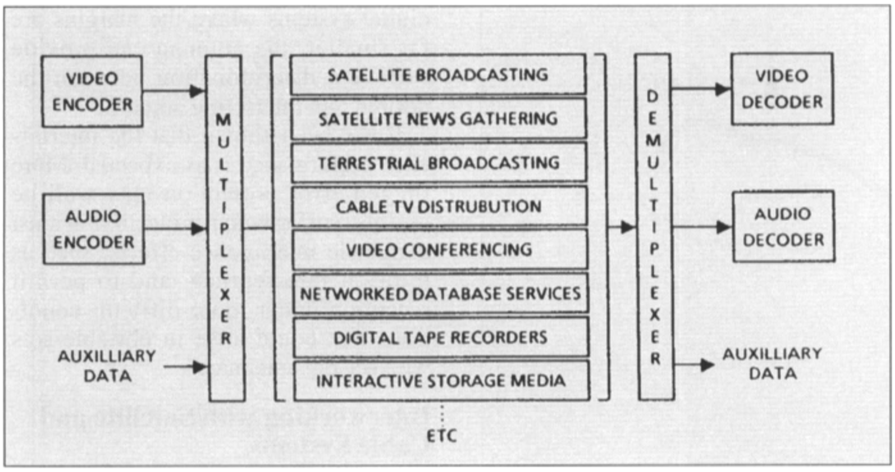

Figure 9. Generic digital TV.

digital receivers without further major expenditure by the viewer.

Perhaps we should remind ourselves of the possible digital environment at, say, 4 to 5 years from now. The viewer will receive programs in a variety of ways. The medium used will be unimportant unless the receiver is mobile or portable, in which case terrestrial reception will be essential. As far as processing is concerned, the greater the commonality, the lower the cost impact on the viewer; therefore, it is important to consider the issue of standards.

The process of standardization is being helped by the technology convergence in the broadcasting, telecommunications, and computing fields. For manufacturers, a single standard is essential to achieve the necessary volume and consequential cost reduction of compression encoding and decoding integrated circuits. This process has developed very successfully so far in the MPEG group of ISO/IEC, a group in which all the major players in video compression worldwide are extremely active. For example, to have a common system for the satellite, terrestrial, and cable direct-to-home markets, it is necessary to have agreement on the basic structure of video coding, audio coding, and multiplexing or "systems layer," as it is now called, as well as on modulation, which is satellite-specific.

Generic Digital TV

Figure 9 illustrates that the video audio coding and multiplexing principles can be common to all applications across a wide range of media. These aspects need to be agreed upon very quickly in order to ensure that there is a common standard across all media, irrespective of time frame to introduction. In Europe, the Group on Digital Video Broadcasting is set to build on the work of MPEG, to try to ensure that there is indeed a common standard across different media.

Standardization on the modulation or media aspects of the system is more complex, but it should be noted that it is not essential for all the systems-dependent aspects to be in agreement at the same time. Considering the European scheme, for a moment, it is possible to foresee a situation in which the standards for satellite direct-to-home broadcasting are agreed before the year-end, but chosen in such a way that the future digital terrestrial broadcasting systems can exploit the same main integrated circuits, differing only in the circuits relating to modulation and demodulation.

Conclusion

Digital terrestrial television developments are well advanced in the U.K. There is further work to be carried out in a number of areas, including further study on higher-order modulation systems and on the exploitation of the single-frequency relay characteristics. The technical issues of detailed frequency planning, options for the choice of modulation system, options for the choice of power levels and transmitter locations have been well studied, although further work is required. Nevertheless, the technology is now sufficiently advanced for the ITC to have announced its wish to explore whether digital terrestrial television would be introduced as an experimental or operational service in the U.K.

Even when the main outstanding issues have been resolved for the technical implementation of DTB to be possible, it will be the commercial issues that decide the success or failure of the service. In particular, we should note the costs, which in the case of the terrestrial infrastructure required, could well be higher than for the corresponding satellite infrastructure.

- One satellite transponder can carry up to 16 digital programs and provide coverage over the whole of the U.K. A single satellite can have 16 transponders, offering a package of up to 250 programs.
- Terrestrially, a network of 50 or more digital transmitters on one channel can achieve about 80% coverage of the U.K. for up to about 12 digital programs. The terrestrial network can offer an average of 4 channels, giving a package of around 50 programs, but these programs can readily be regional or local in origin and coverage.

The trials in the U.K. have confirmed the technical feasibility of digital terrestrial broadcasting in the U.K., but it is necessary to consider whether the same system could be used elsewhere in Europe. A European market may be essential for manufacturers to become interested.

For digital terrestrial broadcasting, it is important to identify the services required. For fixed-location TV sets, digital terrestrial broadcasting in a band shared with analog services has been shown to be practicable. With higher levels of error protection and corresponding reduced data capacity, a service to portable sets might be practicable, but this requires further study. Mobile reception does not appear to be feasible while the band is shared with high-power analog services.

In the U.K. and Europe, it is likely that digital terrestrial broadcasting will be introduced after digital satellite and cable, so that DTB will have to offer new features and services beyond those offered by other media if it is to have a commercial success.