Digital television and HDTV in America
A progress report

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The development of advanced and high–definition television systems has been marked by more debate, more spectacular changes of direction and, no doubt, more heart–ache than any other aspect of television technology and programme–making in the past fifty years.

The European television industry has, with varying degrees of enthusiasm, encouraged a full spectrum of analogue, hybrid and digital systems for all quality targets from pocket TV to wide–screen HDTV. In contrast, the decision of the US Federal Communication Commission to set one clear goal – HDTV in 6–MHz terrestrial channels – might have seemed like a simple approach, guaranteed almost to lead rapidly to success.

This presentation of the path trodden by America's HDTV pioneers shows that, even if all the competitors had a rather clear vision of the goal before they started, success has nevertheless demanded compromise and commercial pragmatism as well as good technology.

1. One requirement – twenty–one solutions

When the Federal Communications Committee (FCC) sought private sector advice and formed the Advisory Committee on Advanced Television Service (ACATS) in 1987, under the chairmanship of Richard E. Wiley, to make a recommendation to the FCC for a single terrestrial HDTV transmission standard, it was planned that the recommendation would be made in time for the FCC to set the standard in the second quarter of 1993.

By 1989, there were eight advanced television (ATV) proponents, and thirteen analogue system proposals were being presented to the Advisory Committee.

By 1990, the FCC Advisory Committee had outlined a comprehensive plan for laboratory and over–the–air testing of all the ATV systems. An open, fair and objective decision–making process had been put in place, and the FCC schedule seemed achievable.

The number of ATV proposals peaked at twenty–one, but by 1990 they had shrunk to only nine. Two of these were HDTV simulcast systems and they were both analogue designs.

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In 1990, the major change took place. On 1st June of that year, General Instruments proposed an all–digital HDTV system, just four weeks before the system submission deadline. Television was to change for ever. The digital era had begun and analogue broadcasting was doomed.

By 1991, only five HDTV systems remained and, of these, only one was a hybrid analogue/digital system – the Narrow MUSE system proposed by the Nippon Hoso Kyokai (NHK). The other four were all–digital systems and the change–over to digital systems had extended the Advisory Committee schedule by about six months.

By the Spring of 1992, three of the five HDTV systems had completed their objective laboratory tests and subjective "expert" viewer tests at the Advanced Television Test Centre (ATTC). Also, two of the systems had completed their non–expert viewer tests at the Advanced Television Evaluation Laboratory (ATEL) in Canada.

The final ATTC test reports were scheduled to be finished in mid–October 1993 and the final Canadian ATEL test report was to be finished on 23 October, in time for the decisive system selection meeting of the Special Panel of the Advisory Committee in February 1993.

Thus the task of the technical community, to devise a practical terrestrial HDTV broadcasting system that would give television broadcasters an HDTV option and a gateway into the digital era, was well under way and nearly on schedule.

Meanwhile, the FCC was forming its policy on Advanced Television and HDTV. In April 1990, FCC Chairman Sikes had announced:

...the Commission's intent is to select a simulcast high definition television standard that is compatible with the current 6 MHz channelization plan but employing new design principles independent of NTSC technology. We do not envision ... that the Commission would adopt an enhanced definition standard, if at all, prior to reaching a final decision on an HDTV standard, which ... will be made in the second quarter of 1993.

In September of 1990, in its First Report and Order, the FCC decided:

We do not find it useful to give further consideration to systems that use additional spectrum to "augment" an existing 6–MHz television channel to provide NTSC compatible service.

Consistent with our goal of ensuring excellence in the ATV service, we intend to select a simulcast high definition television system.

A simulcast system also will be spectrum efficient and facilitate the implementation of the advanced television service. Such a system will transmit the increased information of an HDTV signal in the same 6–MHz channel space used in the current television channel plan.

By 1990, therefore, the FCC and the private–sector Advisory Committee had abandoned "enhanced" and "augmentation" systems from further consideration. They had focused further work on incompatible HDTV simulcast systems, frozen the broadcasting spectrum for three more years of testing, and ensured that complete and objective tests would be made on all proponent systems before the approval of any HDTV system.

Thus, America would adopt an incompatible simulcast, full HDTV, terrestrial service.

The FCC released its second Notice of Proposed Rule Making, or NPRM, in November of last year, and this notice proposed how the HDTV service would be defined, the time schedule for its implementation, and for the replacement of the NTSC service.

__Mr. Joseph Flaherty__ received his degree in physics from the University of Rockhurst, Kansas, in 1952. After service in the US Signal Corps, he joined CBS as a television design engineer and became Vice–President and General Manager of CBS Engineering and Development in 1967, a position he held until his promotion to his present position as CBS Senior Vice–President, Technology, in 1990.

Mr. Flaherty has been responsible for many innovations in the television industry, including electronic news–gathering, electronic cinematography, off–line video–tape editing, one–inch video–tape, Plumbicon cameras and the miniature colour camera. He was responsible for opening the HDTV debate in the United States in 1981, and has been an influential figure in this field ever since.

Mr. Flaherty's many contributions to broadcasting have been honoured by the world's leading broadcasting societies and institutions, and he has been awarded the French Légion d'Honneur, the French Ordre des Arts et des Lettres. He is a frequent lecturer on television technology and has published many articles in the television field.

This second FCC NPRM stated:

In keeping with our goal of expediting delivery of advanced television service to the American public, we propose to limit the period of time during which existing broadcasters would have the right to apply for a particular HDTV channel. ... We note that preliminary information appears to indicate that a three–year application and a two–year construction period will permit broadcasters sufficient time to begin transmission in HDTV in the vast majority of cases.

We envision HDTV ... will eventually replace existing NTSC. In order to make a smooth transition to this technology, we earlier decided to permit delivery of advanced television on a separate 6–MHz (simulcast) channel. In order to continue to promote spectrum efficiency, we intend to require broadcasters to "convert" entirely to HDTV – i.e., to surrender one 6 MHz frequency and broadcast only in HDTV once HDTV becomes the prevalent medium.

In its Second Report and Order for implementing the HDTV service, the Commission decided to make a block allotment of frequencies for HDTV; broadcasters will have the first option on these frequencies. However the license application period for the HDTV channel was changed from three to two years, and the construction period was increased from two to three years – less time to apply, more time to build, but still five years total.

In its third Notice of Proposed Rule Making the FCC proposed to make broadcasting evolve to an all HDTV service, and to require broadcasters to surrender one of their two paired channels in 15 years from the date on which an HDTV standard is set or a final table of HDTV channel allotments is effective. At this time the NTSC service would be abandoned, but this schedule will be reviewed in 1998.

In its latest Notice of Proposed Rule Making issued on August 14 1992, the Commission proposed four broad HDTV (channel) allotment objectives for the implementation of HDTV.

– *To accommodate all existing NTSC stations, e.g., provide a second channel for HDTV service for all existing broadcasters;*

– *To maximize the service areas of all HDTV stations to the extent possible, and ensure all HDTV stations have a minimum service area of at least 85–90 km (55 miles) from the station's transmitter;*

– *To allot all HDTV channels to UHF spectrum; and*

– *To prefer HDTV allotments in situations where a choice must be made between providing greater service area for a new HDTV allotment or additional protection for an existing NTSC allotment.*

Thus the FCC was finalising the regulatory procedures and rules that would govern HDTV terrestrial broadcasting, and the recommendation from ACAT for an HDTV standard was to have been made early in 1993. Over–the–air field tests were to follow to confirm the choice and the final FCC action on the HDTV standard and the spectrum allotment plan was to occur in the latter half of 1993.

That, at least, was the intention.

Towards the end of the testing process, in November 1992, each of the system proponents identified a series of improvements for their systems and requested permission of the FCC Advisory Committee to implement the proposals. A Technical Sub–group of the Advisory Committee's Special Panel, chaired by Dr. Irwin Dorros and Dr. J.A. Flaherty, was appointed by the Advisory Committee Chairman to review the improvement proposals and to approve those which it considered appropriate. This Technical Sub–group met on 18 November 1992 and approved many of the proposals.

The Special Panel of the Advisory Committee met on 8 February 1993 to consider the test results and the system improvements with a view to selecting a final HDTV system to recommend to the Advisory Committee.

While all of the systems produced good HDTV pictures in a 6–MHz channel, none of them was judged to have performed sufficiently well, without implementing the improvements, to permit it to be selected as the single standard. Nevertheless, all the all–digital systems performed significantly better than the hybrid analogue/digital Narrow MUSE system, so this system was dropped from further consideration. There remained four systems in contention.

The Special Panel approved the improvements for the four remaining all–digital systems and recommended expeditious re–testing. The full Advisory Committee met on 24 February 1993 and approved the recommendations of the Special Panel.

2. *One solution – The* Grand Alliance

In April 1993, therefore, plans for the fresh series of tests were being finalised, with these tests due to start in May. During this time, and in parallel with the re–test planning, the four digital system proponents – AT&T/Zenith, General Instrument, DSRC/Thomson/Philips, and MIT – began to examine the possibility of combining their efforts into a signle HDTV system proposal, in what has come to be known as the *Grand Alliance*. The *Grand Alliance* was formed and announced on 24 May 1993.

The technical proposal from the Grand Alliance combined various parts of the four separate systems into a single all–digital HDTV transmission system, and recommended that several sub–system tests should be made to finalise the single system specification.

The FCC Advisory Committee assigned to its Technical Sub–group, again chaired by Dr. Dorros and Dr. Flaherty, the task of reviewing the proposal from the Grand Alliance, modifying it as necessary, selecting the final specifications and approving the system for prototype construction.

After this approval had been obtained, the prototype system would be built and subjected to complete objective laboratory testing and subjective expert and non–expert viewer testing before it would be recommended to the FCC for standardization.

The Technical Sub–group received the Grand Alliance proposal, reviewed it with the system proponents and realised that significant modifications would be required in addition to sub–system tests of two transmission systems.

Following detailed system review and modification, the Grand Alliance and the Technical Sub–group recommended specific system parameters for the scanning method, the video compression and the audio systems. There remained a choice to be made between the two contending transmission systems: vestigial side–band (VSB) and quadrature amplitude modulation (QAM). Following sub–system tests on these options, the 8–VSB system was approved on 24 February 1993. The 8–VSB system was originally developed by Zenith but it may incorporate components from the QAM adaptive equalization scheme devloped by General Instruments. At this point, therefore, a complete set of system parameters had been defined, as listed in *Table 1*.

Dual scanning system:

- 720 active lines, 1280 pixels per line, progressive, 59.94 and 60 Hz
- 1080 active lines, 1920 pixels per line, interlaced, 59.94 and 60 Hz

  (Both formats also operate in progressive mode at 30 and 24 frames/s.)

Video compression:

- MPEG2–compatible compression and transport, without "enhancements"

Audio:

- Dolby AC–3, 384 kbit/s

Transmission:

- 8–state vestigial side–band (8–VSB)

Table 1
Principal parameters of the Grand Alliance system.

3. *8–VSB vs. 32–QAM*

The various scanning formats proposed for the Grand Alliance system require a data–rate of about 20 Mbit/s. The problem is how to fit this data into a (US) standard 6–MHz television channel? If the the 20–Mbit/s data–stream was sent serially, with successive bits alternating between logic "0" and logic "1", this data stream would generate a square–wave with a fundamental frequency of 10 MHz. If this was used to modulate a television carrier, it would produce side–bands of plus and minus 10 MHz, for a total of 20 MHz, which is far more than the 6 MHz available.

The Zenith/AT&T members of the Grand Alliance approached this bandwidth problem in much the same way that a standard television signal is transmitted, by cutting off one side–band in a vestigial fashion, thus reducing the occupied bandwidth to a little over 10 MHz. In the next step, rather than sending just two levels for "0"s and "1"s, the bits are gathered in groups of two and sent as four levels: 0, 1, 2, and 3. This brings the bandwidth down by a factor of two, to 5 MHz. This process implies that the receiver will have to distinguish between four carrier levels rather than two, with a consequent need for a 6 dB better carrier–to–noise ratio to prevent bit errors.

Somewhat surprisingly, the carrier–to–noise performance of such a system can be improved by using even more levels. Successive versions used six, then eight levels in the system that has been tested at the ATTC. The system works because, although there are more levels, the system selects the four which are furthest apart from the eight that are available, in a dynamic, bit–pattern–dependent fashion. When this process is depicted graphically in a flow diagram, it has the appearance of a garden trellis, hence the name of the system – trellis coding.

In trellis coding, the transmitted signal is pre–coded so that only certain paths through the trellis are valid; others represent errors which can be corrected by deducing the most likely path from the received data. A low–level pilot signal is sent at the edge of the channel to help with carrier recovery.

The other transmission technique tested by the Grand Alliance is the quadrature amplitude modulation system proposed originally by General Instrument. It has much in common with the NTSC method of encoding I and Q colour information on the 3.58–MHz colour subcarrier. Conceptually, the 20 Mbit/s bit–stream is divided into two bit–streams of 10 Mbit/s each, giving a baseband bandwidth of 5 MHz for each bit–stream. This is further reduced, to 2.5 Mbit/s, by using four–level coding in the same manner as for VSB.

These two four–level bit–streams are carried as double–sideband modulation on two carriers in quadrature, at the television channel frequency.

When viewed on a transmission signal analyser, the signal described so far would produce 16 dots – four in each quadrant. Each dot then represents a four–bit data group. In fact, in the system proposed for the Grand Alliance, 32 vectors (dots) are generated so that trellis coding can be used in a manner similar to VSB, permitting the selection of 16 vectors out of the 32 available, in a data–dependent fashion, to achieve better noise performance.

In order to reduce interference from co–channel NTSC signals, comb filtering is used at the receiver to put notches at the interfering carrier and colour subcarrier frequencies. Pre–coding is used at the transmitter to compensate for the distortion caused by this processing.

The 8–VSB and 32–QAM modulations would both be very susceptible to multipath problems if a channel equalizer were not included in the receiver. This equalizer works very much like a ghost canceller. The incoming signal is passed through a multi–tap digital delay and signals with appropriate delays are used to cancel the multipath. Communications engineers think of this as a channel equalizer, while television engineers think of it as a ghost canceller.

The support of the dual scanning rates and the use of the MPEG–2 compression and transport systems enhance the ability of the system to inter–operate with other media such as computers, and is expected to enhance compatibility with the US National Information Infrastructure as that initiative unfolds in the future. Moreover, on the basis of studies by the consumer equipment industry, it is estimated that this additional flexibility will increase the cost of consumer HDTV receivers and video recorders by only 2 to 5%.

4. The way ahead

The present schedule calls for the 8–VSB transmission sub–system field test to take place as from 11 April 1994, and the construction of the prototype system and the integration of the various sub–systems will continue through the summer and autumn. Laboratory and expert viewing tests of the complete prototype system is scheduled to start at the ATTC in November 1994, followed by non–expert psychophysical tests at the ATEL in Canada in mid–December.

All the test results are scheduled to be completed by 31 March 1995, leading to a recommendation by the Adviosory Committee to the FCC by the end of April 1995. Thus, assuming there is no major change in the programme, it should be possible for the FCC to select a digital advanced television standard and a table of frequency allocations by the end of 1995 – some 2 1/2 years behind the original 7 1/2–year schedule.

How secure is this new schedule?

Naturally, no one is sure.

However, during the last seven years the Advisory Committee has worked 21 system proposals down to five, then to four, and now one. It has seen the replacement of early analogue proposals with today’s all–digital proposal, and has seen the United States come from last place to first place in the World competition for advanced television and HDTV. Europe is now pursuing an all–digital approach similar to that of the Grand Alliance, and Japan is debating the future of its analogue MUSE HDTV system – a system which must be abandoned sooner or later.

The Grand Alliance prototype system is under construction and will undergo final laboratory and field testing this autumn. The end of the process is in sight.

Nevertheless, there is still much work to be done. There have been several new developments over the life of this project. Some of these developments, like the digital technology and the MPEG–2 compression and transport systems, have been incorporated into the HDTV system while others have not.

In 1993, the development in Europe of the COFDM transmission system has led the Advisory Committee Technical Sub–group and the broadcasters to investigate the potential value of COFDM for the American HDTV service. Unfortunately, COFDM hardware for the 6–MHz channel environment is not yet available for test and cannot be available for 16 to 18 months. Moreover, the costs of system construction, laboratory testing and field testing will be very significant and, at the present time, such funds are not available.

These facts notwithstanding, the study is going forward, and a prototype COFDM system may be budgeted and built for testing as an alternative transmission scheme to the 8–VSB system.

In any case, when the FCC decision is made, the growth of digital television and HDTV in the consumer market will depend not only on the availability and cost of HDTV receivers, and on the quantity of HDTV programmes, but, most of all, on the rate of conversion of the local television stations to the digital domain.

The digital era is here, and broadcasters must emigrate from analogue NTSC to digital transmission or become an analogue island in an all–digital sea.

America's "Information Super Highway" will have no analogue lanes. All the services on this highway, and on similar "information highways" around the world, will be digital services.

In America, cable, fibre, and DBS operators have no technical or regulatory impediments to pursuing all–digital HDTV and multi–channel digital programme services. They can move into the digital domain whenever the market for these services unfolds.

On the contrary, terrestrial broadcasters *cannot* move from their soon–to–be–obsolete analogue NTSC service to a competitive all–digital service without a second simulcast "transition" channel!

That second channel is the digital HDTV channel. With this second channel, and *only with* this second channel, the terrestrial broadcaster will be able to move to, and compete in, this new all–digital television market.

In short, the second digital HDTV channel is the key to terrestrial broadcasting's survival!

If broadcasters do not embrace this opportunity to improve their television service via digital technology and HDTV, they could find themselves permanently relegated to a less–than–competitive position vis–a–vis DBS, cable, fibre, and home video services.

Unthinkable as it seems today, the present 525 and 625–line analogue television services around the world will give way to the new digital era and to HDTV. DBS, cable, and home video and international competition will see to that.

Digital technology will permit terrestrial broadcasters to operate on the "information highways", to introduce interactive services, and to transmit data to the home as well as to "closed user groups".

The digital receiver will be an intelligent terminal with a large data storage capacity which can be used to download large amounts of programme–related and non–programme–related interactive information. Additionally, those receivers connected to wired circuits on the "information highway" will have a two–way capability; together, these facilities will allow broadcasters to compete in the interactive marketplace with other information providers.

If American broadcasters do not seize the hour and embrace this opportunity to move into digital television and HDTV, they could lose the second channel and their only gateway into the digital world.

In a similar situation, General Sarnoff, then the President of the RCA, in closing his briefing to the NBC affiliates on the emergence of television at their annual convention in Atlantic City on 13 September, 1947, said:

Therefore, may I leave you with this final thought: I am not here to urge you to enter the field of television beyond the point where you yourselves think it is good business for you to do so or to propose that you plunge all at one time. Rather, I would suggest that you reflect carefully and thoughtfully upon the possible ultimate effects of television upon your established radio business if you do nothing, and of the great opportunities for your present and future business if you do the right thing!