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December 18, 1995

Dear Advisory Committee Member:

Enclosed for your records is the Advisory Committee's Final Report and Recommendation as approved and submitted to the Federal Communications Commission. Let me take this opportunity to thank you for your service to the Committee and, ultimately, to the American public. All of you have reason to be proud of your work and outstanding achievement. It is my sincere hope that we have an opportunity to work together again in the future.

Best regards.

Sincerely yours,

Paul E. Misener

PEM:Lfh
Attach.

f: ATV Committee
(Advanced
Television)

Technology - HDTV

ADVISORY COMMITTEE
FINAL REPORT AND RECOMMENDATION

FEDERAL COMMUNICATIONS COMMISSION

ADVISORY COMMITTEE ON ADVANCED TELEVISION SERVICE

November 28, 1995

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I. INTRODUCTION

This is the final report and recommendation of the FCC's Advisory Committee on Advanced Television Service. It was adopted by the Advisory Committee at its ninth and final meeting, held in Washington, DC, on November 28, 1995.

This year is the 100th anniversary of radio broadcasting. Television is only half as old; it was introduced in 1941 when the FCC adopted the current NTSC standard.[1] Subsequently, TV was improved in 1953 when the Commission approved the NTSC color standard. Only a few minor improvements (most notably, the addition of stereo audio in 1986) have been made in the ensuing four decades. This report heralds the greatest advance in broadcast television technology since its inception over fifty years ago. The possibilities for the future include dazzling pictures, CD-quality sound, the flexibility for multiple programs and data streams, and interoperability with alternative media and systems including computers.

In 1987, the FCC and Advisory Committee began to study the potentially great technical improvements that might be possible with advanced television ("ATV").[2] At the time, new transmission systems were being developed for direct broadcasting satellite and other media. It was not certain, however, whether a complete ATV system could work in 6 MHz over-the-air

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[1] The NTSC standard, which is named after the National Television Systems Committee which developed and modified it, is embodied in Part 73 of the Commission's Rules, *See* 47 C.F.R. § 73.682 (1994).

[2] The FCC defines ATV to "include any system that results in improved television audio and video quality . . .." *Tentative Decision and Further Notice of Inquiry* in MM Docket No. 87-268, 3 F.C.C. Rcd 6520, 6521 note 1 (1988). High definition television ("HDTV"), a subset of ATV, generally refers to systems that provide quality approaching that of 35 mm film. *Id.* HDTV "has a resolution of approximately twice that of conventional television in both the horizontal (H) and vertical (V) dimensions and a picture aspect ratio (HxV) of 16:9." ATSC Digital Television Standard at 5.

channels. Now, eight years later, after countless public meetings involving hundreds of industry volunteers and a rigorous program of testing and analysis conducted on seven prototype ATV systems at three futuristic laboratories, the Advisory Committee on Advanced Television Service herein recommends that the Federal Communications Commission adopt the "ATSC Digital Television Standard" as the U.S. standard for ATV broadcasting.

This standard represents truly world-leading technology. It will allow American television broadcasters and viewers to participate in the digital age and is equally available for cable TV providers and subscribers. In addition, more than any other ATV system in the world, the technology is interoperable with other imaging media and systems.

The present document has two principal sections. First, the Advisory Committee reports on its history, progress and results, including the final tests on a prototype advanced television system from a consortium of companies known as the Digital HDTV Grand Alliance. Second, the Committee sets forth the details of its recommendation.

II. REPORT OF THE ADVISORY COMMITTEE

A. Purpose of the Committee

In early 1987, the Federal Communications Commission ("FCC" or "Commission") initiated a rule making proceeding on advanced television ("ATV") service "to consider the technical and public policy issues surrounding the use of advanced television technologies by television broadcast licensees."[3] Later that year, and in order to assist the FCC "in gathering and

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3 *Notice of Inquiry* in MM Docket No. 87-268, 2 F.C.C. Rcd 5125, 5126 (1987).

processing much of the necessary information" on ATV,[4] the Commission established the Advisory Committee on Advanced Television Service ("Advisory Committee" or "ACATS").[5]

In its Charter, the Advisory Committee was given the broad mandate to "advise the Federal Communications Commission on the facts and circumstances regarding advanced television systems for Commission consideration of the technical and public policy issue[s]."[6] The Committee's Charter also directed that

> In the event that the Commission decides that adoption of some form of advanced broadcast television is in the public interest the Committee would also recommend policies, standards and regulations that would facilitate the orderly and timely introduction of advanced television services in the United States.[7]

The Advisory Committee's work became more specifically directed on advising the FCC on a technical standard for ATV broadcasting when, in late 1990, it entered a Memorandum of Understanding ("MOU") with the Commission and two ATV test laboratories.[8] This narrowed focus was articulated by the Committee a few months later: "Ultimately, it is the Advisory

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4 *Id.*

5 *Formation of Advisory Committee on Advanced Television Service and Announcement of First Meeting*, 52 Fed. Reg. 38523 (October 16, 1987). ACATS was formally established under the provisions of the Federal Advisory Committee Act ("FACA"), *codified at* 5 U.S.C. App. II (1988). The Committee has operated in accordance with the provisions of the FACA and GSA's Federal Property Management Regulations. 41 C.F.R. § 101-6.10 (1994).

6 *Id.* at p. 38523. The Advisory Committee Charter is attached at Appendix A.

7 *Id.*

8 A copy of the MOU is attached at Appendix B. In accordance with the Charter, the Committee on occasion also has received direction from the Chairman of the FCC.

Committee's goal to agree on an ATV technical description that can be recommended to the FCC for consideration as the next generation television transmission standard."[9]

B. Committee Structure and Participants

The FCC appointed the twenty five members of the Advisory Committee and selected Richard E. Wiley to be its Chairman. Described in the Charter as the "Parent Committee," the membership of this private-sector body was selected to achieve balanced representation from among the broadcasting, cable, consumer electronics, satellite broadcasting, program production, film, and telephone industries. At the time, these were the major industries thought to be involved in advanced television. Due largely to the state of technology in 1987, the FCC did not then perceive the computer industry as being significantly affected by ATV broadcasting. However, subsequent technological advances, particularly the introduction of digital transmission technology that enhances interoperability with computers and other media and systems, generated significant interest within that industry. Thereafter, computer company officials participated actively and effectively in ACATS activities. Additionally, the Chairman of the FCC recently appointed two industry members to the Parent Committee to replace other members who had resigned.[10]

This Parent Committee has met roughly once per year since its inception and, as enumerated below, has presented several interim reports to the Commission. The work of the

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9 Fourth Interim Report of the Advisory Committee on Advanced Television Service ("ACATS Fourth Interim Report") at pp. 18-19 (April 1, 1991). Obviously, the Commission, not the Advisory Committee has the authority to establish a broadcasting standard. *See* 47 U.S.C. § 303 (e), (f) (1988).

10 A current membership list of the Parent Committee is attached at Appendix C.

Advisory Committee, however, was achieved primarily by volunteers organized in various groups under the Parent Committee. Part of this staff organization was described in the Charter, which listed the Planning, Systems, and Implementation Subcommittees. The Advisory Committee also formed a "Special Panel" in early 1992,[11] and a "Technical Subgroup" later that year.[12] Both of these bodies were comprised of leading technical experts and were structured with constituent subgroups.[13] As with all Advisory Committee bodies, the leadership of these groups was selected to balance the interests of the various affected industries.

By some estimates, over 1000 individuals have participated in the Advisory Committee's work during its eight year history. Participants have come from the broadcasting, cable, consumer electronics, computer, program production, film, telephone, and other industries -- many of them recognized experts in their fields. Representatives of labor, academia, and public interest groups also have taken part. Moreover, because all Committee meetings have been open to the public, interested citizens and the press also have attended meetings of the Parent Committee and its many subgroups.

To the great benefit of the Advisory Committee, members of the FCC's staff often have observed and participated in Committee meetings. The Commission's guidance, expressed formally in rule making proceedings and informally in myriad interactions with Advisory Committee officials, has been invaluable to our work. However, the Committee has received no

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11 Minutes, Advisory Committee Meeting p. 3 (March 24, 1992).

12 Letter, Richard E. Wiley to ATV System Proponents (August 21, 1992).

13 A list of the Advisory Committee staff structure is attached at Appendix D.

funding from the Commission or other government bodies. Its operating costs (*e.g.*, postage, photocopying, and telephone) have been underwritten solely by small donations from Committee members.[14]

C. Relationship with Other Bodies

Several organizations not directly part of the Advisory Committee were critical to its mission and success. Key among these were the three laboratories that tested ATV hardware from several system proponents including the Digital HDTV Grand Alliance. The largest of the three was the Advanced Television Test Center ("ATTC"), a private, non-profit organization established in 1988 and developed by American broadcasting and electronic industry entities. Using over $15 million in contributions from its sponsors, and $7.5 million in fees from system proponents, the ATTC -- under the expert leadership of its President, Peter Fannon -- constructed a state of the art radio frequency testing facility in Alexandria, Virginia, and conducted the broadcasting laboratory-based tests for the Advisory Committee. Collocated with the ATTC was the ATV facility of the Cable Laboratories, Inc. ("CableLabs"), a research and development consortium of American cable television system operators. CableLabs carried out the cable portions of the Committee's lab and field testing programs. Finally, the Advanced Television Evaluation Laboratory ("ATEL"), an Ottawa-based facility of Canada's Department of

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[14] *See* Letter, Richard E. Wiley to Advisory Committee Members (May 4, 1993). Early in the Advisory Committee's history, nineteen members contributed $5,000 each, for a sum of $95,000 and, in the summer of 1993, thirteen members contributed $3,000 each, for a grand total of $134,000. Parent Committee members from small organizations or providing special services were not asked to contribute to this operating fund. A small balance remains.

Communications managed by the Canadian Communications Research Centre, conducted subjective tests using non-expert viewers from both Canada and the United States.[15]

Another organization which made highly valuable contributions to the Advisory Committee's report was the Advanced Television Systems Committee ("ATSC"), a standards organization formed in 1983 by the Joint Committee on Intersociety Cooperation ("JCIC").[16] With the approval of the FCC, the ATSC has done vital work in documenting the ATV broadcasting standard recommended herein.[17] The ATSC is ably chaired by James C. McKinney, a member of the Advisory Committee.

D. Advisory Committee Accomplishments

Over its eight year history, and in the course of making numerous decisions, the Advisory Committee produced thousands of public documents, among which are five Interim Reports to the FCC, and ATV System Recommendation dated February 24, 1993, and a report to Congress in 1989.

Given its primary mandate to advise the FCC on a standard for ATV broadcasting, one of the most critical early determinations was that the Committee would evaluate and recommend a

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15 In addition, the Association for Maximum Service Television ("MSTV") and the Public Broadcasting Service ("PBS") played key roles in the Advisory Committee's field testing process in Charlotte, North Carolina.

16 The JCIC itself was formed by the Electronic Industries Association, the Institute of Electrical and Electronics Engineers, the National Association of Broadcasters, the National Cable Television Association, and the Society of Motion Picture and Television Engineers.

17 *Memorandum Opinion and Order / Third Further Notice of Proposed Rule Making* in MM 87-268, 7 F.C.C. Rcd 6924, 6982-6983 (1992).

system to the Commission only if it had been tested in hardware form.[18] Thereafter, work was focused on preparing for, conducting, and analyzing ATV hardware tests.

Initially, some 23 different concepts for an ATV broadcasting system were submitted to the Committee. All of them employed analog video transmission techniques. Some proposals were for enhanced definition television ("EDTV") systems, which would augment, either within the existing channel or with additional spectrum, the quality of NTSC broadcasts. Other entities proposed so-called "simulcast" HDTV systems, which would operate on different channels and in a manner unrelated to NTSC broadcasts. Through proponent mergers and attrition, the 23 proposals soon were reduced to a handful.

In 1990, the FCC made a key decision to "select a 'simulcast' high definition television (HDTV) system -- that is, a system that employs design principles independent of the existing NTSC technology for ATV service."[19] That same year, one of the remaining system proponents, General Instrument Corporation, submitted a new proposal incorporating all-digital transmission. Three of the other four remaining HDTV systems thereafter adopted this technological advance; only NHK retained its original analog transmission design. Although the introduction of digital eventually resulted in at least two years' delay in the Advisory Committee schedule, the advance was well worth the wait. Indeed, after much more time and money spent with analog ATV proposals, both Japan and Europe now are pursuing digital solutions.

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18 *See Operating Procedures* of the Committee's Systems Subcommittee (approved April 29, 1988): "[o]nly candidate ATV systems which have been reduced to hardware will be evaluated and tested by [Systems Subcommittee] Working Party 2."

19 *Report and Order* in MM Docket No. 87-268, 5 F.C.C. Rcd 5627 (adopted August 24, 1990).

From mid-1991 through the end of 1992, the one remaining EDTV system and all five HDTV systems were subjected to an exacting program of laboratory tests at the ATTC, CableLabs, and ATEL.[20] As described above, these laboratories are designed to emulate the broadcast and cable transmission environments, as well as the home viewing environment. The test procedures were exhaustively developed by the Advisory Committee, with the objective of determining which of the competing systems should be recommended to the FCC as the basis for a new transmission standard. For a variety of reasons, not the least of which was the limited availability of test equipment and space, the systems were tested serially rather than in head-to-head comparisons, and video subjective testing was conducted by comparing pictures produced by each system to a single studio reference picture rather than to each other.

There were innumerable tasks and countless meetings involved in preparing for and conducting the test program. For example, detailed test plans, sometimes specific to the particular system under test, had to be developed. Then, after testing procedures for the analog systems had been developed, the Committee was required to redesign many of them with the advent of digital transmission systems. Moreover, new pieces of hardware had to be constructed solely for use in testing, and great care and precision was required to create video and audio test sequences in order to make certain that the systems were completely tested.

All of these efforts took time. On some occasions, implementation errors in the proposed ATV systems caused additional delays in testing. Further, considerable effort was invested in

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20 At the request of its proponents, the Advisory Committee did not report or consider the test results on the EDTV system. Letter, James E. Carnes to Richard E. Wiley (March 2, 1992); Letter Richard E. Wiley to James E. Carnes (March 5, 1992).

fashioning evaluation methods and criteria to allow the Advisory Committee to assess all of the test results. These criteria included video/audio quality, interoperability, spectrum issues, and cost issues.[21]

Chaired by Dr. Robert Hopkins, the Special Panel convened for four days in early 1993 to consider the test results. Under the rigorous technical criteria established by the Committee, the four digital HDTV systems proved superior to the analog proposal which, accordingly, was eliminated from further consideration. Although the Panel explicitly found that "digital HDTV is achievable for the United States,"[22] it also concluded that each of the digital entries had shortcomings that required further technical refinements. Indeed, in presentations at a November 1992 meeting of the Technical Subgroup formed for this purpose,[23] the remaining proponents had suggested a number of significant improvements to their respective systems.

In February 1993, and based on the Special Panel Report, the Advisory Committee offered the proponents two options: either undergo a second, expensive and time-consuming testing process or, alternatively, combine their efforts into a single "best of the best" (or so-called "grand alliance") system[24]. There were three key advantages to the latter option: first, because

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21 Letter, Richard E. Wiley to FCC Chairman Alfred C. Sikes (January 10, 1992). This letter forwarded to the Commission the Advisory Committee's proposed ATV System Recommendation Process.

22 ATV System Recommendation at p. 1-1 (February 24, 1993).

23 Letters, Richard E. Wiley to Advisory Committee Members and ATV System Proponents (August 21, 1992). The Technical Subgroup was co-chaired by Joseph A. Flaherty of CBS and Irwin Dorros, formerly of Bellcore.

24 Press Release, FCC Advisory Committee on Advanced Television Service (February 24, 1993). The Committee already was aware that such an alliance might be formed. *See* Letter, Richard E. Wiley to Advisory Committee Members (January 18, 1993).

the systems were becoming more alike as their proponents learned from each other's technical advances, the Advisory Committee's eventual task of selecting between them was becoming more problematic; second, the retesting process was certain to be expensive and time-consuming for all concerned; and third, and most importantly, a single system -- encompassing the best features of various proposals -- might lead to the development of a truly superior technology. This option of combining the systems had been discussed by the Committee two years earlier.[25]

After many months of arduous business and technical negotiations, the proponents chose the latter course. In late May, 1993, a consortium called the Digital HDTV Grand Alliance was formed with a number of major American and European entities: AT&T, the David Sarnoff Research Center, General Instrument, the Massachusetts Institute of Technology, North American Philips, Thomson Consumer Electronics, and Zenith Electronics.[26]

At the time, the Advisory Committee made clear to the Grand Alliance members that they should not present the Committee with an inflexible, technical *fait accompli*; the Committee's work had been, and must remain, a public process.[27] Accordingly, the Committee directed the Technical Subgroup to work with the Alliance, optimize its proposal, and generate agreement on specifications for a prototype system.[28] Thereafter, the Subgroup would supervise construction

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25 *See* ACATS Fourth Interim Report at p. 19 (April 1, 1991): "[I]n the unlikely event that each system proves to be inadequate, a new design could be composed of elements drawn from the different systems. If so, the Advisory Committee would encourage the establishment of voluntary agreements among proponents to synthesize their designs."

26 ACATS Press Release (May 24, 1993). Attached at Appendix E.

27 Letter, Richard E. Wiley to ATV System Proponents (May 11, 1993).

28 Letter, Richard E. Wiley to Advisory Committee Members (May 24, 1993).

and testing of the system and, if all went well, the Advisory Committee would recommend it to the Commission.

Six so-called "Expert Groups" were formed within the Technical Subgroup, each to focus on selected aspects of the Grand Alliance proposal. After detailed discussions between these Groups and the Alliance extending over many months, a modified and considerably enhanced system proposal was developed. In October 1993 and February 1994, the Advisory Committee approved for prototype construction all the elements of this proposal.[29]

The Grand Alliance system was tested at the ATTC, CableLabs, and ATEL facilities from March through August, 1995. The complete Alliance system also was evaluated in the field, by PBS, MSTV, and CableLabs, at the Advisory Committee broadcasting facilities in Charlotte, in July and August 1995.[30] Detailed test reports were prepared by each organization.[31] Based on these reports, the Technical Subgroup prepared the Committee's Final Technical Report.[32]

In early 1995, the Chairman of the FCC asked the Advisory Committee to investigate specific scanning formats for so-called standard definition television ("SDTV").[33] Several

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29 Press Releases, Advisory Committee on Advanced Television Service (October 21, 1993, and February 24, 1994).

30 Field tests on the Grand Alliance VSB modem alone already had shown it to perform "significantly better" than NTSC. Press Release, Advisory Committee on Advanced Television Service (September 19, 1994).

31 The test reports are attached at the Annex "Record of Test Results."

32 Attached at Appendix F.

33 This term is used to signify a digital television system in which the quality is approximately equivalent to that of NTSC. ATSC Digital Television Standard at 8.

months earlier, the Technical Subgroup had prepared a "White Paper,"[34] which described how the Grand Alliance system could carry multiple streams of data that, for example, could each be an SDTV program. The Technical Subgroup considered the merits of various proposed SDTV scanning formats and, on July 19, 1995, based on the recommendation of its Expert Group, adopted two such formats for inclusion in the ATV standard.[35]

E. Description of the Grand Alliance System

As indicated above, the Advisory Committee approved system specifications premised on the ATV proposal from the Digital HDTV Grand Alliance. From these specifications, which were also used by the Alliance to construct its prototype system, the ATSC Digital Television Standard was derived.[36] In essence, the ATSC standard describes five subsystems: scanning, video and audio compression, transport, and transmission.[37]

For scanning, the standard includes two HDTV formats: a 720 lines x 1280 pixels per line format at 24, 30, and 60 frames per second progressively scanned, and a 1080 lines x 1920 pixels per line format at 24 and 30 frames per second progressively scanned and 60 fields

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[34] Attached at Appendix G.

[35] *See* Report on SDTV Video Formats, Expert Group on Scanning Formats / Compression at p. 1 (July 19, 1995). Attached at Appendix H.

[36] ATV technological developments have occurred since the Grand Alliance prototype system was designed and constructed, and will continue to occur in the future. It would be appropriate to perform hardware demonstrations of such developments (including SDTV) that are documented in the ATSC standard.

[37] The Advisory Committee approved the Grand Alliance system specifications and herein recommends FCC adoption of the ATSC standard specifically taking into account a wide variety of issues, including the Nation's future technological needs and the embedded investments of American consumers and industries (investments that the Committee beliveves should not be unduly diminished).

per second interlaced scanned. Two SDTV formats also are described: 480 lines by 704 pixels per line in both 4:3 and 16:9 aspect ratios, and 480 lines by 640 pixels per line in 4:3 aspect ratio. Each SDTV format offers progressive scanning modes.

This balance of scanning formats -- designed to accommodate the interests of various industries operating within the Advisory Committee -- was reached only after considerable deliberation in the Advisory Committee's subgroups. Proponents of various formats argued vigorously for their respective positions but, ultimately, agreed on one point: that an over 1000-line 60 Hz progressive scanning format would be preferable. Unfortunately, this format is not possible with current state-of-the-art compression technology. The Committee foresees, however, that improvements in compression will allow the ATV standard to "migrate" to incorporate it in the coming years.[38] The Committee also believes that including the interlace scanned 1080-line, 60 Hz format will provide such a migration path.

For digital video compression, the Alliance system incorporates MPEG-2 parameters, including "B-frames." Audio compression employs 5.1-channel Dolby AC-3 techniques. The packetized data transport system incorporates features and services of MPEG-2 that are applicable to ATV and provided for in the MPEG-2 transport layer. Finally, the transmission subsystem is based on 8- and 16-VSB technology for broadcasting and cable, respectively.

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[38] The Information Technology Industry Council, an association of information technology product and service providers, has endorsed this rapid migration approach in order to "best achieve the maximum benefits to consumers." Letter, Rhett Dawson, ITI President, to Richard E. Wiley (October 31, 1995).

F. Interoperability with Alternative Media and Systems

Since its inception, the Advisory Committee has emphasized the need for U.S. ATV broadcasting technology to be interoperable with alternative media, particularly cable television systems. The Committee believes interoperability also takes on critical importance given the future needs for high resolution digital imagery in American homes and the development of a National Information Infrastructure ("NII"). Indeed, entertainment-based HDTV receivers will introduce digital video transmissions into many residences.

As noted above, interoperability was one of the selection criteria adopted by the Committee. Over four years ago, the working party tasked to study interoperability was asked to reexamine this issue following introduction of the digital HDTV systems. It developed recommendations that led to agreement on so-called "headers and descriptors." This method of data identification, combined with advanced data packetization techniques, acts as a kind of translator to tell all digital devices what type of data is being transmitted.

The working party and an "interoperability review panel" also adopted a list of eleven characteristics critical to interoperability.[39] The Advisory Committee believes the Grand Alliance system adequately addresses all of these factors. For example, compliance with the MPEG-2 standard was emphasized by the Technical Subgroup and adopted by the Grand

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[39] The list of characteristics is attached at Appendix I. These "were based on the needs and desires exhibited by alternative media advocates, not only for the delivery of terrestrial broadcast programming, but also for other delivery approaches and applications relating to computing, communications, motion pictures, and imaging." ATV System Recommendation at pp. 4-4, 4-5 (February 24, 1993).

Alliance to increase international compatibility and, more importantly, interoperability among a variety of digital devices.

A critical aspect of the scanning format scheme, unanimously recommended by the Technical Subgroup, is the availability of progressive scanning and square pixels. These attributes are preferable for some -- particularly computer -- applications. However, interlaced scanning also is important: it is a video data compression technique in which although only half the amount of data is transmitted, the bulk of the video picture remains. In particular, the test results on the Grand Alliance system demonstrate that there are advantages to both higher line number interlaced, and lower line number progressive scanning formats, and that there is no evidence in the Advisory Committee's record that would justify dropping either format at this time.

In all, the Advisory Committee believes that the Grand Alliance plan strikes the best balance between various technical considerations and needs of different industries. It is a balance that has been endorsed by, among others, a subgroup of the Federal Government's Information Infrastructure Task Force, the 1994 NIST/ARPA Workshop on Advanced Digital Video, and the Information Technology Industry Council. In this regard, it is noteworthy that all other ATV broadcasting systems being developed in the world do not include *any* progressive scanning format. The U.S. approach wisely incorporates the best of *both* scanning techniques.

G. Other Technologies

As required by the 1990 MOU with the FCC and test laboratories, the Advisory Committee has reviewed

> new technical advancements in the state of the art, not already provided by the ATV systems pre-certified by the Advisory Committee, that appear to offer important benefits to the public and are sufficiently concrete so as to be tested contemporaneously with the pre-certified systems.[40]

In early 1992, the Advisory Committee found, based on a review of current technology, that there were no new concepts "sufficiently concrete so as to be tested contemporaneously with the pre-certified systems," and that the five HDTV proponent systems then under consideration represented the state of available technology.[41] Later that year, another meeting concluded that a few recently-proposed systems were not sufficiently developed to be considered further by the Advisory Committee. This assessment that was ratified by the Special Panel.[42]

In 1994-95, at the request of an industry consortium eventually known as the COFDM-Limited Liability Corporation ("COFDM-LLC"), the Committee reviewed a proposal for an ATV modem that would operate using coded orthogonal frequency division multiplexing ("COFDM") techniques.[43] The Technical Subgroup established a Certification Experts Group, and tasked it to review the COFDM-LLC proposal which, if it were shown to be "demonstrably superior" to the VSB-based modem already approved as part of the Grand Alliance system, would be recommended for further evaluation and testing by the Advisory Committee. The Experts Group found, however, "based on the claimed benefits of COFDM techniques and,

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40 MOU at p. 3. *See* Appendix B.

41 Fifth Interim Report of the Advisory Committee on Advanced Television Service (March 24, 1992).

42 Special Panel Document No. SP-019 (February 8, 1993).

43 Letters, Richard E. Wiley to Advisory Committee Members (February 18, 1994), and to Michael J. Sherlock (April 21, 1994, and September 15, 1994).

specifically, of the COFDM modem proposed by the COFDM-LLC, as well as the shortcomings discussed [in the report]", that "[t]he modem presented by the COFDM-LLC is not ready for test at this time," and "[t]he COFDM-LLC did not demonstrate the superiority of COFDM over VSB for the majority of markets."[44]

H. Final Technical Report

As noted above, the Advisory Committee's Technical Subgroup adopted a Final Technical Report for the Advisory Committee on October 31, 1995.[45] Based on Advisory Committee-approved specifications and thorough laboratory and field testing of the prototype ATV system as designed and constructed by the Digital HDTV Grand Alliance, the Technical Subgroup found that: (1) the Grand Alliance system meets the Committee's performance objectives and is better than any of the four original digital ATV systems; (2) the Grand Alliance system is superior to any known alternative system; and (3) the ATSC Digital Television Standard,[46] based on the Advisory Committee design specifications and Grand Alliance system, fulfills the requirements for the U.S. ATV broadcasting standard. Thus, the Subgroup recommended that the ATSC standard be adopted as the U.S. ATV broadcasting standard.

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44 Report of the Certification Experts Group at p. 4 (August 8, 1995). Attached at Appendix J. COFDM technology continues to be developed for use in Europe and Asia.

45 Attached at Appendix F.

46 Attached at Appendix K.

III. RECOMMENDATIONS OF THE ADVISORY COMMITTEE

The Advisory Committee hereby adopts the findings of the Technical Subgroup. Specifically, the Grand Alliance system meets the Committee's performance objectives and is better than any of the four original digital ATV systems; the Grand Alliance system is superior to any known alternative system; and the ATSC Digital Television Standard, based on the Advisory Committee design specifications and Grand Alliance system, fulfills the requirements for the U.S. ATV broadcasting standard.

Accordingly, *the Advisory Committee on Advanced Television Service recommends that the Federal Communications Commission adopt the ATSC Digital Television Standard as the U.S. standard for ATV broadcasting.*

Although this standard, in accordance with the limited mandate of the Advisory Committee, is recommended for terrestrial ATV broadcasting, the Committee believes that it is suitably interoperable with other video delivery media and imaging systems, including cable television, direct broadcast satellite, and computer systems. The extent to which various features and applications of the standard are allowed or required to be applied to alternative media must be left to the discretion of the FCC as part of its deliberations in the ongoing rulemaking proceeding.

In addition, other ATV regulatory issues, including some previously addressed by the Advisory Committee (*e.g.*, broadcasting allotment and assignment planning), are also being addressed directly by the FCC. For example, the Committee worked at length on broadcasting allotment and assignment planning issues but, more recently, the FCC requested that the

Committee discontinue its efforts in deference to the rule making proceeding. Additionally, the Technical Subgroup has recommended that the Commission require that receivers (and set-top boxes designed to receive ATV broadcasts for display on NTSC sets) be able to receive adequately all ATV formats. This issue now is being addressed in the FCC's rule making.[47]

IV. CONCLUDING REMARKS

The Advisory Committee is indebted to the hundreds of companies, entities, and individuals which have been involved in this entire project. Their cooperative and productive efforts have made a great contribution to the advancement of the video medium in this country and the rest of the world. The Committee also is grateful for the continuous oversight, guidance and support provided by the FCC, particularly the four Chairmen with which the Committee has been honored to work, and the staffs of the Mass Media Bureau, Office of Engineering and Technology, and Office of Plans and Policy.

Respectfully submitted,

FCC ADVISORY COMMITTEE ON
ADVANCED TELEVISION SERVICE

By: Richard E. Wiley
Richard E. Wiley, Chairman

November 28, 1995

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[47] *Fourth Further Notice of Proposed Rule Making and Third Notice of Inquiry* in MM Docket No. 87-268, FCC 95-315, 60 Fed. Reg. 42,130 (August 15, 1995).

Appendix A.

Charter of the
Advisory Committee on Advanced Television Service

FEDERAL COMMUNICATIOINS COMMISSION

Formation of Advisory Committee on Advanced Television Service and Announcement of First Meeting

The Federal Communications Commission has established an advisory committee to assist the Commission in considering the issues surrounding the introduction of advanced television service in the United States. The committee is expected to advise the Commission on the facts and circumstances regarding advanced television systems and to recommend policies, standards, and regulations that could accommodate the orderly and timely introduction of advanced television service. The charter for the committee is attached.

The first meeting of the Advisory Committee on Advanced Television Service will be held on November 17, 1987, in the Commision Meeting Room, Room 856, 1919 M Street, N.W., Washington, D.C. The meeting will start at 2:00 P.M. All interested parties are invited to attend.

The agenda for the first meeting will consist of:

1. FCC Chairman's Remarks;
2. Administrative Matters:
3. Committee Charter;
4. Committee Work Plan—
   Proposed Schedule
   Discussion and Approval;
5. Designation of Subsequent Meetings;
6. Concluding Remarks.

Any questions regarding this meeting should be directed to Mr. William Hassinger at (202) 632-6460 or Mr. Victor Tawil at (202) 653-8162.

Charter for Advisory Committee on Advanced Television Service

A. The Committee's Official Designation

Advisory Committee on Advanced Television Service

The Advisory Committee will have no more than twenty-five members and will function as a Parent Committee. These members will be chosen by the Commission so as to obtain diverse and representative viewpoints. The Advisory committee Chairman will direct the activities of the Committee and Subcommittees and will receive guidance, advice and instructions from the Chairman of the Federal Communications Commission.

B. Name of Subcommittee(s)

Three Subcommittees: Planning Subcommittee, Systems Subcommittee, Implementation Subcommittee.

Membership of Subcommittees will be open to all interested parties.

C. Committee's Objectives and Scope of its Activity

Parent Committee

Objective: The Committee will advise the Federal communications Commission on the facts and circumstances regarding advanced televsion systems for Commission consideration of the technical and public policy issue. In the event that the Commission decides that adoption of some form of advanced broadcast television is in the public interest, the Committee would also recommend policies, standards and regulations that would facilitate the orderly and timely introduction of advanced television services in the United States.

Scope of activity: All steps necessary to assemble information, analyze information, deliberate upon appropriate policies and actions, and develop recommendations regarding the introduction of terrestrial advanced television service. Includes technical, economic, legal and regulatory issues.

Planning Subcommittee

Objective: To plan the attributes of advanced television service in the United States.

Scope of Activity: All steps necessary to provide advice on desired features of terrestrial advanced television service.

(a) Define the desirable characteristics of advanced television service: for example, in terms such as picture quality, population served, costs to broadcaster/consumer/manufacturers, relationship to existing broadcast service, relationship to non-broadcast services.

(b) Review the technical planning factors for the existing television service and recommend planning factors for advanced television service, including consideration of factors such as coverage area, quality of service, frequency reuse criteria, receiver quality, spectrum allocations.

Systems Subcommittee

Objective: To specify the transmission/reception facilities appropriate for providing advanced television service in the United States.

Scope of Activity: All steps necessary to provide advice on the parameters of systems to provide terrestrial advanced television service.

(a) Evaluate, on technical and economic bases, advanced television systems now under development for the purpose of determining feasibility for implementation in the United States.

(b) Recommend advanced television system(s) now under development as candidate(s) for implementation, or specify the design of an appropriate system.

(c) Advise on the appropriate transmission/reception technical standards and spectrum requirements for the recommended system(s).

Implementation Subcommittee

Objective: To establish a scheme for implementation of advanced television servi in the United States.

Scope of Activity: All steps necessary to provide advice on policies, regulations and standards for implementation of terrestrial advanced television service.

(a) Develop a transition scheme for implementation of advanced television service in the United States.

(b) Recommend appropriate FCC policies and regulations to oversee implementation of advanced television service and develop guidelines for industry activities.

D. Period of Time Necessary for the Committee To Carry out its Purposes

An initial written report containing recommendations of the Committee on fundamental parameters and spectrum requirements must be submitted by 6 months from the date of the first meeting.

E. Official to Whom the Committee Reports

The Chairman of the Federal Communication Commission.

F. Agency Responsible for Providing Necessary Support for the Committee

The Federal Communications Commission will furnish necessary administrative support, including facilities needed for conducting meetings of the Committee.

G. Description of Duties for Which the Committee is Responsible

The duties of the Committee and its Subcommittees will be to assemble information, to conduct deliberations and to prepare and submit recommendations appropriate to the attainment of the objectives listed under (C) above.

H. Estimated Annual Operating Costs in Dollars and Person Years

The estimated operating costs are $10,000 for the FCC. Estimated person-years are 3.0 for the FCC and 25.0 for non-government participants.

I. Estimated Number and Frequency of Committee Meetings

The Committee will meet three times per year or at such intervals as the Committee decides. Subcommittees are expected to meet on a monthly basis until completion of their tasks.

J. Committee's Termination Date

The Committee will terminate September 30, 1989.

Federal Communications Commission.

William J. Tricarico,

Secretary.

[FR Doc. 87-24147 Filed 10-15-87; 8:45am]

BILLING CODE 6712-01-M

Appendix B.

Memorandum of Understanding

MEMORANDUM OF UNDERSTANDING

The Federal Communications Commission ("FCC"), the Advisory Committee on Advanced Television Service ("Advisory Committee"), and the ATV testing laboratories [the Advanced Television Test Center, Inc. ("ATTC"), Cable Television Laboratories, Inc. ("CableLabs") and the Canadian Communications Research Centre ("CRC")[1]] are engaged in a collaborative effort to bring about the implementation of advanced television ("ATV") service for the American public.

Three years ago, the FCC in conjunction with industry, launched a comprehensive plan to establish advanced television service. The Commission's primary goal in the ATV proceeding is to ensure the development of a technically excellent ATV service that will most efficiently meet the needs of terrestrial broadcasters, receiver manufacturers, cable television operators and, most important, consumers. As the Advisory Committee enters the active testing phase of its program for evaluating ATV transmission systems, we observe that substantial progress has already been made toward making the selection of a standard for advanced television service. The efforts of the Advisory Committee, the testing

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1 In this particular effort, CRC is joined by the Canadian Broadcasting Corporation, the Canadian Department of Communications, Leitch Video International and Telesat Canada.

laboratories, and other industry parties have significantly advanced the Commission's ability to assess the merits of ATV technical designs. In addition, system designers have made advancements in developing new technical schemes for transmitting ATV service.

The Commission has stated that it intends to complete action on this project as promptly as possible. This objective is a considerable undertaking that poses a number of formidable challenges. The FCC's stated intention is to select an ATV standard by the second quarter of 1993. The successful, on-time accomplishment of all of the tasks of the ATV project will require hard work, dedication, and cooperation on the part of all of those involved. To this end, the undersigned parties agree to resolve any disagreements or contingencies that may arise in a prompt and cooperative manner.

In order to meet these challenges and accomplish our goals, the Commission, the Advisory Committee, and the testing laboratories will continue to work together to complete, in a timely manner, the major tasks undertaken by each. This memorandum of understanding describes the role and activities of each of these parties in this process.

FCC

The FCC, consistent with its policy-making and other responsibilities, will continue to review the Advisory Committee's testing plans and procedures, including the plans and procedures for field testing. The FCC will assist the Advisory Committee and testing laboratories in the testing process. This will include on-site observers and participants and participation on the "expert viewer panel." The FCC will contribute, as feasible, staff and mobile monitoring facilities for field testing. The FCC will also take all necessary steps, including the development of analytic tools, to prepare an allotment table and/or assignment plan for ATV channels. This will ensure that channels are available for ATV service in a timely manner.

<u>Advisory Committee</u>

The Advisory Committee will continue to refine the testing plans and procedures, including finalizing the data reporting formats and developing the plans and procedures for field testing. Through its oversight and direction, the Advisory Committee will continue to work with ATTC, CableLabs, and CRC to seek to carry out the established procedures within the established deadlines. The Advisory Committee will also continue to work with ATV system proponents to ensure the timely delivery of systems for testing. The Advisory Committee will continue to maintain close coordination with the Commission through regular contacts with key staff members and periodic meetings with the FCC Chairman.

The Advisory Committee will develop a plan for reviewing new technical advancements in the state of the art, not already provided by the ATV systems pre-certified by the Advisory Committee, that appear to offer important benefits to the public and are sufficiently concrete so as to be tested contemporaneously with the pre-certified systems. Accordingly, it will prepare a report and recommendation to the Commission by early 1992, on whether any of these new developments should be tested and the impact such additional testing would have on the test schedule.

Subject to the provisions of this memorandum of understanding, the Advisory Committee will complete all of its work and submit its final report to the Commission by September 30, 1992.

Testing Laboratories

ATTC and CableLabs will make all reasonable efforts to carry out their laboratory testing activities (which do not include field testing) consistent with the plans and procedures established by the Advisory Committee and will coordinate with the CRC to seek to ensure the continuity and integrity of the ATV testing program. ATTC and CableLabs, in cooperation with the Advisory Committee Chairman, will maintain regular c -tact with the Commission and its staff. Results of tests performed by ATTC and CableLabs will be provided to the Commission on a prompt and regular basis.

Consistent with the above, ATTC and CableLabs will seek to ensure that testing of proponents' systems certified for testing by the Advisory Committee begins in a timely manner and is completed so as to permit the Advisory Committee to deliver its final report to the FCC on time.

In summary, the essential intent of this agreement is to ensure that the research and work necessary for introducing ATV service to the American public is developed in a cooperative and efficient manner, and is not intended to create any obligations to non-signatories or to alter in any way the obligations between ATTC and CableLabs.

Alfred C. Sikes, Chairman
FCC

Richard E. Wiley, Chairman
FCC Advisory Committee

Joel Chaseman, Chairman
Advanced Television Test
Center, Inc.

Richard R. Green, President
Cable Television
Laboratories, Inc.

Date: November 14, 1990

Appendix C.

Parent Advisory Committee

Advisory Committee on Advanced Television Service

Chairman

Richard E. Wiley, Wiley, Rein & Fielding

Members

Frank Biondi, Viacom International, Inc.
Joel Chaseman, Chaseman Enterprises International
Joseph Collins, American T.V. & Comm. Corp.
William Connolly
Martin Davis, Wellspring Associates, Inc.
Irwin Dorros
James C. Dowdle, Tribune Broadcasting Co.
Ervin S. Duggan, PBS
Joseph Flaherty, CBS, Inc.
Samuel Fuller, Digital Equipment Corporation
Stanley S. Hubbard, Hubbard Broadcasting
James Kennedy, Cox Enterprises
James C. McKinney, Advanced Television Systems Committee
Craig Mundie, Microsoft Corporation
Thomas S. Murphy, Capital Cities/ABC Inc.
Rupert Murdoch, Fox, Inc.
Jerry K. Pearlman, Zenith Electronics Corporation
F. Jack Pluckhahn, Quasar
Ward Quaal, The Ward L. Quaal Company
Richard D. Roberts, TeleCable Corporation
Burton Staniar, The Knoll Group
James Tietjen, SRI International
Laurence Tisch, CBS, Inc.
Robert Wright, NBC

Ex officio (non-voting) Members

Peter Bingham, Philips Laboratories
Wendell Bailey, National Cable Television Association
Henry L. Baumann, National Association of Broadcasters
Joseph Donahue, Thomson Consumer Electronics, Inc.
Brenda L. Fox, Dow, Lohnes & Albertson
Richard Friedland, General Instrument Corporation
Robert Graves, R.K. Graves Associates
Larry Irving, U.S. Department of Commerce, NTIA
Keiichi Kubota, NHK Science & Technical Research Labs
Jae Lim, Massachusetts Institute of Technology
Vonya B. McCann, U.S. Department of State
George Vradenburg III, Latham & Watkins
Margita White, MSTV

Appendix D.

Advisory Committee Staff Structure

Advisory Committee Staff Structure

Parent Committee

Planning Subcommittee

PS/WP-1	Technology Attributes and Assessment
PS/WP-2	Testing and Evaluation Specifications
PS/WP-3	Spectrum Utilization and Alternatives
PS/WP-4	Alternative Media Technology and Broadcast Interface
PS/WP-5	Economic Factors and Market Penetration
PS/WP-6	Systems Subjective Assessment
PS/WP-7	Audience Research
PS/AG-1	Creative Issues
PS/AG-2	Consumer/Trade Issues

Systems Subcommittee

SS/WP-1	Systems Analysis
SS/WP-2	System Evaluation and Testing
SS/WP-3	Economic Assessment
SS/WP-4	System Standards

Implementation Subcommittee

IS/WP-1	Policy and Regulation
IS/WP-2	Transition Scenarios

Field Test Technical Oversight Committee

Special Panel

Technical Subgroup

- Experts Group on Scanning Formats / Compression
- Experts Group on Audio
- Experts Group on Transport
- Joint Experts Group on Interoperability
- Experts Group on Transmission
- Experts Group on Cost Factors

Experts Group on Certification

Appendix E.

ACATS Press Release (May 24, 1993)

Advisory Committee on Advanced Television Service

FOR IMMEDIATE RELEASE: May 24, 1993

HDTV "Grand Alliance" Proposal
<u>Will Be Considered by FCC Advisory Committee</u>

Washington, D.C. The Federal Communications Commission's Advisory Committee on Advanced Television Service (established by the Commission in 1987) will review a single digital high definition television (HDTV) system proposed today by a "Grand Alliance" of entities that, until now, had sponsored the four remaining competitive HDTV systems. These entities (AT&T, the David Sarnoff Research Center, General Instrument, Massachusetts Institute of Technology (MIT), North American Philips, Thomson Consumer Electronics, and Zenith Electronics) today reached a business and technical agreement and submitted to the Committee a merged system proposal.

The proposed system, if recommended by the Advisory Committee and adopted by the FCC, could place the U.S. in the forefront of high definition video technology. An all-digital standard, which would facilitate interoperability among broadcasting, cable, computer, and telecommunications technologies, has worldwide potential.

Advisory Committee Chairman Richard E. Wiley, who had encouraged the complex negotiations leading to the agreement, said "I believe the Grand Alliance proposal, subject to Advisory Committee and ultimate FCC approval, will help to conclude a process that has fostered the development of highly advanced digital HDTV technology. The members of the Alliance should be commended for their accomplishments." Wiley added that the benefits of the Grand Alliance include development of a digital system incorporating the best elements of the four systems and acceleration of HDTV service implementation. The FCC's Advisory Committee endorsed the Alliance concept at a meeting in February.

Important aspects of the Grand Alliance technical proposal submitted today include the employment of progressive scan transmission (where entire picture frames are transmitted sequentially) and the use of so-called "square pixels" (where the dots on a television screen are arranged in equally spaced rows and columns). Both of these design aspects are important for the interoperability of HDTV with computers, telecommunications, and other media and applications. Interlaced scan transmission (as deployed in today's TV systems) would also be accommodated in the initial deployment.[1]

Specifically, the proponents agree that all large-screen HDTV receivers (34 inches in diagonal and above) will incorporate a 60 frame per second 787.5 line or higher progressive scan display mode. Progressive display would be optional initially for smaller screen receivers. The proponents also concur that all transmission of film material will be in a progressive scan format beginning immediately upon the commencement of HDTV service. Finally, the Grand Alliance proponents unanimously endorse the objective of migrating the standard to a high line number (i.e. thousand-line plus) progressive scan transmission, as soon as feasible, and will work together to eliminate interlaced scanning format from the transmission path in the future.

To support multiple transmission formats, the merged system will feature source adaptive processing. Moreover, to promote system flexibility and extensibility, the merged system also will feature a prioritized, packetized data transport structure. Additionally, the

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[1] MIT believes that a digital video broadcast standard that exclusively utilizes progressive scan transmission, from the beginning, is in the best interests of the United States.

Grand Alliance entities agree to support the Alliance's proposed HDTV compression system in the International Standards Organization as the MPEG-2 HDTV profile.

Over the next few weeks, Advisory Committee participants will review the technical merits of the Grand Alliance proposal, which includes procedures for deciding on a few remaining component designs based on the results of specific tests. Various subgroups of the Advisory Committee will work with the Grand Alliance members as their merged system concept is finalized and, eventually, will oversee the testing of the completed system. Based on the results of those tests, the Committee may recommend the system to the FCC as the basis for a high definition television standard for our country. The FCC, of course, has the ultimate authority to adopt transmission standards.

Appendix F.

Final Technical Report

FINAL TECHNICAL REPORT

Federal Communications Commission
Advisory Committee on Advanced Television Service
October 31, 1995

FINAL TECHNICAL REPORT

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FINAL TECHNICAL REPORT

1. INTRODUCTION

This is the final technical report of the Advisory Committee on Advanced Television Service. It was prepared by the Advisory Committee's Technical Subgroup, and is presented as the primary appendix to the Advisory Committee's November 1995 final report to the Federal Communications Commission.

This final technical report is primarily a report and analysis of extensive tests conducted by the Advisory Committee on the ATV system proposed by the Digital HDTV Grand Alliance. It also contains comparisons of the Grand Alliance system with the four original digital systems previously tested by the Advisory Committee. Organized in accordance with the four principal subsystems of the Grand Alliance system, this report addresses scanning formats, compression (video and audio), transport, and transmission (spectrum utilization and transmission robustness). Finally, and based on the information in this report, the conclusions of the Technical Subgroup are presented for the Advisory Committee's consideration.

2. SCANNING FORMATS

Scanning formats supported by the ATV system are shown in Table 2.1. In the table, 60I means 60 Hz interlaced scanning, 60P means 60 Hz progressive scanning, 30P means 30 Hz progressive scanning, and 24P means 24 Hz progressive scanning. These rates can be the stated integer value, or 1000/1001 times the integer value (e.g., 59.94 Hz). The Digital HDTV Grand Alliance System prototype was designed before the 480-line formats were included in the ATV system specification, and supports only the high definition ATV formats, i.e., the 1080 x 1920 and 720 x 1280 formats.

Table 2.1 ATV system scanning formats.

Vertical Lines	Horizontal Pixels	Aspect Ratio		Picture Rate			
1080	1920	16:9		60I		30P	24P
720	1280	16:9			60P	30P	24P
480	704	16:9	4:3	60I	60P	30P	24P
480	640		4:3	60I	60P	30P	24P

2.1. RESOLUTION

During testing, measurements were made to determine how the resolution of the Digital HDTV Grand Alliance System compared with the target specifications. Had data been available from the four original digital systems, target specifications would have been derived as the "Best of the Best." Data from the previous systems were not given in the Advisory Committee's report "ATV System Recommendation," however, because of apparent irregularities in the data. Therefore, the Scanning Formats / Compression Expert Group, in order to establish target specifications for resolution, assumed that an interlaced scanning system should deliver limiting vertical resolution equal to 65 % of the number of active scanning lines, and that a progressive scan system should deliver 90 %. The Expert Group assumed that horizontal resolution would be limited to about 80 % of the number of active samples because of filtering, and that the diagonal resolution would be the vector sum of the horizontal and vertical resolution. Dynamic resolution was assumed to be about 80 % of the static resolution. In the case of an interlaced scanning system, for vertical resolution under motion, the picture will take on the characteristics of a progressively scanned system with half the number of scanning lines (i.e., vertical resolution of 1080I becomes 540P under motion). The chrominance resolution of the Grand Alliance System, because it is based on the MPEG-2 Main Profile, should be half the luminance resolution in both the horizontal and vertical directions. These assumptions give rise to the target specifications shown in Table 2.2. Note that all values are expressed as cycles per active picture height. It should be further noted that these target specifications were generated on the assumption that the video compression is transparent (i.e., the target specifications estimate the resolution of the input to the system and assume that there will be no measurable loss due to video compression).

Table 2.2 Target specifications for resolution.

	1080 x 1920			720 x 1280		
	Horizontal	Vertical	Diagonal	Horizontal	Vertical	Diagonal
Static Luma (c/aph)	430	350	550	290	325	435
Static Chroma (c/aph)	215	175	275	145	160	215
Dynamic Luma (c/aph)	345	195*	395*	230	260	345
Dynamic Chroma (c/aph)	170	95*	195*	115	130	170

* Because of error calculating dynamic vertical resolution with interlaced scanning, the following values have been replaced: 195 replaced 280, 395 replaced 440, 95 replaced 140, and 195 replaced 220.

Static resolution was measured using an electronic circular zone plate. Dynamic resolution was measured using an electronic radial resolution pattern that was held stationary and rotated at 0.5, 1.5, and 5.0 revolutions per minute.

Table 2.3 gives a summary of the measurements and the target specifications. Dynamic resolution is shown only at the maximum rotation rate, 5.0 rpm. In all cases, the lowest dynamic resolution was measured at this rotation rate. At lower rotation rates, the system met, or exceeded, most target specifications.

2.1.1. Static Luminance Resolution

For the 1080I format, static luminance resolution exceeded the target specification for both horizontal and vertical resolution, but missed the target for diagonal resolution by 2 %.

For the 720P format, static luminance resolution exceeded the target specification for horizontal resolution, but missed by 15 % for vertical resolution and 8 % for diagonal resolution.

2.1.2. Static Chrominance Resolution

For the 1080I format, static chrominance resolution exceeded the target specification for horizontal resolution, but missed the target by 20 % for vertical resolution and 5 % for diagonal resolution.

For the 720P format, static chrominance resolution exceeded the target for horizontal, vertical, and diagonal resolution.

Table 2.3 Resolution of the Digital HDTV Grand Alliance system.

1080 x 1920	Target Specification			Measured Value			Comments
	H	V	D	H	V	D	
Static Resolution, Luma (c/aph)	430	350	550	460	400	540	See Note 1
Static Resolution , Chroma (c/aph)	215	175	275	250	140	260	See Note 2
Dynamic Resolution, 5.0 rpm, Luma (c/aph)	345	195	395	500	200	540	
Dynamic Resolution, 5.0 rpm, Chroma (c/aph)	170	95	195	135	100	135	See Note 3

720 x 1280	Target Specification			Measured Value			Comments
	H	V	D	H	V	D	
Static Resolution, Luma (c/aph)	290	325	435	320	275	400	See Note 4
Static Resolution , Chroma (c/aph)	145	160	215	180	180	230	
Dynamic Resolution, 5.0 rpm, Luma (c/aph)	230	260	345	300	210	360	See Note 5
Dynamic Resolution, 5.0 rpm, Chroma (c/aph)	115	130	170	170	160	183	

Note 1: The difference between the target specification and the measured value for diagonal resolution is within the range of measurement error likely in the test procedure.

Note 2: To avoid smearing in horizontal motion, the Grand Alliance prototype employed field-based, rather than frame-based, vertical chroma decimation. Target specifications for vertical and diagonal do not account for this.

Note 3: To process material rotating at 5.0 rpm, coarse coefficient quantization is necessary, particularly in chroma. Performance of horizontal resolution is better than specification at lower rotational velocities.

Note 4: The target specification for vertical resolution assumes a limiting vertical resolution of 90 % of the number of scanning lines. This may be too optimistic an assumption. The specification for diagonal resolution is partially derived from the vertical resolution.

Note 5: The target specification for vertical resolution is derived from that for static luminance resolution, which may be too optimistic (see also Note 3).

2.1.3. Dynamic Luminance Resolution

For the 1080I format, the dynamic horizontal and diagonal luminance resolution, at all rotation speeds, exceeded the target and did not vary. The vertical resolution exceeded the target at all rotation speeds, although it did decrease at 5.0 rpm.

For the 720P format, the dynamic horizontal and diagonal resolutions, at all rotation speeds, exceeded the target and did not vary. The vertical resolution exceeded the target at 0.5 rpm, but missed by 8 % at 1.5 rpm and by 19 % at 5.0 rpm.

2.1.4. Dynamic Chrominance Resolution

For the 1080I format, the dynamic vertical chrominance resolution exceeded the target at all rotation speeds. The horizontal resolution exceeded the target at all rotation speeds except 5.0 rpm where it missed by 21 %. The diagonal resolution missed at all speeds by 18 % except for 5.0 rpm where it missed by 31 %.

For the 720 format, dynamic chrominance resolution exceeded the target at all rotation speeds.

2.2. FORMAT CONVERSION

Tests were run at ATEL to determine the quality loss when a 1080I signal is transmitted, but displayed on a 720P monitor rather than a 1080I monitor; and the quality loss when a 720P signal is transmitted, but displayed on a 1080I monitor rather than a 720P monitor. The sequences that were selected for assessment were ones in which the expert observers were able to see differences. Furthermore, on two of the motion sequences, a more critical portion of the sequence was used for assessment than was used in the Quality, Basic Material test.

In the case of transmitted 1080I signals, tests were run using two still pictures and four moving sequences. Of these six sequences, two are considered "basic material," two are considered "graphics," and two are considered "noise and cuts." A weighted average of the target specification for this combination of sequences, when not using format conversion, is -0.77 grade. The target specification with format conversion is -1.0 grade. The average measured value without format conversion (i.e., 1080I was transmitted and displayed as 1080I) was -0.54 grade. The average measured value with format conversion (i.e., 1080I was transmitted and scan converted in the receiver for display as 720P) was -0.58 grade. The average difference in quality was 0.04 grade (i.e., scan converting for the 720P display showed a loss of quality of 0.04 grade compared with the 1080I display).

In the case of transmitted 720P signals, tests were run using one still and six moving sequences. Of these seven sequences, four are considered "basic material," one is considered "graphics", and two are considered "noise and cuts." A weighted average of the target specification for this combination of sequences, when not using format conversion, is -0.6 grade. The target specification with format conversion is -1.0 grade. The average measured value without format conversion (i.e., 720P was transmitted and displayed as 720P) was -0.51 grade. The average measured value with format conversion (i.e., 720P was transmitted and scan converted in the receiver for display as 1080I) was -0.69 grade. The average difference in quality was 0.18 grade (i.e., scan converting for the 1080I display showed a loss of quality of 0.18 grade compared with the 720P display).

In both cases, the target specification of less than 1.0 grade was met. The target specification can be viewed in another way. For "basic material," the target specification allowed for video compression (without scan conversion) is 0.3 grade. The target specification for video compression plus scan conversion is 1.0 grade. This means that 0.7 grade is allowed for quality loss due to scan conversion. In the case of 720P transmission and scan conversion to 1080I, the average loss was 0.04 grade. In the case of 1080I transmission and scan conversion to 720P, the average loss was 0.18 grade. In both cases, again, the target specification was met. The difference seen by the non-expert viewers was very small, much less than had been anticipated. Table 2.4 gives a summary of the measurements and the target specification. The expert observers characterized the conversions as slightly poorer than when presented in the original format. They said the quality loss was manifested as a slight loss in resolution and a slight increase in noise.

Table 2.4 Scan conversion quality of the Digital HDTV Grand Alliance system.

	Target Specification	Measured Value	Comments
Quality, Receiver Conversion, 720-lines transmission, 1080-lines display	≤ 0.7 Grade below non-conversion	-0.18 Grade	
Quality, Receiver Conversion, 1080-lines transmission, 720-lines display	≤ 0.7 Grade below non-conversion	-0.04 Grade	

Note: Grade is the average over all sequences tested in each category, not the maximum

3. COMPRESSION

3.1. VIDEO

Video compression in the Digital HDTV Grand Alliance System is based on the MPEG-2 Main Profile. To determine the quality after video compression, twenty-six different sequences were used to test the system. Table 3.1 is a summary of the results. All test categories were well within the target specification. Recognizing that the target specifications were based on the "Best of the Best" of the four original digital systems, the Grand Alliance System is clearly the superior system in both the 1080I mode and the 720P mode.

Table 3.1 Quality of the Digital HDTV Grand Alliance system measured by non-expert viewers.

	Target Specification	Measured Value		Comments
		1080 x 1920	720 x 1280	
Quality, Basic Material	≤ 0.3 Grade below reference	-0.12 Grade	-0.11 Grade	
Quality, Noise & Cuts	≤ 1.0 Grade below reference	-0.40 Grade	-0.50 Grade	
Quality, Graphics & NII	≤ 1.0 Grade below reference	-0.06 Grade	-0.04 Grade	
Quality, 24 fps Film	≤ 0.25 Grade below reference	-0.04 Grade	-0.01 Grade	

Note: Grade is the average over all sequences tested in each category, not the maximum

In the first round of testing, the DigiCipher system, across all sequences, was found to be 0.3 grade lower in quality than the reference (0.3 for stills and 0.3 for motion sequences), DSC-HDTV was 0.9 grade lower in quality than the reference (0.5 for stills and 1.2 for motion sequences), AD-HDTV was 0.3 grade lower in quality than the reference (0.3 for stills and 0.3 for motion sequences), and CCDC was 1.0 grade lower in quality than the reference (0.5 for stills and 1.3 for motion sequences).

In the second round of testing, the Grand Alliance System, across all sequences, was 0.15 grade lower in quality than the reference in both the 1080I mode (0.0 for stills and 0.2 for motion sequences) and the 720P mode (0.1 for stills and 0.2 for motion sequences). It should be noted that in the second round of testing, 10 image sequences were retained from the first round and 16 new sequences were selected, many of which are more critical than those in the first round. The

Grand Alliance System performed better than the systems from the first round, despite the inclusion of the more critical sequences.

In detail, in the 1080I mode, nineteen of the twenty-six sequences were statistically indistinguishable from the reference. For the seven sequences that were statistically significant, the average quality loss was 0.4 grade. One sequence, M49 (Picnic with Ants), which consists of a central still image with noise encroaching from the sides, is known to be particularly stressful for image compression algorithms. For that sequence, the quality loss was 0.75 grade. In the 720P mode, twenty-one of the twenty-six sequences were statistically indistinguishable from the reference. For the five sequences that were statistically significant, the average quality loss was 0.5 grade. Sequence M49 showed a quality loss of 1.3 grades.

Figure 3.1 shows the quality scores for the four original digital systems, and for the Grand Alliance System in the 720P mode and in the 1080I mode. Only the sequences that were common in the two rounds of testing are included in the figure. A list of all sequences, with a brief statement giving the attributes of each sequence, can be found in the subjective assessment portion of the laboratory test report.

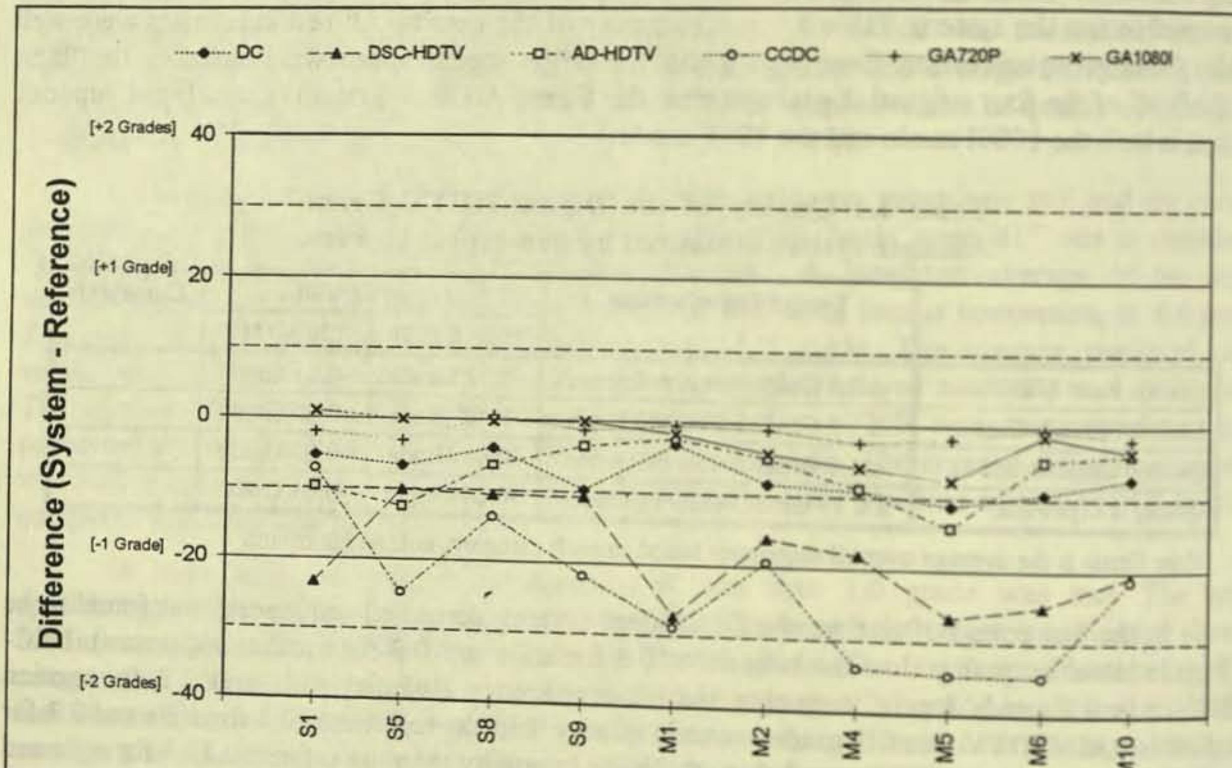


Figure 3.1 Quality of the Digital HDTV Grand Alliance system and the four original digital systems compared with the 1125-line studio quality reference.

Figure 3.2 shows the quality scores for the Grand Alliance System on all sequences used in the second round of testing. The figure shows that both modes performed close to reference, and that the relative performance of the two modes varied from test sequence to test sequence.

The 1080I mode shows improvement over the interlaced scanning systems in the first round of testing; the 720P mode shows substantial improvement. The improvement in the 720P mode has been attributed to two factors: 1) good performance of the Grand Alliance System in the 720P mode, and 2) the use of less noisy source material for the six core camera originated motion sequences.

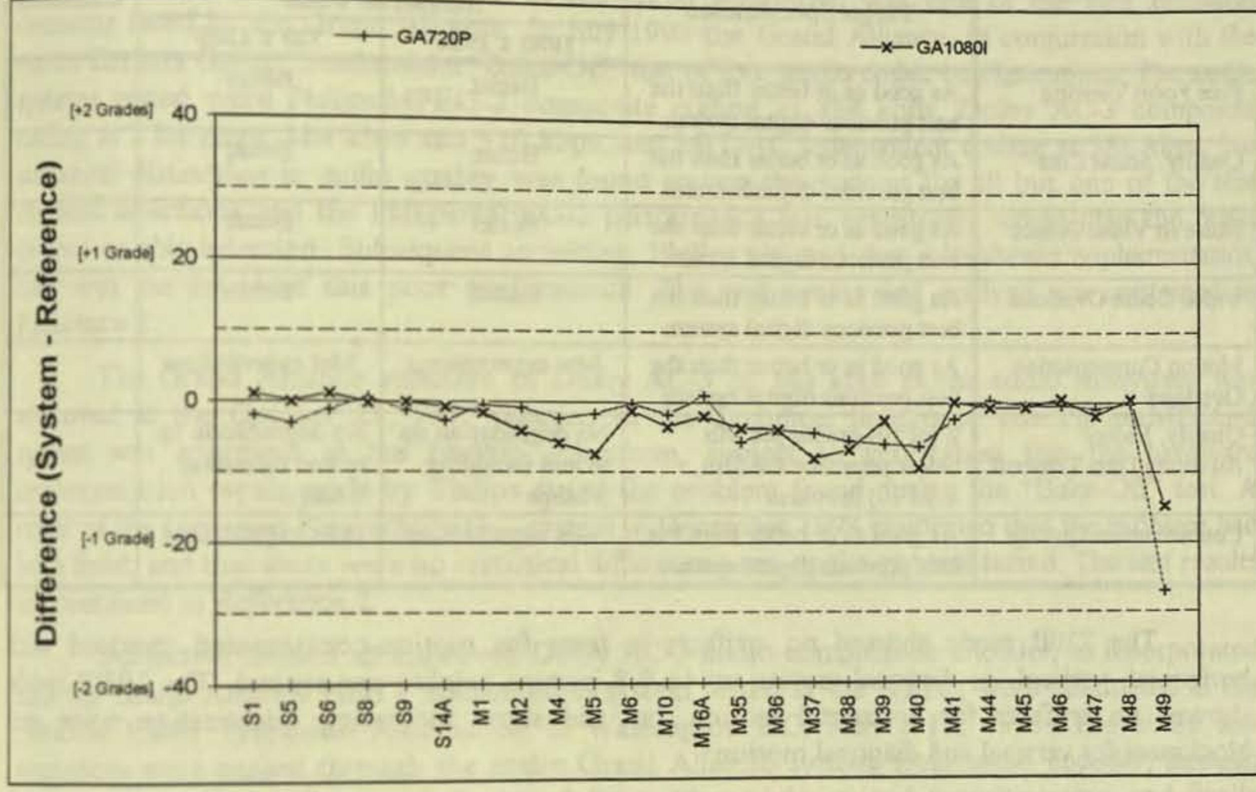


Figure 3.2 Quality of the Digital HDTV Grand Alliance system across all sequences compared with the 1125-line studio quality reference.

A number of tests were conducted by the expert observers. A summary is shown with the target specifications in Table 3.2. The expert observers found that the video quality of the Digital HDTV Grand Alliance System was clearly superior to that of any of the previous proponent systems, and they said that applies to all types of video tested — still images, motion sequences, computer graphics, and film. They did observe some compression artifacts, but only on the most difficult images. The level of compression artifacts, they said, was significantly lower than for any previous system. The expert observers, like the non-expert viewers, found the quality of the Grand Alliance System, in both modes, to be excellent and superior to any of the previous systems. They noted that scene cut performance was much improved over the previous systems.

When noise was introduced into the 1080I source, no enhancement of the noise was found at low noise levels. At the highest level of added noise, an increase in blockiness was seen, but the image exhibited much better quality than was observed at POU. When noise was introduced into the 720P source, a slight increase in image artifacts was found. At high levels, there was an increase in the blockiness of the image, but the image exhibited much better quality than was observed at POU.

Table 3.2 Quality of the Digital HDTV Grand Alliance system measured by expert observers.

	Target Specification	Measured Value		Comments
		1080 x 1920	720 x 1280	
Free Form Viewing	As good as or better than the best previous digital system	Better	Better	
Quality, Scene Cuts	As good as or better than the best previous digital system	Better	Better	
Noise in Video Source	As good as or better than the best previous digital system	Better	Better	
Video Coder Overload	As good as or better than the best previous digital system	Better	Better	
Motion Compensation Overload	As good as or better than the best previous digital system	Met expectations	Met expectations	
Quality, Video/ Auxiliary Data Tradeoff	2 (of 10) grades per Mb below reference for film, 4 (of 10) for video	No degradation up to and including 3 Mbps	No degradation up to and including 3 Mbps	
Concatenation Quality	As good as or better than the best previous digital system	Met expectations	Met expectations	

The 720P mode showed no artifacts in tests for motion-compensated overload with horizontal, vertical, or diagonal motion up to 0.8 picture heights per second. The 1080I mode showed no artifacts for horizontal motion, but did show increasing quantization noise and blockiness for vertical and diagonal motion.

The Grand Alliance has commented that two factors may have contributed to this difference in performance. First, the frame rate for 720P is greater than that for 1080I (60 frames per second rather than an effective 30 frames per second) and, in consequence, the time range over which the search operates is greater for 720P. And, second, the spatial range of the search is a fixed number of pixels for both formats and, because pixel spacing is greater in 720P, the effective search range also is greater.

The expert observers conducted tests to see how image quality deteriorated as channel capacity was reduced by transmitting auxiliary data. They found little or no increase in artifacts as the auxiliary data rate was increased to 3 Mbps. At 4 Mbps, the sequence M40 (Dream Team) showed a clear increase in the visibility of artifacts. The expert observers concluded that care must be exercised in combining an auxiliary channel with a high data rate together with video scenes with high peak complex motion; subjective degradation of the video may increase rapidly as channel capacity is diverted from video to auxiliary data.

When video material was passed through the system twice, somewhat more noise was seen on the second pass in the 1080I mode. For the 720P mode, more blockiness and noise were visible. The effects were worse with 720P than 1080I.

3.2. AUDIO

3.2.1. Audio and Long Form Entertainment Tests

Following the formation of the Grand Alliance in May 1993 it became necessary to select specific subsystems to be incorporated into the complete HDTV transmission system to be tested by the Advisory Committee. Choice of the audio subsystem was one of the first technical decisions faced by the Grand Alliance. In July 1993 the Grand Alliance, in conjunction with the Audio Experts Group, conducted a "Bake-Off" test of four audio codec configurations. The audio systems tested were Philips/MPEG-2 composite coding at 384 kbps, Dolby AC-3 composite coding at 2 bit rates, 384 kbps and 320 kbps, and MIT-AC independent coding at 580 kbps. No statistical distinction in audio quality was found among the systems for all but one of the test material selections and the Philips/MPEG-2 performance was definitively worse than the other codecs on this selection. Subsequent to testing, Philips claimed that a hardware implementation flaw was the cause of this poor performance. The test results and analysis are contained in Reference 1.

The Grand Alliance selection of Dolby AC-3 at 384 kbps as the audio subsystem was approved at the October 21, 1993 meeting of the Technical Subgroup. The Philips/MPEG-2 system was approved as the backup subsystem, subject to verification that the hardware implementation repair made by Philips cured the problem found during the "Bake-Off" test. A retest of the corrected Philips/MPEG-2 system in December 1993 confirmed that the problem had been fixed, and that there were no statistical differences among the systems tested. The test results are contained in Reference 2.

Subjective tests of an improved Dolby AC-3 audio compression encoder, as incorporated into the Grand Alliance HDTV transmission system tested at the ATTC, were conducted at the National Cable Television Association in Washington DC, May 8-18, 1995. The audio test sequences were passed through the entire Grand Alliance system, from audio encoder, through system multiplexing and transmission modulation, demodulation and demultiplexing, and finally audio decoding. The primary goal of these tests was to verify that the audio coder used in the Grand Alliance system was as good as or better than the coder tested in 1993.

The full report of the FCC ACATS SS/WP2 Audio Task Force is contained in Reference 3 but, in summary, it was concluded that:

1. The audio quality of the fully integrated Grand Alliance coder is better than that of the coder tested in 1993.
2. The audio quality of the Grand Alliance coder in the multi-channel mode was indistinguishable from that of the source.
3. The audio quality of the Grand Alliance coder in the 5.1 mode with 2 channel reproduction, while it can be detected by some expert listeners on some audio test material, is very nearly transparent (better than grade 4.5 on the 5 point impairment scale).
4. The audio quality of the Grand Alliance coder in the 2 channel mode is very nearly transparent (better than grade 4.7 on the 5 point impairment scale).

The Long Form Entertainment Tests were originally proposed by PS/WP6 (Subjective Assessment) to verify that the system could successfully handle program length audio and video HDTV test materials. The test materials consist of two reels. The first reel is 50 minutes in length and contains a wide variety of video segments with associated stereo and mono audio. The second reel contains several segments from the film "Hunt for Red October" with 6 channel surround-sound audio and is 23 minutes in length. The Long Form Entertainment Tests were conducted in October 1995 and the results are contained in Reference 5.

Table 3.3 contains the results of the Audio and Long Form Entertainment Tests.

Table 3.3 ATV subjective audio and long form entertainment tests.

	Target Specification	Measured Value	Comments
ATV Multi-channel Audio	Subjectively as good as or better than the Grand Alliance/ Audio Experts Group tests	Better	
Long Form Entertainment Program	EO&C, no noticeable impairments	Met expectations	

3.2.2. Dual Stream Audio

On February 3, 1992 the ATSC Executive Committee approved the release of document T3/186 that offered guidance to industry on desirable features for digital audio and data services associated with an Advanced Television service. Conformance with this document was subsequently incorporated into the FCC ACATS selection criteria for the audio subsystem of the proposed Grand Alliance HDTV system. One of the attributes recommended in T3/186 was the capability to decode two audio bit streams simultaneously to allow visually impaired services, voice-overs, multiple languages and other services to be combined with a main audio service in a receiver. This dual stream audio capability requires two audio decoders in the receiver or at least the ability of a single decoder to handle two independent bit streams simultaneously. The need for all receivers to have dual stream audio capability was challenged and the Audio and Transport Experts Groups were requested to make a recommendation to the Technical Subgroup on the subject.

On May 16, 1995 a joint open meeting of the Audio and Transport Experts Groups was held to discuss and analyze the dual stream audio issue and a recommendation resulting from that meeting, that dual stream audio should be optional, was made to the Technical Subgroup on May 18, 1995. The Technical Subgroup was unable to approve the recommendation at that meeting and the Experts Groups were requested to produce a white paper on dual stream audio that also explained the rationale behind the recommendation.

The paper was completed as a joint effort by members of the two Experts Groups and presented to the Technical Subgroup by Jim Gaspar, Chair of the Audio Experts Group, at the July 19, 1995 meeting. The paper and the recommendation for optional dual stream audio decoding were approved unanimously at the meeting. The impact of making dual stream audio optional is that it requires at least one complete main audio service to be included in the audio service mix provided by the broadcaster. The dual stream white paper is contained in Reference 4.

3.2.3. References

1. "Analysis of Grand Alliance Audio Tests July 28, 29, 30," August 28, 1993.
2. "Analysis of Grand Alliance Audio Tests December 7 and 8," December 15, 1993.
3. "Report on Multichannel and Stereo Listening Tests," July, 1995.
4. "An Explanation of Dual Stream Audio Decoding," July 14, 1995.
5. "Report on the Long Form Viewing Tests," October, 1995.

4. TRANSPORT

A number of tests were performed to examine the Grand Alliance prototype's ability to perform the transport layer functions prescribed by the ATSC Digital Television Standard. The target specifications list four tests as demonstrations, as shown in Table 4.1.

Table 4.1 Interoperability and Packetization Target Specifications.

	Target Specification
Header/Descriptor Robustness	Demonstration only
Switching between Compressed Data Streams	Demonstration only
Simulation of ATM Network Transmission	Demonstration only
Transport Interoperability with Computer Networks	Demonstration only

4.1. SWITCHING BETWEEN COMPRESSED DATA STREAMS

The Grand Alliance conducted a laboratory demonstration indicating the practicality of decoding video from a bit stream created by concatenating various video elementary streams. Within the range of test material prescribed for this demonstration, the test showed the feasibility of switching between compressed data streams.

4.2. HEADER/DESCRIPTOR ROBUSTNESS

The Grand Alliance demonstrated that the prototype ATV receiver recovers from loss of certain header information, as expected, with visible artifacts in the reconstructed video. For this demonstration, slice headers and picture headers for I, P, and B-frames were deliberately delivered in error. It was observed that for errors on I-frame headers, the visible artifacts could affect the entire group of pictures (GOP). For loss of a B-frame header, the subjective impact is limited to that B-frame only. When a P-frame header is lost, the duration of visible artifacts lies between the duration for loss of an I-frame header and a B-frame header.

4.3. COMPRESSION AND TRANSPORT LAYER INTEROPERABILITY

4.3.1. Syntactic and Semantic Compliance of the ATV Bit Stream

A bit stream recorded at the output of the Grand Alliance encoding system was analyzed through the use of software specially developed to check for MPEG-2 and ATSC syntactic and semantic compliance. Note that although a great number of bit stream elements were checked, practical considerations prevented the tests from being absolutely exhaustive. As a result, these tests did not verify that the Grand Alliance encoder would be completely compliant under all coding conditions. For instance, coded bit streams were not tested for video formats other than 720P at 59.94 Hz frame rate, and 1080I at 29.97 Hz frame rate.

A list of the specific bit stream elements tested is beyond the scope of this summary report; however, for perspective, the following is a summary of the quantities of syntactic and semantic elements tested:

- 66 elements of the MPEG-2 Systems Standard (ISO/IEC 13818-1)
- 14 elements of the ATSC Digital Television Standard, Annex C, "Service Multiplex and Transport Systems Characteristics" (ATSC A/53)
- 34 elements of the MPEG-2 Video Standard (ISO/IEC 13818-2)
- 3 elements of the ATSC Digital Television Standard, Annex A, "Video Systems Characteristics" (ATSC A/53)

Compliance violations were detected in the Program Association Table, the Program Map Table, the Program Paradigm, in Descriptors, in PES Headers, and in Video Syntax Start Codes. All were considered minor syntactic or semantic violations, and correction of these violations should be straightforward. These corrections, however, may be critical to receivers' ability to decode correctly ATV programs. The detected violations do not represent any impairment in picture quality or transmission coverage, and thus did not affect any test results in these areas.

Any commercial encoding systems produced for the marketplace must be produced in full compliance with the overall ATSC Standard.

4.3.2. Interoperability with ATM Networks

The goal of this series of tests was to demonstrate that a 19 Mbps ATV transport bit stream can be interfaced to, and transported by, an Asynchronous Transfer Mode (ATM) network. The tests were conducted at the Charlotte, North Carolina field test site utilizing fiber-based ATM transport facilities provided by Bell South.

Using equipment provided by the Grand Alliance, ATV transport data stream packets were split into ATM-sized payloads and then formed into ATM cells with appropriate ATM headers and syntax. These were then transmitted via the ATM network, through a single ATM switch, and returned to the field test site. Here they were converted back into ATV transport packets. The ATM channel was selected for constant bit rate, which provides minimum timing errors, or "jitter."

The first of the three tests was designed to verify the basic connection to the ATM network. A D-3 VTR provided 19 Mbps source data, in ATV transport stream format, but consisting of pseudo-random data sequences. These were successfully passed through the ATM channel with no bit errors detected.

The second of the tests utilized a D-3 VTR to feed into the ATM network a transport stream consisting of compressed HDTV pictures and sound. The returned ATM signal was reconverted to an ATV transport stream and fed to the Grand Alliance 8 VSB modulator, and then broadcast via the channel 53 transmitter, and also transmitted via cable television plant (in the 16 VSB mode). Error-free reception was achieved at both broadcast and cable receive sites.

The third test involved increasing the length of the ATM path to a total distance of approximately 450 miles, and increasing the number of ATM switches in the circuit to six. While generally successful, at times ATM packet jitter exceeded the buffer capacity of the ATM receiver, resulting in errors in the decoded picture that were different in appearance from those caused by typical over-the-air impairments.

In summary, all three tests proved the feasibility of carrying the ATV transport stream over a public carrier's fiber-based ATM network, but indicated that commercial equipment will need to be designed to cope with packet jitter that arises in more complex ATM network configurations.

4.3.3. Multiple Ancillary Data Services

In order to demonstrate, in a limited fashion, the ability of the Grand Alliance prototype system to deliver multiple independent programs within a single 6 MHz RF channel, the system was configured for this test to transmit simultaneously four data channels at bit rates as follows: 4.738 Mbps, 5.744 Mbps, 3.747 Mbps, and 4.717 Mbps. The transmission channel was unimpaired, and a strong level signal (-28 dBm) was presented to the receiver. Each of the "sub-channels" was selected, in turn, for output at the decoder, and each was received error-free.

4.4. AUDIO/VIDEO/CAPTIONING LATENCY

Because the signal processing in a digital television system has the potential to introduce varying delays between the audio, video and closed-captioning data signals, tests were performed on the Grand Alliance prototype system to measure these absolute and relative delays.

4.4.1. Absolute Latency

For the 1080I format, the absolute delay for video was 846 ms. For the 720P mode, the absolute delay for video was 813 ms. These latencies may be of interest to future designers of interactive television systems utilizing the Grand Alliance system, because these delays set the lower bound for responsiveness of the system to a user request for a high definition video sequence.

4.4.2. Relative Latencies

For the 1080I format, audio was found to lag the video by 9 - 13 ms, with variations over this range depending upon the channel examined in the 5.1-channel audio configuration. Such a lag is not considered to be perceptible to viewers, except in cases of concatenated processing through a series of ATV encoding systems, through which the audio lag would accumulate. The Grand Alliance is encouraged to investigate whether this relative delay in audio content can be reduced through encoding system design changes.

For the 720P format, audio was found to lead the video by 36 - 40 ms, varying by channel in the 5.1-channel audio configuration. Such a lead in audio timing is nearing the perceptible threshold, but can be expected to be corrected via a relatively inexpensive delay in the audio signal at the appropriate point in the ATV encoding system.

As to captioning, for the 1080I format, captioning was found to lead the video by 17 - 33 ms (that is, by one or two fields), depending upon whether the captioning was presented to the encoder on Field One or Field Two. Correction of this lead can be expected to be a relatively simple matter for future encoder designs.

For the 720P format, captioning latency essentially matched the video latency, leading the video by only 1 ms.

Target specifications and measured values for relative latencies are given in Table 4.2.

Table 4.2 Relative latencies of the Digital HDTV Grand Alliance system.

	Target Specification	Measured Value		Comments
		1080 x 1920	720 x 1280	
Video-Audio Relative Latency	< 15 ms	10.3 ms	38.4 ms	See Note 1
Video-Captioning Relative Latency	< 100 ms	33 ms	1 ms	

Note 1: Relative timing of video and audio is fully programmable. In the prototype system, timing was not optimized for the 720P mode.

5. TRANSMISSION

5.1. SPECTRUM UTILIZATION

5.1.1. Introduction

The Advisory Committee on Advanced Television Service considered two criteria for spectrum utilization — accommodation percentage and service area. "Accommodation percentage" specifies the fraction of existing NTSC television stations that could be assigned an ATV channel. "Service area" refers to the interference-limited coverage area of new ATV stations. The methodology for calculating the results of the analyses of these criteria was described in Chapter 8 of the "ATV System Recommendation" adopted by the Advisory Committee on February 24, 1993.

5.1.2. Accommodation Percentage

Allotment studies were undertaken based on the results of laboratory testing of the Grand Alliance prototype ATV system. For terrestrial broadcasting, an allotment/assignment plan that provides a second channel for each television licensee, construction permit holder, and construction permit applicant was developed. In the plan, an attempt was made to match the new ATV coverage with the existing coverage of the companion NTSC station. Approximate realization of that objective was achieved through reducing ATV coverage of some stations and allowing new interference to the coverage areas of some NTSC stations. The effect of the interference tradeoffs is detailed in the following section.

5.1.3. Service Area

Table 5.1 shows the planning factors employed in the devising of the allotment/assignment table and in the analyses of service and interference. Shown also in Table 5.1 are the target specifications which are based on the "Best of the Best" values from the four original digital systems. The carrier-to-noise, co-channel, and adjacent-channel interference data were derived from laboratory testing of the Grand Alliance prototype. Of particular note is the matter of interference to NTSC from an upper adjacent-channel ATV operation.

Table 5.1 System-specific planning factors for Grand Alliance prototype (D/U in dB).

	Target Specification	Measured Value	Comments
Carrier-To-Noise	< 15.6 dB	+15.19 dB	

Co-Channel	Target Specification	Measured Value	Comments
ATV-into-NTSC	< 36.5 dB	+34.44 dB	
NTSC-into-ATV	< 3.5 dB	+1.81 dB	
ATV-into-ATV	< 16.6 dB	+15.27 dB	

Adjacent-Channel	Target Specification	Measured Value	Comments
Lower ATV-into-NTSC	< -14.5 dB	-17.43 dB	
Upper ATV-into-NTSC	< -12.5 dB	-11.95 dB	See Note 1
Lower NTSC-into-ATV	< -41.5 dB	-47.73 dB	
Upper NTSC-into-ATV	< -43.0 dB	-48.71 dB	
Lower ATV-into-ATV	< -37.5 dB	-41.98 dB	
Upper ATV-into-ATV	< -37.5 dB	-43.17 dB	

Note 1: Target specification is based on video interference which was met during testing (-17.00 dB). During testing, it was discovered that audio interference occurs before video interference; the measured value shown in this table is based on audio interference.

In the 1993 testing of the original systems, and in the 1994 comparative testing of the 8 VSB and 32 QAM transmission subsystems (called the bake-off), consideration was given only to video interference. In the 1995 testing of the Grand Alliance prototype, interference from ATV into BTSC stereo and the second audio program (SAP) channel were tested also. In a substantial number of the twenty-four NTSC receivers used in the ATTC testing program, audio was found to degrade before video when the interfering signal was ATV in the upper adjacent-channel. The threshold for video performance degradation to CCIR Grade 3 was found to be at a desired-to-undesired (D/U) ratio of -17.00 dB for the median receiver. The threshold for audio performance degradation to CCIR Grade 3 for the median receiver was found to be at a D/U ratio of -11.95 dB.[1] Since the D/U ratio for audio is greater than the D/U ratio for video (i.e., audio degraded before video), in the instance of upper adjacent-channel ATV-into-NTSC interference, the audio ratio was used in service and interference determinations. In all other interference considerations, video degraded before audio, therefore video D/U ratios were used.

5.1.3.1. Service Area Evaluation

Nationwide coverage area and population analyses are summarized in Table 5.2 and Table 5.3. In this analysis, the data base is the same as that used for the bake-off analysis. The

[1] The threshold for audio performance degradation to CCIR Grade 3 was found to be at a D/U ratio of -7.95 dB for twenty percent of the receivers, and at -10.95 dB for thirty percent of the receivers. For further information, see the coverage analysis report of the Transmission Expert Group.

VHF/UHF scenario is assumed, and co-channel, adjacent-channel, and taboo constraints are used ATV performance, based on the prototype testing, was essentially equivalent[2] to the performance predicted on the basis of the bake-off test results, and substantially better than the four original digital systems. Areas and populations served are greater and interference is less.

Table 5.2 Aggregate population statistics for Grand Alliance prototype (VHF/UHF scenario, co-channel, adjacent-channel, and taboo constraints).

Aggregate Population Statistics	Based on Median Video	Based on Median Audio
Total population for ATV and NTSC coverage areas	2,912.03 M	2,912.03 M
NTSC population lost due to NTSC interference	301.30 M	301.30 M
NTSC population lost due to ATV interference	93.2 M	118.36 M
ATV population lost due to NTSC and ATV interference	73.07 M	73.07 M
ATV population lost due to ATV-only interference	38.45 M	38.45 M

Table 5.3 NTSC population statistics for Grand Alliance prototype (VHF/UHF scenario, co-channel, adjacent-channel, and taboo constraints).

Population loss relative to population in coverage area	NTSC stations with added population loss due to ATV: Based on Median Video	Based on Median Audio
No Interference	60.9 %	57.6 %
0 - 5 %	24.7 %	24.4 %
5 - 10 %	5.1 %	6.1 %
10 - 15 %	2.8 %	3.6 %
15 - 20 %	1.8 %	2.1 %
20 - 25 %	1.3 %	1.5 %
25 - 30 %	0.5 %	1.5 %
30 - 35 %	0.7 %	0.3 %
> 35 %	2.2 %	2.9 %

Interference to NTSC audio from the upper adjacent-channel ATV had to be present during the bake-off testing, but audio effects were not tested; concentration was on video. A reasonable assumption is that, had audio effects been considered in the bake-off tests, coverage analysis based on upper adjacent audio would have yielded similar results to those shown in Table 5.2.

Table 5.2 compares the effects of NTSC and ATV interference on the viewing population. The numbers entered in the table for "population" are the product of the number of viewers and the number of stations they potentially receive. This accounts for a total "population" of almost 3 billion. The table shows that the biggest "lost" population is potential NTSC viewership already lost because of NTSC interference; this population statistic describes the situation as it exists today and forms a baseline. Compared with this number, the effects on existing NTSC of adding a new ATV service are small. The ruggedness of the new ATV service is apparent also because its

[2] Based on upper adjacent video.

"lost" population is smaller than the present "lost" population with NTSC. These results indicate that the loss of population coverage due to interference will be significantly decreased after the transition to ATV is completed.

5.1.3.2. *Comparison with Four Original Digital Systems*

Figure 5.1 and Table 5.4 have been provided to allow comparisons to the 1993 testing of the four original digital systems. Results of the previous tests are included in the "ATV System Recommendation." The computer input for this analysis is based on the 1993 data base, assumes the VHF/UHF scenario, considers only co-channel and adjacent-channel interfering sources, and uses the upper adjacent-channel ATV-into-NTSC D/U ratio of -17.00 dB, which is the video threshold.

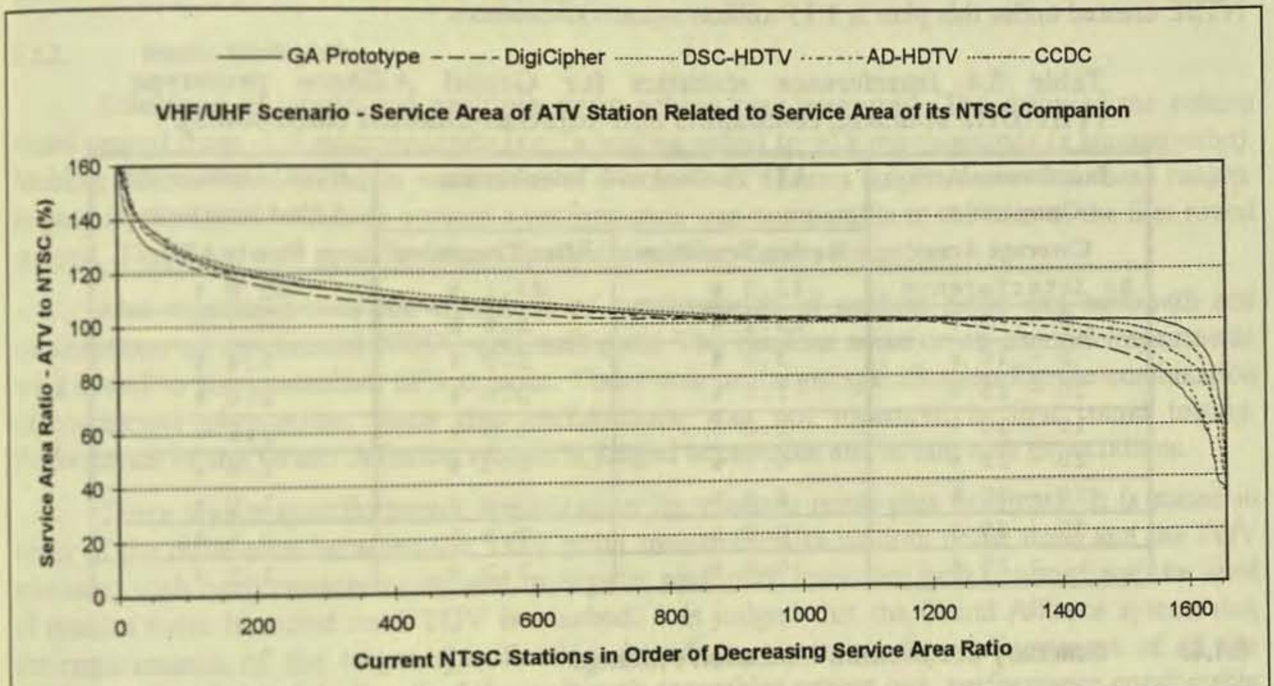


Figure 5.1 Interference-limited service area of each ATV station relative to the interference-limited service area of its companion NTSC station (VHF/UHF scenario, co-channel and adjacent-channel constraints).

Figure 5.1 depicts the interference-limited service area of each ATV station, during the transition period, relative to the interference-limited service area of its companion NTSC station under the VHF/UHF scenario, taking into account co-channel and adjacent-channel constraints. The graph shows the Grand Alliance prototype, as a solid line, along with the four original digital systems. In the graph, the 1,657 current NTSC stations are placed in order of decreasing ATV to NTSC service area ratio. Examination of the graph for the Grand Alliance prototype reveals that 11 % (183) of the ATV stations under this scenario would have an ATV service area at least 20 % larger than their companion NTSC service area, and 98.85 % (1,638) would have an ATV service area at least 80 % of their companion NTSC service area. The total ATV interference-limited service area for all 1,657 stations is 39.7 million square kilometers. It is clear from this graph that the performance of the Digital HDTV Grand Alliance System exceeds that of any of the four original digital systems.

Table 5.4 shows the interference statistics for the VHF/UHF scenario, taking into account co-channel and adjacent-channel constraints. During the transition period, 82.3 % of ATV stations would receive no interference. This would rise to 89.1 % after the transition period ends. Also during the transition period, 0.4 % of the ATV stations would receive interference in more than 35 % of their noise-limited coverage area. This would decrease to 0.2 % after the transition period ends. The total interference area created within the ATV noise-limited coverage area during the transition period is 0.41 million square kilometers. Of the existing NTSC stations, 63.8 % would not receive any new interference because of the ATV service, while 2.2 % would receive new interference in more than 35 % of their Grade B area. The total new interference into NTSC created under this plan is 1.15 million square kilometers.

Table 5.4 Interference statistics for Grand Alliance prototype (VHF/UHF scenario, co-channel and adjacent-channel constraints).

Interference Area Compared to Coverage Area	ATV Stations with Interference		NTSC Stations with Added Interference Due to ATV
	During Transition	After Transition	
No Interference	82.3 %	89.1 %	63.8 %
0 - 5 %	10.1 %	6.6 %	20.7 %
5 - 10 %	3.5 %	1.8 %	5.4 %
10 - 15 %	1.5 %	0.9 %	2.8 %
15 - 20 %	0.6 %	0.5 %	2.2 %
20 - 25 %	0.7 %	0.3 %	1.4 %
25 - 30 %	0.3 %	0.3 %	1.0 %
30 - 35 %	0.3 %	0.3 %	0.5 %
> 35 %	0.4 %	0.2 %	2.2 %

5.1.4. Summary of Spectrum Utilization Findings

Based on this analysis, the Advisory Committee finds that the Grand Alliance system is superior to all of the previously analyzed proponent systems in utilization of spectrum.

5.2. Transmission Robustness

This section identifies the various tests of transmission performance. For each test, the purpose and importance of the test and the test methodology is summarized. A brief statement of the results is given also for each test, with emphasis on comparison of performance of this Grand Alliance system with the previous proponent systems.

5.2.1. Random RF Noise Performance

Random noise was added at RF to the desired digital signal. As expected for the Grand Alliance system's modulation and error correction, random RF noise has no effect on the recovered video and audio data until the level of noise is raised to a point very close to a "threshold" value. The value of carrier-to-noise ratio (C/N) where the effects of noise begin to be visible is called the Threshold of Visibility (TOV).

For the Grand Alliance system, the C/N at TOV was 15.19 dB.

As expected and designed into the system, the threshold is very sharp. Visible image impairments change from just barely visible to destructive of the picture within ~ 1 dB of worsening of the C/N.

A similar measure can be made on the recovered audio data (Threshold of Audibility). For the Grand Alliance system, the C/N at TOA was 14.92 dB.

As expected, the video and audio fail approximately together, with audio measuring as slightly more robust against RF noise. Audio does not fail before video.

Performance in the presence of RF noise impairment is superior to the first round systems and meets target specifications. See Table 5.5.

5.2.2. Static Multipath

Tolerance of single and multiple static echoes was measured. The delay of the echoes tested ranged from -1.8 microseconds (i.e., a leading echo) to +18 microseconds (a lagging echo). Multiple echoes were tested in ensembles of 5 echoes at various amplitudes within these ranges. In general, the Grand Alliance system's performance was comparable to the best of the first round systems. There were no specific target specifications for these parameters.

Also measured was the tolerance of combinations of random noise and multipath and combinations of co-channel NTSC and multipath. The random noise or co-channel impairments were added to the ensembles of 5 echoes. There was no target specification for the combination of co-channel plus noise, since this performance was not measured in first round testing. Performance of the Grand Alliance system is judged acceptable and in line with expectations.

There was a specific target specification for random noise plus multipath. It is stated in terms of the difference between the TOV point measured with random noise alone and the TOV measured with both random noise and multipath; multipath levels are held constant and the level of random noise is varied until TOV is reached. It is judged that the Grand Alliance system met the requirements of the target specification, based on averaging the performances of all the ensembles. See Table 5.5. (In all of the multipath ensembles except one, performance comfortably surpassed the requirements of the specification; the one exception was worse than target by 0.14 dB.)

Table 5.5 Random RF noise performance of Grand Alliance prototype.

	Target Specification	Measured Value	Comments
Threshold Characteristics for Random Noise - Video	< 15.6 dB	15.19 dB	
Threshold Characteristics for Random Noise - Audio	< 15.6 dB	14.92 dB	
Threshold Characteristics for Random Noise (Audio + Video)	Audio usable at or beyond video POU	Audio did not fail before video	
Random Noise in Presence of Multipath	< 3.5 dB	2.42 (±1.22) dB	

5.2.3. Flutter

Flutter is time-varying or dynamic multipath. This performance attribute was tested with both ensembles of ghosts and with single ghosts at various rates of "motion" from 0.05 Hz to 5 Hz. This testing was more extensive than in the first round. Where comparable data exist, the Grand Alliance system shows improved performance.

5.2.4. Impulse Noise (Burst Error)

Both over the air and cable reception suffer interference from bursts or impulses of noise. The ability to deliver corrected data in the presence of bursts of interference is important.

The 8 VSB Grand Alliance system performed better than the target specification by withstanding a 169 μs burst at a repetition rate of 10 Hz. The second part of the test specified a time duration for the pulse as a percentage of the threshold pulse width, and not the width specified in the target values, so a comparison with the target value is not possible. See Table 5.9.

The 16 VSB Grand Alliance system was able to withstand a 120 μs burst at a repetition rate of 10 Hz which almost met the target value of 129 μs at 10 Hz. See Table 5.10.

5.2.5. Discrete Frequency Interference

The intent of this test is to probe for sensitivity of the digital signal to particular interfering frequencies, such as could be encountered from RF signals other than broadcast television. Discrete frequency interference tolerance was tested both from tones within the desired ATV channel and from tones in adjacent channels.

The Grand Alliance system performed better than the target specifications. See Table 5.6.

Table 5.6 Discrete frequency interference performance of the Grand Alliance prototype.

	Target Specification	Measured Value	Comments
Discrete Frequencies (25)	< -39.5 dB adj. ch.	-48.5 (±3.5) dB	
	< 12.75 dB in band	11.1 (±2.0) dB	

5.2.6. Co-channel Interference into ATV

Tests measured both ATV-into-ATV and NTSC-into-ATV co-channel interference, at both moderate and weak power levels. The Grand Alliance system performed better than target specifications on all of these tests. See Table 5.1.

5.2.7. Co-channel Interference into NTSC

The test measured ATV-into-NTSC co-channel interference at moderate and weak power levels. The Grand Alliance system performed better than target specifications on all of these tests. See Table 5.1.

5.2.8. Adjacent-Channel Interference

Upper and lower adjacent-channel interference were both tested, and tests were performed in both directions, i.e., ATV-into-NTSC and NTSC-into-ATV. Tests were performed at strong, moderate, and weak power levels.

With regard to ATV-into-ATV tests, the threshold of visibility at weak and moderate desired power exceeded performance in the first round tests. At strong desired power, the threshold of visibility exceeded that level of interference expected to occur under real-world conditions.

The Grand Alliance system performed better than target specifications on all NTSC-into-ATV tests and on lower adjacent-channel ATV-into-NTSC. With regard to upper adjacent-channel video interference ATV-into-NTSC, the tests found a "color stripe" artifact in the NTSC video at all NTSC power levels. Analysis shows that it is caused by the ATV pilot carrier frequency "beating" with the NTSC color subcarrier. Analysis also suggests that another "luminance beat," hidden during the testing by the color beat, would be present, caused by the ATV pilot carrier beating with the NTSC visual carrier. Finally, during these tests, some NTSC receivers showed loss of color and other picture artifacts.

The analysis shows that use of precision carrier offset between the ATV pilot and the NTSC color subcarrier will eliminate visibility of both artifacts. The loss of color and other artifacts, however, would not be affected by carrier offset.

Given the above, also examined carefully were the effects of upper adjacent-channel ATV-into-NTSC interference on the BTSC stereo signal and on the SAP channel. Results show that the stereo and SAP signals are more sensitive to upper adjacent-channel interference than is the video. Assuming the use of offset to eliminate the video beat artifacts, coverage was computed based on the interference levels measured for the stereo and SAP channels. Nevertheless, the system met target specifications, because those targets were based on video performance. See Table 5.1.

5.2.9. Taboo Interference

Tests were performed at all the significant traditional UHF taboo channels. The Grand Alliance system performed better than target specifications an all taboos except N+2, ATV-into-NTSC. It missed that target by about 0.6 dB. The taboo performance of the Grand Alliance system is judged acceptable. See Table 5.7.

5.2.10. Peak-to-Average Power

The ratio of peak-to-average power, with 99.9 % probability was measured as 5.9 dB, which was lower (i.e., better) than target specification. See Table 5.8.

5.2.11. Threshold Characteristics

Thresholds against impairments are generally sharp for digital systems with error correction. The Grand Alliance system exhibited the expected sharp thresholds, as discussed above in individual test summaries.

5.2.12. Cable Transmission

5.2.12.1. Composite Second Order

Composite second order (CSO) impairment arises from the distortion characteristics of active elements in a cable television system. System performance in the presence of CSO impairment is a function of the spectral characteristics of the modulation scheme and the receiver front end design. The ability to withstand high levels of CSO is desirable.

Table 5.7 Taboo interference performance of Grand Alliance prototype.

	Target Specification	Measured Value	Comments
N-2 Taboo A/N	< -23.5 dB	-23.73 dB	
N+2 Taboo A/N	< -28.5 dB	-27.93 dB	See Note 1
N+4 Taboo A/N	< -22.5 dB	-24.96 dB	
N+14 Taboo A/N	< -32.5 dB	-33.38 dB	
N+15 Taboo A/N	< -22.5 dB	-30.58 dB	
N-8 Taboo A/N	< -25.5 dB	-31.62 dB	
N+8 Taboo A/N	< -36.5 dB	-43.22 dB	
N-2 Taboo N/A	< -53 dB	-62.45 dB	
N-2 Taboo A/A	< -53 dB	-60.52 dB	
N+2 Taboo N/A	< -53 dB	-59.86 dB	
N+2 Taboo A/A	< -53 dB	-59.13 dB	
N-3 Taboo N/A	< -53 dB	< -61.79 dB	
N-3 Taboo A/A	< -53 dB	< -60.61 dB	
N+3 Taboo N/A	< -53 dB	< -62.49 dB	
N+3 Taboo A/A	< -53 dB	< -61.53 dB	

Note 1: Target specification missed by less than 0.6 dB. This is judged acceptable.

Table 5.8 Peak-to-average power for the Grand Alliance prototype.

	Target Specification	Measured Value	Comments
Peak/Average Power (99.9% probability)	< 6.95 dB	5.9 dB	

The 8 VSB Grand Alliance system had a measured carrier-to-interference level of 27 dB which is slightly poorer than the target value of < 25 dB, however, as NTSC pictures start exhibiting interference in the 50 dB range, it is unlikely the 8 VSB system would have to operate in a mid-20's carrier-to-interference environment. See Table 5.9.

The 16 VSB Grand Alliance system had a measured carrier-to-interference level of 35 dB which meets the target value of < 38 dB. See Table 5.10.

5.2.12.2. Composite Triple Beat

Composite triple beat (CTB) impairment also arises from the distortion characteristics of active elements in a cable television system. Along with random noise, it is one of the primary limiting characteristics in cable system transmission performance. System performance in the presence of CTB impairment is a function of the spectral characteristics of the modulation scheme and the receiver front-end design. The ability to withstand high levels of CTB is desirable.

The 8 VSB Grand Alliance system had a measured carrier-to-interference level of 39 dB which is slightly poorer than the target specification of < 37 dB; however, as NTSC pictures start exhibiting this interference in the 50 dB range, it is unlikely the 8 VSB system would have to operate in a high-30's carrier-to-interference environment. See Table 5.9.

The 16 VSB Grand Alliance system had a measured carrier-to-interference level of 47 dB which meets the target specification of < 49 dB. See Table 5.10.

5.2.12.3. *Phase Noise*

Phase noise is a function of the stability of oscillators used in the transmission chain to generate or translate the frequency of the transmitted signal. The ability to withstand high levels of phase noise is desirable.

The 8 VSB Grand Alliance system had a measured carrier-to-phase noise ratio of 78 dB which was better than the target specification of < 81 dB. See Table 5.9.

The 16 VSB Grand Alliance system had a measured carrier-to-phase noise ratio of 82 dB which was better than the target specification of < 87 dB. See Table 5.10.

5.2.12.4. *Residual FM*

Residual frequency modulation is another form of deviation in oscillators used in frequency conversion equipment. The ability to withstand high levels of residual FM is desirable.

The 8 VSB Grand Alliance system had a threshold residual FM of 9 kHz which was better than the target specification of > 6.5 kHz. See Table 5.9.

The 16 VSB Grand Alliance system had a threshold residual FM of 7 kHz which was better than the target specification of > 4 kHz. See Table 5.10.

5.2.12.5. *Fiber Optics*

Cable systems are increasingly introducing amplitude modulated fiber optic links to reduce amplifier cascades and improve system reliability. The lasers will clip if over-modulated resulting in distortion in the channels.

The 8 VSB Grand Alliance system reached threshold BER with a laser modulation level of 7.8 % which was better than the target value of 4.5 %; however, the number of carriers available to modulate the laser was lower than the number used to set the target and a direct comparison is not possible. See Table 5.9.

The 16 VSB Grand Alliance system reached threshold BER with a laser modulation level of 7.3 % which was better than the target value of 4 %; however, the number of carriers available to modulate the laser was lower than the number used to set the target and a direct comparison is not possible. See Table 5.10.

5.2.12.6. *Channel Change and Channel Acquisition*

Current television viewers are accustomed to rapid channel change capability, and an ATV service must emulate this feature closely if consumer frustration is to be avoided. Channel change time is a function of two processes: carrier acquisition and bit stream synchronization; and bit stream decompression through recognizable picture display and presentation of audio.

The 8 VSB Grand Alliance system exhibited an average channel acquisition time of 0.7 seconds which just met the target value for acquisition. See Table 5.9.

The 16 VSB Grand Alliance system, with an average acquisition time of 1.1 seconds, was slower than the target value of 0.7 seconds. See Table 5.10.

5.2.12.7. Multiple Impairment — Second Order vs. Noise

The ability of digital systems to handle a specific impairment is normally reduced if a second impairment is present. Noise and second order distortion trade-off was determined by decreasing the amount of noise necessary to reach threshold when the amount of second order distortion was decreased a specified amount.

The level of second order interference was reduced 6 dB before the noise-only threshold was reached on the 8 VSB Grand Alliance system. With the second order distortion 3 dB below the threshold value, the amount of noise necessary to reach threshold was within 0.5 dB of the noise threshold. The system was better than the random noise target value of < 15.6 dB. See Table 5.9.

The 16 VSB Grand Alliance system traded-off between noise and distortion until the distortion was reduced 15 dB below its threshold value. With the second order distortion 3 dB below its threshold value, noise was 3 dB from its threshold value. The system was slightly below the random noise threshold target value of 28.85 dB with a threshold of 29.1 dB. This was due to the lower tuner input level compared to the previous tests. See Table 5.10.

5.2.12.8. Multiple Impairment — Third Order vs. Noise

The trade-off between noise and composite third order distortion was determined by reducing the level of the third order distortion in specified steps and determining the noise necessary to reach threshold.

The noise-only threshold was reached on the 8 VSB Grand Alliance system when the third order distortion was reduced 3 dB.

The 16 VSB Grand Alliance system reached the noise threshold level when the third order distortion was reduced 6 dB below its threshold value. With the third order distortion 3 dB below its threshold value, noise was 0.4 dB from its threshold value.

5.2.12.9. Multiple Impairment — Phase Noise vs. Noise

The relationship between phase noise and random noise was determined by reducing the phase noise below its threshold level in specified steps and determining the level of random noise necessary to reach threshold at those levels.

The 8 VSB Grand Alliance system reached the noise threshold when the phase noise was reduced 15 dB below its threshold level. The system was within 2 dB of its noise threshold with the phase noise reduced 3 dB below threshold.

The 16 VSB system reached the noise threshold when the phase noise was reduced 9 dB below its threshold and was within 1 dB of threshold with the phase noise reduced 3 dB below threshold.

Table 5.9 Cable television tests performed on the Grand Alliance prototype.

	Target Specification	Measured Value	Comments
Composite Second Order Distortion	< 25 dB	27.1 dB	See Note 1
Composite Triple Beat Distortion	< 37 dB	39.1 dB	See Note 1
Phase Noise	< 81 dB	78.3 dB	
Residual FM	> 6.5 kHz	9.2 kHz	
Fiber Optic Tests	> 4.5 %	7.8 %	
Channel Change / Channel Acquisition	< 0.7 s	0.7 s	
Threshold Characteristics for Random Noise - Data	< 15.6 dB	15.0 dB	
Local Oscillator Instability	> ±89 kHz	> ±100 kHz	
Dynamic Multipath - Acquisition Time in the Presence of Multipath and Noise	< 0.75 s	0.9 s	See Note 2
Burst Error Correction	> 169 μs @ 10 Hz	180 μs @ 10 Hz	
	> 1.05 kHz @ 20 μs	240 Hz @ 118 μs	See Note 3

Note 1: The measured value missed the target specification by 2 dB, but there is more than 20 dB margin with typical operating conditions. This is judged acceptable.

Note 2: Test included more severe multipath conditions than anticipated when target specification was set.

Note 3: The test was different from the target specification.

Table 5.10 High data rate cable television tests performed on the Grand Alliance prototype.

	Target Specification	Measured Value	Comments
Composite Second Order Distortion	< 38 dB	35.4 dB	
Composite Triple Beat Distortion	< 49 dB	47.2 dB	
Phase Noise	< 87 dB	81.8 dB	
Residual FM	> 4.0 kHz	7.0 kHz	
Fiber Optic Tests	> 4.0 %	7.3 %	
Channel Change / Channel Acquisition	< 0.7 s	1.1 s	See Note 1
Threshold Characteristics for Random Noise - Data	< 28.85 dB	29.1 dB	See Note 2
Local Oscillator Instability	> ±89 kHz	> ±100 kHz	
Dynamic Multipath - Acquisition Time in the Presence of Multipath and Noise	< 0.75 s	1.2 s	See Note 3
Burst Error Correction	> 129 μs @ 10 Hz	120 μs @ 10 Hz	See Note 4
	> 1.45 kHz @ 20 μs	480 Hz @ 68 μs	See Note 5

Note 1: Measured value reflects prototype hardware anomaly, not a system characteristic. Intended design was for identical acquisition performance in both 8 VSB and 16 VSB modes.

Note 2: Measured value missed target specification by 0.25 dB. This is judged acceptable.

Note 3: Test included more severe multipath conditions than anticipated when target specification was set.

Note 4: Measured value missed target specification by 7.5 %. This is judged acceptable.

Note 5: The test was different from the target specification.

5.2.12.10. *Multiple Impairment — Residual FM vs. Noise*

The residual FM vs. random noise relationship was determined by reducing the residual FM in specified steps and determining the amount of noise necessary to reach threshold at those FM levels.

The 8 VSB Grand Alliance system did not reach the noise threshold when the residual FM was reduced to 25 % (2.2 kHz) of its threshold level.

The 16 VSB Grand Alliance system reached the noise threshold when the residual FM was reduced to 25 % (1.5 kHz) of its threshold value. At 75 % of the FM threshold value, the noise was within 0.4 dB of the threshold value for noise only. (16 VSB performed better than 8 VSB in this regard.)

5.2.12.11. *Local Oscillator Instability*

Variations in received frequencies are of concern to both broadcasters and cable operators. A consumer receiver must be able to identify and acquire signals that are offset from the nominal frequency assignment.

Both the 8 VSB and 16 VSB Grand Alliance systems were better than the target value pull-in range of > ±89 kHz. See Table 5.9 and Table 5.10.

5.2.12.12. *Minimum Isolation between Receivers*

Changing channels on one TV set connected to the same splitter as a second TV set may change the frequency response of the signal fed to the second set. The equalizer in the second set must respond quickly to minimize errors. The minimum isolation was defined as the highest level of ghost that could be switched in and out without causing errors in the data.

The 8 VSB Grand Alliance system was able to tolerate a 17 dB down ghost without producing any errors. There is no target value.

The 16 VSB Grand Alliance system was able to tolerate a 28 dB down ghost without producing any errors. There is no target value.

5.2.12.13. *Effect of High Level Sweep*

Summation sweep systems used on cable systems to determine frequency response come in two general types, a high level sweep and a lower level "bursty" system.

The 8 VSB Grand Alliance system exhibited periodic data errors with the high level sweep and no errors with the "bursty" type system.

The 16 VSB Grand Alliance system exhibited periodic data errors with the high level sweep and no errors with the lower level "bursty" sweep system.

There is no target specification for sweep systems. The high level sweep system causes interference in NTSC pictures.

5.2.12.14. *Hum Modulation*

Faulty amplifier power supplies can amplitude modulate RF signals at power line frequencies.

The 8 VSB Grand Alliance system reached threshold with 6.7 % hum modulation while the 16 VSB system reached threshold at 6 % modulation. There is no target value for hum modulation, but these values are well above the modulation level that would result in visible hum on an NTSC picture.

5.2.13. Summary of Transmission Robustness Findings

The performance of the Grand Alliance system in laboratory testing has met the expectations defined by the target specifications. In the few instances where individual test results did not meet the target values stated for that particular test, the deviations were minor and do not have any significant effect on image quality or spectrum utilization.

5.3. FIELD TEST

Field testing was performed under both terrestrial broadcasting and cable conditions.

For terrestrial broadcasting, the complete system was tested at a set of sites selected for their difficult reception conditions, as measured in an earlier field test of the modem subsystem (documented in SS/WP2-1354). In those earlier modem-only tests, a bit error rate (BER) of $3x10^{-6}$ was selected as the criterion for the threshold of visibility (TOV) of video impairments. Full system testing, including subjective observation of pictures and sound, verified the reliability of that value of BER. Because the locations for full system testing were a selected and difficult sub-set of the complete group of test locations, they are not a representative sample. The full system testing, however, verified the utility of the data taken on the full set of locations. The sites for full system testing included 10 sites in homes where tests were performed both within the residence using a set-top antenna, and outdoors, adjacent to the residence, using a mast-mounted antenna.

Complete system field testing began on July 25, 1995 and was completed on August 23. The tests were conducted using the same facilities near Charlotte, North Carolina, as employed in modem-only tests. As before, the NTSC transmitted peak visual effective radiated powers (ERP) on channels 6 and 53 were one-tenth of the maximum allowed by FCC rules, and the average ATV ERP was approximately one-sixteenth (12 dB below) of the NTSC peak visual ERP.

Tests of the complete system showed, as also indicated by the earlier modem subsystem testing, that satisfactory digital HDTV reception is available more widely than satisfactory analog NTSC reception. Even where objective measurements of BER indicate the probability of momentary impairment of the signal, subjective observation of picture and sound fails to detect impairment.

An objective measurement that should permit reliable prediction of satisfactory HDTV service at UHF is field strength; subjective assessment of video and audio correlated very well with field strength in channel 53 tests. That correlation did not hold at channel 6 because sample size and impulse interference effects prevented a proper channel 6 analysis. At only two of the seven sites, with signal strength at or below that which laboratory testing had indicated to be the limit of HDTV service, was subjectively satisfactory service observed. On the other hand, every site except one (out of a total of 15) where the signal strength was weak, but above the threshold, had subjectively satisfactory HDTV service. The 28 sites with moderate or strong signal strength all had subjectively satisfactory HDTV service.

In brief, terrestrial transmission testing of the complete system supports the conclusion that HDTV service will be available where NTSC service is presently available, and in many instances where NTSC service is unacceptable.

The complete system, with both 8 VSB and 16 VSB modulation, was tested also in cable environments in Charlotte, including existing cable systems and fiber optic links. Tests of 16 VSB were the more stringent. The 16 VSB receiver worked at all locations where the delivered signal met FCC specifications, and at many sites where it did not. Some systems were tested at frequencies beyond their maximum design frequency, resulting in less than FCC-specification conditions. Also, strong in-band beats were observed on some systems that affected both the NTSC and HDTV signals. The 16 VSB receiver continued to operate in these situations until the carrier-to-noise threshold was reached.

6. CONCLUSIONS

Based on Advisory Committee approved specifications, and thorough laboratory and field testing of the prototype ATV system as designed and constructed by the Digital HDTV Grand Alliance, the Technical Subgroup finds the following:

1. the Grand Alliance system meets the Committee's performance objectives and is better than any of the four original digital ATV systems;
2. the Grand Alliance system is superior to any known alternative system; and
3. the ATSC Digital Television Standard, based on the Advisory Committee design specifications and Grand Alliance system, fulfills the requirements for the U.S. ATV broadcasting standard.

Accordingly, the Technical Subgroup recommends that the ATSC Standard be adopted as the U.S. ATV broadcasting standard.

Appendix G.

White Paper
on
Multiple Service Transmission
Via the Grand Alliance System

Multiple Service Transmission via the Grand Alliance System

May 1995

The purpose of this paper is to 1) provide an overview of the capabilities and flexibility of the Grand Alliance system, 2) assess the capability of the Grand Alliance system for the multiple service concept, and 3) provide examples of service models that might be considered for multiple service transmission.

Executive Summary

The FCC Advisory Committee on Advanced Television Service (ACATS) Technical Subgroup has approved the specifications for the Grand Alliance Advanced Television System. While the efforts of ACATS have been centered on high definition television (wide screen, high resolution), the television industry recognizes other potential benefits inherent in a flexible digital broadcast television system.

The Grand Alliance system utilizes a layered digital system architecture. This approach coupled with a flexible, packetized transport and a standardized approach to video compression provide the ability to support transmission of multiple services.

The transport layer provides the ability to multiplex and demulitiplex multiple program and data services.

The utilization of MPEG-2 for video compression provides the features required to support additional program formats such as wide screen and 4x3 aspect ratio at various resolutions. These features include the ability to specify sampling structure, picture aspect ratio, input format and information to support pan and scan. MPEG-2 also provides the ability to dynamically allocate the number of bits per service which is essential for multiple service transmission.

Utilization of the Grand Alliance System for multiple service transmission can be supported by a variety of consumer products including digital HDTV, wide screen and standard definition receivers. Set-top adapters are also possible.

1. Introduction

The efforts of the FCC Advisory Committee on Advanced Television Service (ACATS) have been centered around high definition television (HDTV). HDTV will provide wide screen, high resolution images coupled with high quality sound. Many organizations and individuals now recognize the potential power inherent in a digital broadcast television system and there is significant interest in the use of the Grand Alliance system for distribution of a variety of services in addition to HDTV. This might include such things as transmission of multiple 4x3 aspect ratio or wide screen programs with resolution equivalent or better than the current analog NTSC system. Utilization of the GA system for transmission of data and other services has also been contemplated.

This paper will describe the flexibility of the Grand Alliance System to provide multiple services and provide some examples of how these services could be implemented. It will also describe some of the consumer devices likely to be needed to implement these new services.

2. Overview of the Grand Alliance system

The Grand Alliance system utilizes a layered digital system architecture with headers/descriptors to provide flexible operating characteristics. The layers of the GA system are: picture, sound, compression, transport and transmission.

The picture layer consists of raw pixel data, organized as pixels, scan lines and frames. The GA system supports multiple formats and frame rates.

The compression layer transforms the raw video and audio samples into a coded bit stream that can be executed by the receiver to recreate the picture and sound. The video compression syntax conforms to the ISO-MPEG MPEG-2 video standard, at a nominal data rate of approximately 18.9 Mbps. The Dolby AC-3 audio compression is used in the GA system to provide 5.1 channel surround-sound at a nominal rate of 384 kbps.

The GA transport layer provides the means for dynamic allocation of video, audio and auxiliary data.

The transmission layer modulates a serial bit stream into a signal that can be transmitted ov.r a 6 MHz television channel. The transmission system is based on a trellis-coded 8 vestigial sideband (VSB) modulation technique for terrestrial broadcasting. 16 VSB can be used for cable television applications.

3. System capable of multiple services

The GA system design is based on the ISO layer architecture which inherently provides flexibility and interoperability. The following sections of this paper will describe the capability of the GA system for transmission of multiple services.

3.1 Video compression system

Multiple service transmission will not impose any significant technical difficulty on the GA video compression system. The assumption here is that the information generated by each individual service will not exceed the specification of the GA system. The specific specifications for multiple service transmission is examined against the GA and MPEG-2 specifications.

Input source

The GA system supports two main format variations, with different numbers of lines per frame. These two formats have 720 active lines and 1080 active lines per frame. For multiple service transmission, the input sources could be the composite (SMPTE 170M) and component (SMPTE 253) analog NTSC signals, digital parallel and serial NTSC signals. MPEG-2 specification provide,the mechanism to indicate the video format by use of a three-bit integer indicating the representation of the picture prior to coding. The eight video formats specified are component (000), PAL (001), NTSC (010), SECAM (011), MAC (100), unspecified video format (101), reserved (110 & 111).

Sampling structure

In the MPEG-2 specification the sampling size is specified in the sequence header as horizontal/vertical_size_value and horizontal/vertical-size. The horizontal/vertical_size_value is the width/height of the displayable part of the luminance component of pictures in samples and forms the 12 least significant bits of horizontal/vertical_size. The horizontal/vertical_size is a 14-bit unsigned integer, the 12 least significant bits are defined in horizontal/vertical_size_value, the 2 most significant bits are defined in horizontal/vertical_size_extension. For multiple service the sampling structure can be specified based on the standards mentioned in the section of input source.

Colorimetry

The SMPTE 274M is one of the input formats specified by the GA system. The SMPTE 274M which underlies the HDTV 1920 x 1080 format allows for the use of SMPTE 240M colorimetry as an interim measure while specifying ultimate use of ITU-R Recommendation 709. It is desirable for multiple service to have identical colorimetry as specified in the GA system. In the MPEG-2 specification a flag called color_description can be set to "1" to indicate the presence of color_primaries, transfer_characteristics and matrix_coefficients in the bitstream. Both SMPTE 240M and ITU-R Recommendation 709 colormetry parameters can be specified by the color_primaries, transfer_characteristics and matrix_coefficients.

Picture aspect ratio

In MPEG-2, the picture aspect ratio information is defined by a four-bit integer. The aspect ratio information is provided by means of aspect_ratio_information in the sequence header and (optional) display_horizontal/vertical_size in the sequence_display_extension. The aspect_ratio_information either specifies the "sample aspect ratio" (SAR) of the reconstructed frame or alternatively it gives the "display aspect ratio" (DAR). If sequence_diaplay_extension is not present the sample aspect ratio may be calculated as follows:

$$SAR = DAR \times \frac{\text{horizontal\_size}}{\text{vertical\_size}}$$

In this case horizontal_size and vertical_size are constrained by the SAR of the source and the DAR selected.

If sequence_display_extension is present, the sample aspect ratio may be calculated as follows:

$$SAR = DAR \times \frac{\text{display\_horizontal\_size}}{\text{display\_vertical\_size}}$$

Examples of appropriate values for signals sampled in accordance with ITU-R Rec. 601 for 525-line format are 704 (display_horizontal_size) and 480 (display_vertical_size).

For multiple service transmission both 16x9 and 4x3 aspect ratios can be used. The GA system, since it is based on the MPEG-2 specification, is capable of supporting both aspect ratios.

Pan and scan

Since the aspect ratio of the input source may differ from that of the display, pan and scan is an essential feature. Pan and scan information is supported within the GA video syntax. This information is transmitted as an extension within the picture layer syntax. The MPEG-2 video syntax does communicate certain display parameters for use in reconstructing the video. A display window within the encoded raster may be defined as a window on a large area display device. In the case of pan and scan position of the window representing the displayed region of a large picture can be specified on a field-by-field basis. It is specified in the picture display extension. A typical use of the pan-scan window is to describe the 4:3 aspect ratio rectangle within a 16x9 video sequence.

Transparent coding of composite video

Decoding NTSC before transmission and recording to NTSC after transmission of composite source signals in contribution and distribution requires a precise reconstruction of the carrier amplitude and phase reference signal. The MPEG-2 specification provides the capability that the input format can be indicated in the sequence header using the video_format bits. Reconstruction of the carrier signal is possible by using the carrier parameters such as field_sequence, sub_carrier, burst_amplitude and sub_carrier phase that are enabled by setting the composite_display_flag in the picture header.

Picture quality

Within the total data stream supported by the GA compression system the picture quality depends on the number of services multiplexed. Picture quality is defined by the bit rate used. Provision for high picture quality is made by high bit rate limits relating to a certain level in a particular profile. The level specifies the spatial resolution and determines the maximum data rate it can support. For multiple service applications, high, main and low levels defined by the MPEG-2 can be used to provide services with different picture quality. The profile defines the picture quality in terms of coding latency, resolution and scalability. The levels that can be used to support multiple services are simple profile, main profile and scalable profile.

In the GA system specification chrominance band quality is specified as 4:2:0 (half as many samples in the horizontal and vertical directions). Selectable color primaries are specified by the MPEG-2. The chrominance can be sampled in one of three formats: the 4:2:0 , 4:2:2 (half as many samples in the horizontal direction only) and 4:4:4 (identical samples as luminance signal). However, the 4:4:4 chrominance is currently not supported in any profile.

Data rate control

It is essential that the number of transmitted bits per service can be dynamically allocated. Certain program services may contain more information and demand more bits to be allocated for required quality while others may need less. The data rate control can be implemented in two ways, which are both supported by the MPEG-2 specification. A bit_rate description is transmitted with the Sequence Header Code.

For constant bit rate (CBR) coding, the number of transmitted bits per service is constant on the channel. Since the encoder output rate generally varies depending on the picture content, the constant rate is regulated by buffering. In this mode, picture quality may vary depending on its content.

The other mode is known as variable bit rate (VBR) coding, in which case the number of transmitted bits per service may vary on the channel under some constriction. VBR is meant to provide constant quality coding. VBR can be used in conjunction with statistical multiplexing for multiple service to achieve coding efficiency.

Low delay mode

A low coding delay may be desirable for some services, such as live interview and call-in programs. Low coding delay mode can be obtained by setting the low_delay flag in the Sequence Header code.

The total encoding and decoding delay can be kept low by not using B-pictures. This eliminates frame reordering delay. A low buffer occupancy for both encoder and decoder is needed for low delay. By using intra update (progressive refresh) on the basis of one or more slices per frame instead of intra frames this can be accommodated.

Examples of video compression models for multiple service

Based on the MPEG-2 specification two video compression models are discussed in this section. They are MPEG-2 MP@ML and SP@ML.

In the MPEG-2 specification, profiles and levels provide a means of defining the syntax and semantics. A profile is a defined sub-set of the entire bit stream syntax. The profile can be defined by the profile identification. A level is a defined set of constraints imposed on parameters in the bit stream. For a given profile, the same syntax set is supported regardless of level. Decoders defined for a specified compliance point (profile and level) shall be capable of accommodating images encoded at lower-order compliance points.

The MP@ML stands for a main profile at main level. The specification for this model includes: I, P and B-frames, 4:2:0 chrominance sampling, frame rate of 30/29.9 Hz, maximum active horizontal pixels of 720 and vertical lines of 480 with maximum data rate of 15 Mbps. It is believed that this model is sufficient to provide high picture quality for multiple service. GA decoders are capable of decoding a MP@ML bit stream.

The second model, SP@ML, is a simple profile with main level. The difference between SP@ML and MP@ML is that SP@ML provides lower coding delay than that of MP@ML. By not using B-frames in SP@ML frame reordering delay can be reduced (0 frame delay for the field-based, 1 frame delay for the frame-based).

3.2 Audio compression system

The audio compression system in the GA system is the Dolby AC-3 multiple-channel audio compression system. It can support up to six audio channels for every video channel. The AC-3 syntax support bit rates ranging from 32 kbps to 640 kbps per individual AC-3 elementary stream. An AC-3 elementary stream may convey many types of audio services. The major service types are main service and associated service. Under the GA system specification receivers shall support the decoding of main audio services at bit rates up to and including 384 kbps, and support the decoding of the combination of a main service and a single associated service with a combined maximum bit rate of 512 kbps.

For multiple services, the total number of audio channels can be determined by the number of video services and the number of audio channels associated with each video service. The total audio data rate in a multiple service data stream is determined by not only the total number of audio channels, but also the audio quality associated with each service.

Examples of audio compression model for multiple service

To estimate the audio data rate needed for multiple services a potential model is presented: Assume that a total of four video channels are transmitted in the GA data stream and four audio channels are associated with each video service. For each video channel four audio channels are further defined as main service and associated service with 2-channel each. The main service could be a stereo pair. The associated service could be a second audio program (SAP) and a descriptive video service (DVS). In this example both the maximum data rate and minimum data rate constrained by the AC-3 specification are used for each category. With these assumptions the total audio data rate can be calculated as follows:

• Maximum data rate case:

Total audio data rate = 4 x (2 x 256 + 2 x 192) = 3.584 Mbps

• Minimum data rate case:

Total audio data rate = 4 x (2 x 128 + 2 x 96) = 1.792 Mbps

3.3 Transport system

The GA transport system is based on the MPEG-2 transport system specification. MPEG-2 transport system compatibility implies that a GA transport bit stream may handle other MPEG-2 applications. The GA transport system provides three major functions: packetization, multiplexing and synchronization.

Fixed length transport stream

In the GA transport system the MPEG-2 transport stream approach is utilized. Transport streams have advantages for environments where errors and data loss events are likely. Furthermore, the transport stream combines one or more programs with one or more independent time bases into a single stream. In the GA transport stream each packet is transmitted in a fixed length with transport header preceded. The fixed length packetization offers a great deal of flexibility when attempting to multiplex multiple service data on a single bit stream.

Dynamic capacity allocation

By using fixed length packets complete flexibility to allocate channel capacity for multiple video, audio and auxiliary data services can be obtained. The use of a packet id (PID) in the packet header as a means of bit stream identification makes it possible to have a mix of multiple video, audio and auxiliary data services. The entire channel capacity could also be used in bursts for data delivery.

Packet identification

Packet identification (PID) is essential for multiple service transmission in the GA transport system. It provides the mechanism for multiplexing and demultiplexing bit streams by enabling identification of packets belonging to a particular elementary or control bit stream.

Program specific information (PSI)

The MPEG-2 transport system is designed to multiplex a set of programs into a single data stream. These programs, along with their associated elementary video, audio and data streams, are identified by the program specific information (PSI) tables. These tables provide the structure for the management of the programs within the transport stream, thus enabling a decoder to extract, re-assemble, and display individual programs selected by users. All specific information in the tables is treated as private data and left for broadcasters and other service providers to sort out among themselves.

Multiplexing

The GA multiplexing approach can be defined as a combination of multiplexing at two different layers. In the first layer a program transport stream is formed by multiplexing one or more elementary bit streams such as video, audio and data. In the second layer the program transport streams are combined (using asynchronous packet multiplexing) to form the overall system. The second layer is called the system multiplex which is the key for the transmission of multiple services. Multiplexing of multiple services within a single bit stream is achieved before the modulator in the transmitter. Demultiplexing takes place after the demodulator in the receiver.

Single program transport multiplex

In this layer a transport stream is formed by multiplexing individual packetized elementary bit streams sharing a common time-base and a control bit stream that describes the program. Elementary PID defines a coded video, coded audio or other coded bit stream by indicating the type of data stored in the packet payload. Individual programs in a multiple service transmission data stream can be extracted by identifying assigned PIDs. Elementary PID is stored in the link header. The program_map_table which is one of the tables defined by the PSI in the transport stream provides the mappings between program numbers and the elementary streams that comprise them.

The transport syntax allows a program to be comprised of a large number of elementary bit streams, with no restriction on the types of applications required within a program. A program transport stream does not need to contain compressed video or audio bit streams, or for example, it could contain multiple audio bit streams for a given video bit stream.

System multiplex

In the GA transport system, multiple services can be achieved by use of the system multiplex. In addition to the transport bit streams (with the corresponding PIDs) that define the individual programs, a system level control bit stream with PID = 0 is defined. This bit stream carries the program_association_table that maps program identities to their program transport streams. The program_association_table enables demultiplexing of programs by decoders. The program identity is represented by a number in the program_association_table. The map indicates the program_map_PID of the bit stream containing the program_map_table for a program. As a table specified by the PSI layer, the program_association_table is transmitted as the payload of the bit stream.

The process of identifying a program and its contents takes place in two stages. In the first stage the PID of the bit stream carrying the program_map_table for the program is identified by using the program_association_table in the PID = 0 bit stream. In the second stage the PIDs of the elementary bit streams that make up the program from the appropriate program_map_table are obtained. Once the process is completed the filters at a demultiplexer can be set to receive the transport bit streams that correspond to the program of interest.

Statistical multiplexing

Statistical multiplexing is an efficient mechanism to provide higher quality and more consistent video relative to a fixed bandwidth system when bits can be dynamically allocated among the video streams. The benefit of statistical multiplexing depends on the number of video programs sharing the bit stream and the picture content associated with each individual programs. The benefit of statistical multiplexing increases as the number of multiplexed programs are increased.

The data rate control mechanism in the video compression layer makes the implementation of statistical multiplexing possible. Various configurations can be implemented for different applications. For example, by using limited statistical multiplexing the bit rate of any designated program video stream cannot fall below a programmable threshold and the rest of the bit rate budget can be shared with other video streams.

Synchronization

Synchronization among multiple elementary streams is accomplished with Presentation Time Stamps (PTS) in the Transport streams. Decoding of N elementary streams is synchronized by adjusting the decoding of streams to a common master time base rather than by adjusting the decoding of one stream to match that of another. The master time base may be one of the N decoders' clocks, the data source's clock, or it may be some external clock.

Synchronization of a decoding system with a channel is achieved through the use of the Program Clock Reference (PCR) in the Transport Stream. Since each program may have its own time base, there are separate PCR fields for each program in a transport stream containing multiple programs.

Access control

Implementation of a conditional access system is supported by the transport syntax with bits defined in the packet header. In the MPEG-2 specification conditional access is defined by conditional_access_table as part of the PSI. The conditional_access_table provides the association between one or more conditional access systems, their entitlement management message (EMM) streams and any special parameters associated with them. The functionality is flexible and complete in the sense of supporting all transmission aspects of applicable key encryption and descrambling approaches that may be used. Conditional access can be exercised on a elementary stream by stream basis, including the ability to selectively scramble bit streams in a program if desired.

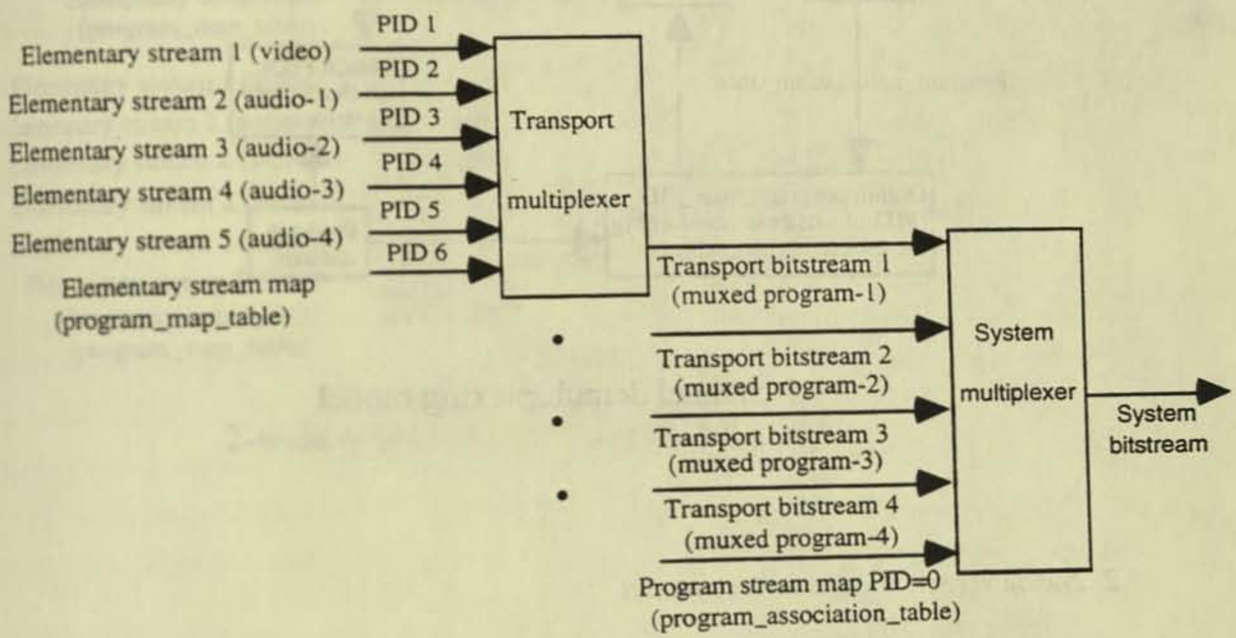
Examples of transport models for multiple service

In this section two examples are studied to examine the capability of the GA transport system for multiple service transmission.

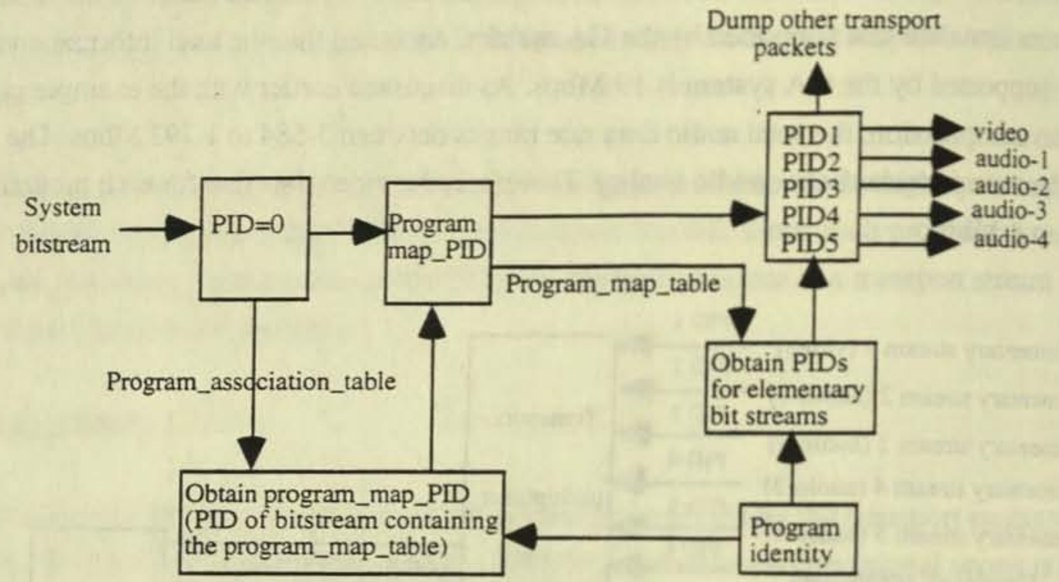
1. 4-channel service example

This model is configured with 4 independent NTSC like program channels. Each video program has four audio channels. The following block diagram illustrates the multiplexing and demultiplexing of transport bit streams. It should be noted that the layered approach to define the multiplexing function does not necessarily imply that program and system multiplexing must be implemented in separate stages. Program and system level multiplexing can be implemented within a single multiplexer stage.

For this example the video data rate for each service can be estimated based on the total information data rate supported by the GA system. Assumed that the total information data rate supported by the GA system is 19 Mbps. As discussed earlier with the example in the audio compression, the total audio data rate ranges between 3.584 to 1.792 Mbps. The higher rate provides better audio quality. Therefore, the video data rate for each program is about 4 Mbps.



4-channel multiplex model

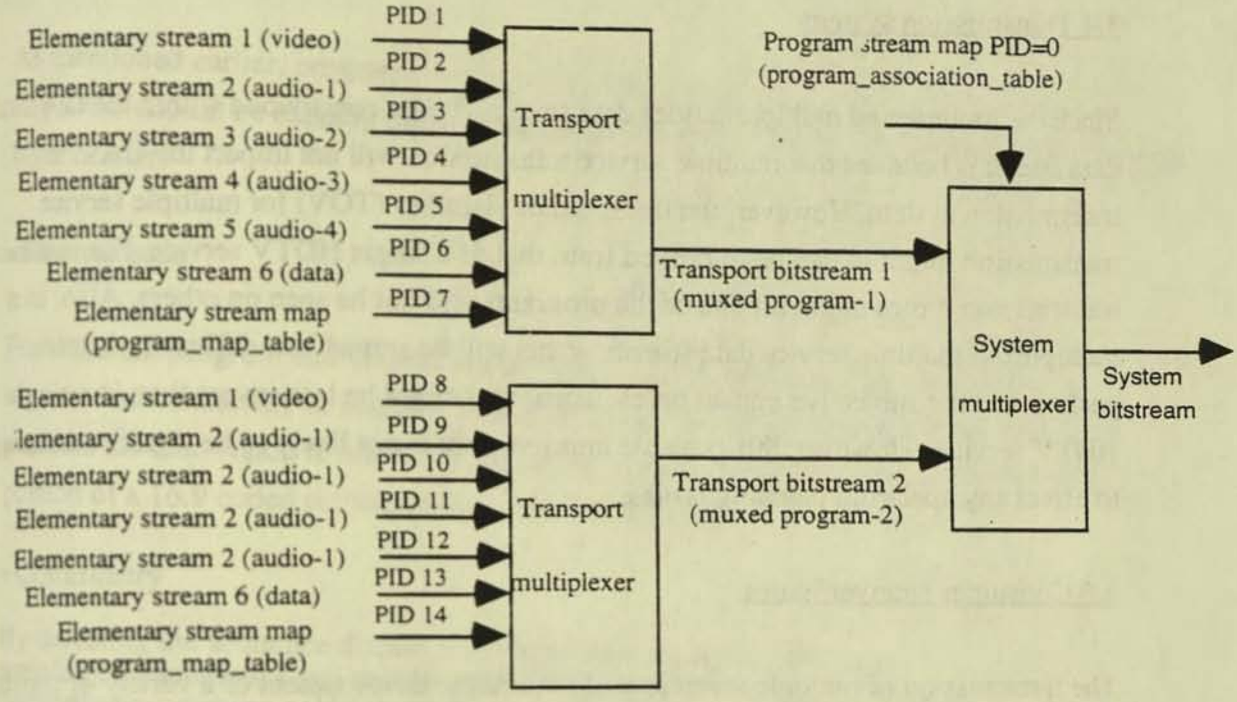


4-channel demultiplexing model

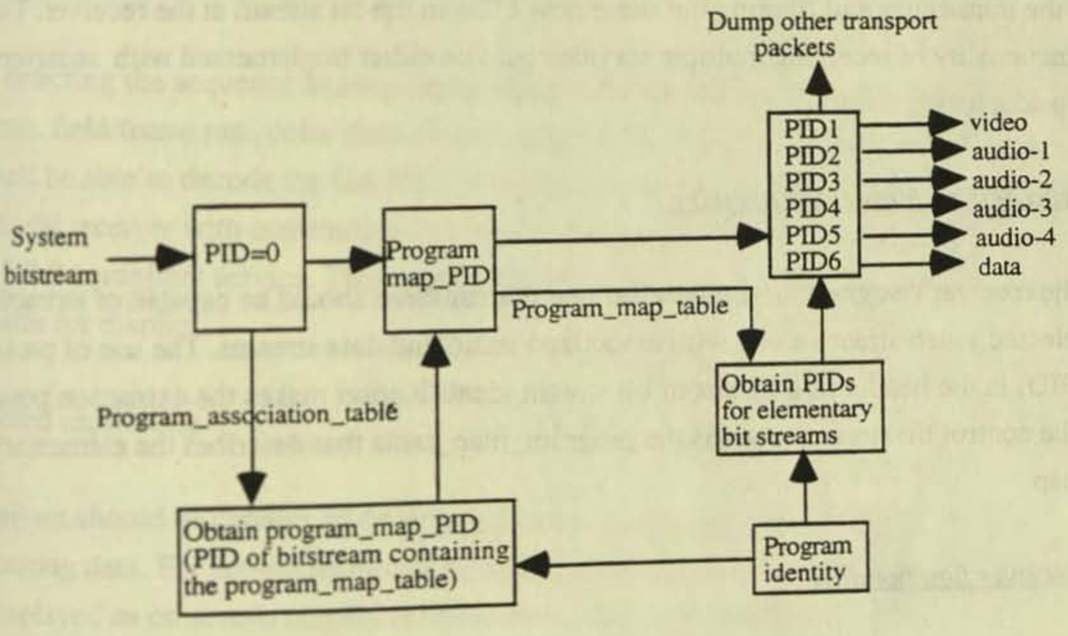
2. 2-wide screen + data service model

This example illustrates a service which provides two wide-screen NTSC programs with 4 audio channels per video program. In addition, a high speed synchronous data channel which is independent of video program service is provided for each video service. The potential applications of data service could be graphics, data and text.

Assume that the data rate of the high speed data channel is 1.5 Mbps (T1 rate) and total audio data rate is between 1.792 to 0.896 Mbps (same assumption made as the example in the section of audio compression), the video data rate for each wide-screen NTSC channel is about 7 Mbps. *It should be noted that at this video data rate the subjective picture quality of wide-screen NTSC has not been evaluated by the authors of this paper.*



2-wide-screen-channel multiplex model



2-wide-screen-channel demultiplexing model

3.4 Transmission system

Since the multiplexed multiple service data stream will be constrained within the GA total data rate, it is believed that multiple service transmission will not impact the GA transmission system. However, the threshold of visibility (TOV) for multiple service transmission might in fact be improved from that of a single HDTV service. For instance, transmission errors might hit one of the programs and not be seen on others. Also, in a multiplexed multiple service data stream, errors will be spread into different program packets and the subjective impact on each program might be less severe than in a single HDTV service. However, this possible improvement is not likely to be significant enough to effect any spectrum planning issues.

3.5 Consumer receiver issues

The transmission of multiple services will require the development of a variety of consumer devices. With the MPEG-2 transport architecture new elementary bit streams could be handled at the transport layer without hardware modifications, by assigning new packet IDs at the transmitter and filtering out these new PIDs in the bit stream at the receiver. The functionality of receiving multiple service could be either implemented with receivers or set-top adaptors.

Data demultiplexer and decoder

The receiver designed for multiple service transmission should be capable of extracting the selected video stream along with associated audio and data streams. The use of packet ID (PID) in the header as a means of bit stream identification makes the extraction possible. The control bit stream contains the program_map_table that describes the elementary stream map.

Receiver functionality

Some receiver functions should be considered so as to ensure that programs transmitted via the GA system can be correctly processed and presented. A receiver can be defined as either a HDTV receiver or a digital receiver with conventional display. The following are some issues to be considered for consumer receivers.

- Aspect ratio

As mentioned earlier, programs with 4:3 and 16:9 aspect ratios may be co-existent. Receivers should be capable of detecting aspect ratio by reading the extension of the picture layer header.

- Pan and scan

For different program and display aspect ratios, the pan and scan function should be executed automatically or selected manually based on user's choices. Receivers should perform the conversion to allow a 4:3 monitor to give a full-screen display of a selected portion of a 16:9 coded picture with correct aspect ratio.

- Colorimetry

By detecting the sequence display extension such as color_primaries, transfer_characteristics and matrix_coefficients, receivers should be capable of converting/processing colorimetry for proper display.

- Display

By detecting the sequence header, receivers should be capable of reconstructing the video format, field/frame rate, color field identification, colorimetry and etc. A HDTV receiver should be able to decode the GA HDTV signal as well as any lower MPEG-2 profile/level. A digital receiver with conventional display should be able to receive and process any MPEG-2 compliant service. This receiver should decode and downconvert HDTV data streams for display.

- Closed captioning

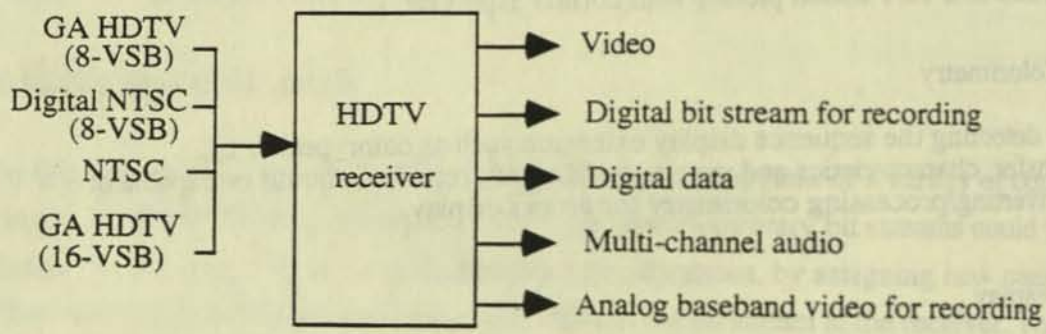
Receivers should be capable of detecting and displaying high speed HDTV closed captioning data. For set-top adaptors the high speed data should be converted so that it can be displayed as on screen display (OSD) or inserted on line 21 for display.

- Graphics and data

The receiver function of handling graphics and displaying data and text should be considered for data or graphic related services. Interface with other devices such as computers can be provided by receivers so that data could be transmitted, displayed, stored and manipulated. Separate ATV modem cards for computers could also be developed.

- Digital and analog VCR recording

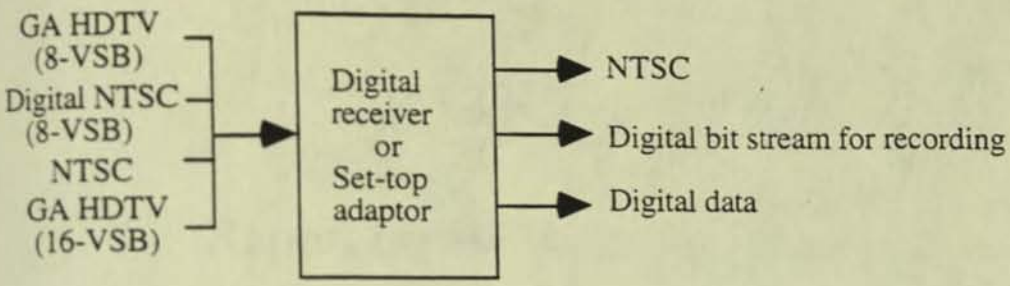
Along with the development of digital consumer VCRs a baseband serial digital interface for digital recording is necessary. The interface may exchange transport streams (packets) with a digital VCR. To provide conventional analog VCR recording, an interface is needed so that an analog baseband signal can be connected to a conventional VCR.



Functional Diagram of HDTV Receiver

Set-top adaptors

The large existing NTSC TV set population provides a consumer market for set-top adaptors. A set-top adaptor should perform the functions of demodulation, demultiplex, program data streams extraction and display format conversion. The output of the adaptor should interface with existing NTSC TV sets.



Functional Diagram of Digital Receiver/Set-top Adaptor

4. Conclusions

The Grand Alliance system utilizes a flexible transport structure along with an internationally recognized standard approach to video compression (MPEG-2). The transport layer provides the ability to multiplex and demulitiplex multiple program and data services.

The utilization of MPEG-2 for video compression provides the features required to support additional program formats such as wide screen and 4x3 aspect ratio at various resolutions. These features include the ability to specify sampling structure, picture aspect ratio, input format and information to support pan and scan. MPEG-2 also provides the ability to dynamically allocate the number of bits per service which is essential for multiple service transmission.

These attributes in conjunction with the inherent benefits of digital transmission can provide some new benefits and opportunities for broadcasters and viewers.

References

1. "Grand Alliance HDTV system specification," Version1.0, April 14, 1994.

2. Draft International Standard, "Generic coding of moving pictures and associated audio-Recommendation H.222.0," ISO/IEC 13818-1, 10 June, 1994.

3. Draft International Standard, "Generic coding of moving pictures and associated audio information: video-Recommendation H.262.0," ISO/IEC 13818-2, 10 June, 1994.

Appendix H.

Report on SDTV Video Formats

Expert Group on Scanning Formats / Compression
Report on SDTV Video Formats

SUMMARY

In a meeting conducted by the Expert Group on Scanning Formats / Compression and attended by more than fifty persons, a consensus was reached by the participants that the Advisory Committee should recommend the following SDTV formats to the FCC to accompany the HDTV formats in the ATV standard:

Recommended SDTV Video Formats

Active Lines	Horizontal Pixels	Picture Aspect Ratio		Picture Rate			
480	704	4:3	16:9	60I	60P	30P	24P
480	640	4:3		60I	60P	30P	24P

BACKGROUND

At the Technical Subgroup meeting on May 18, 1995 ATSC was asked to document the following SDTV video formats:

Active Lines	Horizontal Pixels	Picture Aspect Ratio	Picture Rate
480	704	4:3 & 16:9	60I, 30P, 24P
480	640	4:3	60I, 30P, 24P
360	480 / 640	4:3 / 16:9	60P, 30P, 24P
240	320	4:3	30P, 24P

ATSC began its documentation of the formats, but found that a number of people were concerned that sufficient discussion had not been conducted on the issue. Subsequently, Advisory Committee Chairman Wiley asked the Expert Group on Scanning Formats / Compression to conduct a full and open discussion on the SDTV formats that the Advisory Committee should recommend to the FCC to accompany the HDTV formats in the ATV standard. A review was scheduled for July 13 (and, if necessary, July 14) and widely advertised.

Over 50 persons attended the meeting. Twelve persons made formal presentations. A variety of positions were evident from the presentations. In summary, the combination of the positions stated were that:

1. The two 480-line formats should be combined into one format.
2. A picture rate of 60P should be added to the two 480-line formats.
3. The picture rate of 60I should be deleted from the two 480-line formats.
4. The picture rate of 60I should be retained in the two 480-line formats.

5. The 480-line format with 16:9 aspect ratio should have square pixels.
6. The 360-line format should be deleted.
7. The 360-line format should be retained.
8. The 240-line format should be deleted.
9. The 240-line format should be retained.
10. The pixel formats should be stated as ranges, not fixed numbers.
11. The picture aspect ratio of 2:1 should be added.
12. The picture rates of 36P and 72P should be added, or should replace 30P, 60P, and 60I.

A discussion was conducted on the various points, examining each point to determine where consensus could be reached. The participants did reach consensus on points 2 (a picture rate of 60P should be added to the two 480-line formats), 6 (the 360-line format should be deleted) and 8 (the 240-line format should be deleted). Four persons indicated that they did not agree with the consensus.

Appendix I.

Interoperability Characteristics

Interoperability Characteristics

[From the ATV System Recommendation, pp. 4-4, 4-5 (February 24, 1993)]

PS/WP4 identified a number of characteristics that contribute significantly to Interoperability, Scope of Services and Features, and Extensibility. These were based on needs and desires exhibited by alternative media advocates, not only for the delivery of terrestrial broadcast television programming, but also for other delivery approaches and applications relating to computing, communications, motion pictures, and imaging. In relative order of importance, these characteristics are:

An all-digital implementation based on a layered architecture model;

The use of universal headers and descriptors (as agreed by an industry standards group, for example, SMPTE);

Transmission of the signal in progressive scan format;

Use of a flexible, packet data transport structure;

Viewer transparent channel re-allocation (limited picture and sound while most of the channel capacity is devoted to data transmission for conditional access addressing or other purposes);

Ability to implement lower-performance, low-cost ATV receivers (comparable price/performance options to current NTSC receivers);

Ability to implement a low-cost ATV consumer VCR;

System architecture and implementation that will allow improvements and extensions to be incorporated as technology advances while maintaining backward compatibility;

Square pixels, or at least the option to select square pixel presentation;

Compatibility with relevant international standards, or commitments to this objective; and

Easily-implementable and user-accessible "still/motion multi-window transmission."

Appendix J.

Report of the Experts Group on Certification

Certification Experts Group

July 20, 1995 Meeting

Chairman's Report

Submitted to:

The Hon Richard Wiley
Chairman
ACATS

Submitted by:

Birney Dayton
Chairman
Certification Experts Group

August 8, 1995

The Certification Experts Group (CEG) met on July 20, 1995 to review the presentation of the COFDM-6 proposal by the COFDM-LLC (COFDM-Limited Liability Corporation). The CEG had been formed by the Chairman of the Advisory Committee as part of an effort to determine whether the proposed system was "demonstrably superior" to the Grand Alliance 8-VSB modem already under test.

The proposed modem had been described in an earlier mailing to the CEG, and the CEG had responded with an extensive list of questions 10 days prior to the meeting. The majority of questions had focused on several key areas of concern. Those were the following:

1. Receiver oscillator (and system) phase noise sensitivity.
2. Peak-to-average power ratio.
3. Channel linearity requirements (transmitter linearity and receiver A/D converter bit requirement).
4. Dynamic ghost rejection.
5. ATV to NTSC interference concerns related to the deployment of single frequency networks (SFNs).

The COFDM-LLC's response to some of the simpler questions for clarification of the system definition were relatively clear and concise. Unfortunately, the response to most of the five critical questions above was either not available or the system proposed for test had critical problems in the particular area. A brief summary follows.

1. The original document submitted proposed a -105 dBc (@10 kHz) spec on oscillator stability. The proposal did not clarify whether this was a specification of the receiver oscillator or the entire system. If the requirement was for the receiver only, it would represent a requirement for a 30 to 40 dB improvement over the tuners planned for VSB. If the requirement represented a system specification, then the phase jitter that could be allotted to the receiver would be even less. When questioned about this issue, the COFDM-LLC did not have a direct answer. Eventually, they allowed that in test at the CRC, the system failed at -85 dBc with a high C/N ratio. The CEG panel concluded that the original -105 dBc spec was a reasonable system spec for threshold C/N, since less than 20 dB of margin in phase noise would represent a compromise of the data eye at 64 QAM. The COFDM-LLC pointed to a recent paper by Thomson that proposed a technique to achieve phase noise performance in this region. The system proposed for test, however, achieved the requisite performance by inclusion of a laboratory type HP frequency synthesizer for the local oscillator. It was noted that such oscillators had been included in earlier proposals certified by SS/WP1 for test. It was also noted that the Grand Alliance VSB system does not require such an oscillator.

2. In response to questions about peak-to-average power ratio, the COFDM-LLC indicated that the expected ratio was 2 or 3 dB higher than VSB, and also that the C/N threshold measured in very preliminary testing by CRC was between .5 and 1 dB poorer than the Current VSB system. In the view of the CEG, this

translated to a potential coverage impact for a single transmitter installation of 2 to 4 dB depending on the actual back-off requirements of a real transmitter relative to the peak-to-average ratio.

3. A number of questions were asked regarding the requirements for both transmitter linearity, and receiver dynamic range (focused on the number of bits required in the A/D). The most useful response was that the prototype system used a 12 bit A/D. A chart was presented showing curves for an undefined COFDM system with a "large number of carriers" Whether the chart was generated for a 4 PSK, 16 QAM, or 64 QAM system was not clear. The COFDM-LLC had no quantitative data related directly to the COFDM-6 proposal to show the tradeoff between the number of effective bits in the receiver A/D and the C/N threshold. The CEG concluded that with the data presented, a minimum of 10 useful bits would be required to avoid a performance impact. The typical accuracy reduction of 2+ bits at high signal frequencies for off-the-shelf video A/D converters was pointed out, and the COFDM-LLC was asked to explain how the required A/D could be built cost-effectively. The response pointed to the above mentioned chart with the possibility that 8 effective bits might be enough. No quantitative connection to COFDM-6 or direct answer to the A/D cost issue was offered.

4. During the course of questioning, it was learned that the COFDM-6 prototype had an 8 to 10 second acquisition time, and 6 dB reduction in d/u ratio for even slowly moving ghosts (.05 Hz). After some intense questioning, the COFDM-LLC explained the nature of the acquisition and tracking system in the prototype. It was pointed out that for the system to meet the COFDM claim (and SFN requirement) of 0 dB d/u ratio, in a practical sense, it would have to achieve 0 dB for at least reasonably moving ghosts. It was further pointed out that the reason for this requirement is that, in the real world, the vast majority of ghosts are dynamic virtually all the time. The CEG concluded that to expect test results for the system that would indicate successful SFN deployment in a real world of non-static ghosts, signal acquisition would need to be several times faster, and signal tracking would need to be approximately 2 orders of magnitude faster.

5. In the questions prior to the meeting, the CEG's concern with ATV to NTSC interference was highlighted with a request for examples of COFDM and SFN deployment in several diverse markets. The COFDM-LLC presented a reasonably extensive example of coverage improvement for a single station in the Los Angeles market using one or two regional transmitters in addition to the main Mt. Wilson transmitter. Unfortunately, the presentation did not address several key issues that were highlighted in the advance questions.

   a. The presentation was made with no reference to any of the other many stations and services originating on Mt. Wilson, and the primary concern with SFN deployment is the opportunity for ATV to NTSC interference by the remote ATV transmitters.

b. In the example given, the remote transmitters were fed by microwave. In practice, microwave spectrum would likely not be available for all the stations in the LA market. The cost of fiber optic feeds was not analyzed.

c. The example given did not address how the allocation plan would be affected by the deployment of multiple synchronous transmitters, since the example involved the use of a second transmitter to cover the Mojave desert, where the next potentially interfering channel allocations are in Las Vegas. The CEG had specifically proposed the example of New York City, where many of the expected problems with SFN deployment would surface. Some of those unaddressed issues were as follows:

Lack of tower site availability for peripheral transmitters.
Allocation impact in an already short-spaced area.
Increased ATV to NTSC interference from peripheral transmitters
Potential inadequacy of 64 μs guard interval in flat terrain with multiple transmitters

The members of the CEG had expected that after a year of investigation, the COFDM-LLC would provide much more depth of explanation as to the details of deployment of both COFDM and SFNs, since most of the potential difficulties had been identified in the Technical Subgroup by early 1994.

At the end of the meeting, based on the claimed benefits of COFDM techniques and, specifically, of the COFDM modem proposed by the COFDM-LLC, as well as the shortcomings discussed above, the members of the CEG unanimously agreed on the two following statements:

"The modem presented by the COFDM-LLC is not ready for test at this time"

"The COFDM-LLC did not demonstrate the superiority of COFDM over VSB for the majority of markets."

Subsequent to the above unanimous conclusions, the COFDM-LLC requested a further hearing approximately one week later. The members of the CEG were individually polled to determine their sense of whether sufficient change could take place in a week to affect the outcome. The responses varied from "Very little likelihood that a week will make any difference" to "The same problems that were identified a year and a half ago are still here". None of the CEG members felt that a second review in the near future would change the CEG's conclusion. Accordingly, the CEG unanimously decided to not certify for test the COFDM-6 system proposed by the COFDM-LLC.

Appendix K.

ATSC Digital Television Standard

Doc. A/53
12 Apr 95
16 Sep 95

ATSC DIGITAL TELEVISION STANDARD

ADVANCED TELEVISION SYSTEMS COMMITTEE
James C. McKinney, Chairman
Dr. Robert Hopkins, Executive Director

ATSC DIGITAL TELEVISION STANDARD

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ATSC DIGITAL TELEVISION STANDARD

FOREWORD

This Standard was prepared by the Advanced Television Systems Committee (ATSC) Technology Group on Distribution (T3). The document was approved by the members of T3 on February 23, 1995 for submission by letter ballot to the membership of the full ATSC as an ATSC Standard. The document was approved by the Members of the ATSC on April 12, 1995. Changes to Annex A, to include standard definition video formats, were approved by the members of T3 on August 4, 1995 and by the Members of the ATSC on September 15, 1995.

This Standard consists of a cover document which provides background information and an overview of the digital television system defined by the Standard. The system consists of various subsystems that are described in the annexes.

1. SCOPE & DOCUMENTATION STRUCTURE

1.1 Scope

The Digital Television Standard describes the system characteristics of the U. S. advanced television (ATV) system. The document and its normative annexes provide detailed specification of the parameters of the system including the video encoder input scanning formats and the pre-processing and compression parameters of the video encoder, the audio encoder input signal format and the pre-processing and compression parameters of the audio encoder, the service multiplex and transport layer characteristics and normative specifications, and the VSB RF/Transmission subsystem.

1.2 Documentation structure

The documentation of the Digital Television Standard consists of this document which provides a general system overview, a list of reference documents, and sections relating to the system as a whole. The system is modular in concept and the specifications for each of the modules are provided in the appropriate annex.

2. REFERENCES

Normative references may be found in each normative Annex. The Digital Television Standard is based on the ISO/IEC MPEG-2 Video Standard, the Digital Audio Compression (AC-3) Standard, and the ISO/IEC MPEG-2 Systems Standard. Those references are listed

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NOTE: The user's attention is called to the possibility that compliance with this standard may require use of an invention covered by patent rights. By publication of this standard, no position is taken with respect to the validity of this claim, or of any patent rights in connection therewith. The patent holder has, however, filed a statement of willingness to grant a license under these rights on reasonable and nondiscriminatory terms and conditions to applicants desiring to obtain such a license. Details may be obtained from the publisher.

here for the convenience of the reader. In addition, a guide to the use of the Digital Television Standard is listed.

ATSC Standard A/52 (1995), *Digital Audio Compression (AC-3).*

ATSC Document A/54 (1995), *Guide to the Use of the ATSC Digital Television Standard.*

ISO/IEC IS 13818-1, International Standard (1994), *MPEG-2 Systems.*

ISO/IEC IS 13818-2, International Standard (1994), *MPEG-2 Video.*

3. DEFINITIONS

3.1 Definitions

With respect to definition of terms, abbreviations and units, the practice of the Institute of Electrical and Electronics Engineers (IEEE) as outlined in the Institute's published standards shall be used. Where an abbreviation is not covered by IEEE practice, or industry practice differs from IEEE practice, then the abbreviation in question will be described in Section 3.4 of this document. Many of the definitions included therein are derived from definitions adopted by MPEG.

3.2 Compliance notation

As used in this document, *"shall"* or *"will"* denotes a mandatory provision of the standard. *"Should"* denotes a provision that is recommended but not mandatory. *"May"* denotes a feature whose presence does not preclude compliance, that may or may not be present at the option of the implementor.

3.3 Treatment of syntactic elements

This document contains symbolic references to syntactic elements used in the audio, video, and transport coding subsystems. These references are typographically distinguished by the use of a different font (e.g., restricted), may contain the underscore character (e.g., sequence_end_code) and may consist of character strings that are not English words (e.g., dynrng).

3.4 Terms employed

For the purposes of the Digital Television Standard, the following definition of terms apply:

ACATS: Advisory Committee on Advanced Television Service.

access unit: A coded representation of a presentation unit. In the case of audio, an access unit is the coded representation of an audio frame. In the case of video, an access unit includes all the coded data for a picture, and any stuffing that follows it, up to but not including the start of the next access unit. If a picture is not preceded by a group_start_code or a sequence_header_code, the access unit begins with a the picture start code. If a picture is preceded by a group_start_code and/or a sequence_header_code, the access unit begins with the first byte of the first of these start codes. If it is the last picture preceding a sequence_end_code in the bit stream all bytes between the last byte of the coded picture and the sequence_end_code (including the sequence_end_code) belong to the access unit.

A/D: Analog to digital converter.

AES: Audio Engineering Society.

anchor frame: A video frame that is used for prediction. I-frames and P-frames are generally used as anchor frames, but B-frames are never anchor frames.

ANSI: American National Standards Institute.

Asynchronous Transfer Mode (ATM): A digital signal protocol for efficient transport of both constant-rate and bursty information in broadband digital networks. The ATM digital stream consists of fixed-length packets called "cells," each containing 53 8-bit bytes—a 5-byte header and a 48-byte information payload.

ATEL: Advanced Television Evaluation Laboratory.

ATM: See asynchronous transfer mode.

ATTC: Advanced Television Test Center.

ATV: The U. S. advanced television system.

bidirectional pictures or **B-pictures** or **B-frames:** Pictures that use both future and past pictures as a reference. This technique is termed *bidirectional prediction*. B-pictures provide the most compression. B-pictures do not propagate coding errors as they are never used as a reference.

bit rate: The rate at which the compressed bit stream is delivered from the channel to the input of a decoder.

block: A block is an 8-by-8 array of pel values or DCT coefficients representing luminance or chrominance information.

bps: Bits per second.

byte-aligned: A bit in a coded bit stream is byte-aligned if its position is a multiple of 8-bits from the first bit in the stream.

CDTV: See conventional definition television.

channel: A digital medium that stores or transports a digital television stream.

coded representation: A data element as represented in its encoded form.

compression: Reduction in the number of bits used to represent an item of data.

constant bit rate: Operation where the bit rate is constant from start to finish of the compressed bit stream.

conventional definition television (CDTV): This term is used to signify the *analog* NTSC television system as defined in ITU-R Recommendation 470. See also *standard definition television* and ITU-R Recommendation 1125.

CRC: The cyclic redundancy check to verify the correctness of the data.

D-frame: Frame coded according to an MPEG-1 mode which uses DC coefficients only.

data element: An item of data as represented before encoding and after decoding.

DCT: See discrete cosine transform.

decoded stream: The decoded reconstruction of a compressed bit stream.

decoder: An embodiment of a decoding process.

decoding (process): The process defined in the Digital Television Standard that reads an input coded bit stream and outputs decoded pictures or audio samples.

decoding time-stamp (DTS): A field that may be present in a PES packet header that indicates the time that an access unit is decoded in the system target decoder.

digital storage media (DSM): A digital storage or transmission device or system.

discrete cosine transform: A mathematical transform that can be perfectly undone and which is useful in image compression.

DSM-CC: Digital storage media command and control.

DSM: Digital storage media.

DTS: See decoding time-stamp.

DVCR: Digital video cassette recorder

ECM: See entitlement control message.

editing: A process by which one or more compressed bit streams are manipulated to produce a new compressed bit stream. Conforming edited bit streams are understood to meet the requirements defined in the Digital Television Standard.

elementary stream (ES): A generic term for one of the coded video, coded audio or other coded bit streams. One elementary stream is carried in a sequence of PES packets with one and only one stream_id.

elementary stream clock reference (ESCR): A time stamp in the PES Stream from which decoders of PES streams may derive timing.

EMM: See entitlement management message.

encoder: An embodiment of an encoding process.

encoding (process): A process that reads a stream of input pictures or audio samples and produces a valid coded bit stream as defined in the Digital Television Standard.

entitlement control message (ECM): Entitlement control messages are private conditional access information which specify control words and possibly other stream-specific, scrambling, and/or control parameters.

entitlement management message (EMM): Entitlement management messages are private conditional access information which specify the authorization level or the services of specific decoders. They may be addressed to single decoders or groups of decoders.

entropy coding: Variable length lossless coding of the digital representation of a signal to reduce redundancy.

entry point: Refers to a point in a coded bit stream after which a decoder can become properly initialized and commence syntactically correct decoding. The first transmitted picture after an entry point is either an I-picture or a P-picture. If the first transmitted picture is not an I-picture, the decoder may produce one or more pictures during acquisition.

ES: See elementary stream.

ESCR: See elementary stream clock reference.

event: An event is defined as a collection of elementary streams with a common time base, an associated start time, and an associated end time.

field: For an interlaced video signal, a "field" is the assembly of alternate lines of a frame. Therefore, an interlaced frame is composed of two fields, a top field and a bottom field.

forbidden: This term, when used in clauses defining the coded bit stream, indicates that the value shall never be used. This is usually to avoid emulation of start codes.

FPLL: Frequency and phase locked loop.

frame: A frame contains lines of spatial information of a video signal. For progressive video, these lines contain samples starting from one time instant and continuing through successive lines to the bottom of the frame. For interlaced video a frame consists of two fields, a top field and a bottom field. One of these fields will commence one field later than the other.

GOP: See group of pictures.

Group of pictures (GOP): A group of pictures consists of one or more pictures in sequence.

HDTV: See high definition television.

high definition television (HDTV): High definition television has a resolution of approximately twice that of conventional television in both the horizontal (H) and vertical (V) dimensions and a picture aspect ratio (HxV) of 16:9. ITU-R Recommendation 1125 further defines "HDTV quality" as the delivery of a television picture which is subjectively identical with the interlaced HDTV studio standard.

high level: A range of allowed picture parameters defined by the MPEG-2 video coding specification which corresponds to high definition television.

Huffman coding: A type of source coding that uses codes of different lengths to represent symbols which have unequal likelihood of occurrence.

IEC: International Electrotechnical Commission.

intra-coded pictures or **I-pictures** or **I-frames:** Pictures that are coded using information present only in the picture itself and not depending on information from other pictures. I-pictures provide a mechanism for random access into the compressed video data. I-pictures employ transform coding of the pel blocks and provide only moderate compression.

ISO: International Organization for Standardization.

ITU: International Telecommunication Union.

JEC: Joint Engineering Committee of EIA and NCTA.

layer: One of the levels in the data hierarchy of the video and system specification.

level: A range of allowed picture parameters and combinations of picture parameters.

macroblock: In the advanced television system a macroblock consists of four blocks of luminance and one each Cr and Cb block.

main level: A range of allowed picture parameters defined by the MPEG-2 video coding specification with maximum resolution equivalent to ITU-R Recommendation 601.

main profile: A subset of the syntax of the MPEG-2 video coding specification that is expected to be supported over a large range of applications.

Mbps: 1,000,000 bits per second.

motion vector: A pair of numbers which represent the vertical and horizontal displacement of a region of a reference picture for prediction.

MP@HL: Main profile at high level.

MP@ML: Main profile at main level.

MPEG: Refers to standards developed by the ISO/IEC JTC1/SC29 WG11, *Moving Picture Experts Group*. MPEG may also refer to the Group.

MPEG-1: Refers to ISO/IEC standards 11172-1 (Systems), 11172-2 (Video), 11172-3 (Audio), 11172-4 (Compliance Testing), and 11172-5 (Technical Report).

MPEG-2: Refers to ISO/IEC standards 13818-1 (Systems), 13818-2 (Video), 13818-3 (Audio), 13818-4 (Compliance).

pack: A pack consists of a pack header followed by zero or more packets. It is a layer in the system coding syntax.

packet data: Contiguous bytes of data from an elementary data stream present in the packet.

packet identifier (PID): A unique integer value used to associate elementary streams of a program in a single or multi-program transport stream.

packet: A packet consists of a header followed by a number of contiguous bytes from an elementary data stream. It is a layer in the system coding syntax.

padding: A method to adjust the average length of an audio frame in time to the duration of the corresponding PCM samples, by continuously adding a slot to the audio frame.

payload: Payload refers to the bytes which follow the header byte in a packet. For example, the payload of a transport stream packet includes the PES_packet_header and its PES_packet_data_bytes or pointer_field and PSI sections, or private data. A PES_packet_payload, however, consists only of PES_packet_data_bytes. The transport stream packet header and adaptation fields are not payload.

PCR: See program clock reference.

pel: See pixel.

PES packet header: The leading fields in a PES packet up to but not including the PES_packet_data_byte fields where the stream is not a padding stream. In the case of a padding stream, the PES packet header is defined as the leading fields in a PES packet up to but not including the padding_byte fields.

PES packet: The data structure used to carry elementary stream data. It consists of a packet header followed by PES packet payload.

PES Stream: A PES stream consists of PES packets, all of whose payloads consist of data from a single elementary stream, and all of which have the same stream_id.

PES: An abbreviation for packetized elementary stream.

picture: Source, coded or reconstructed image data. A source or reconstructed picture consists of three rectangular matrices representing the luminance and two chrominance signals.

PID: See packet identifier.

pixel: "Picture element" or "pel." A pixel is a digital sample of the color intensity values of a picture at a single point.

predicted pictures or **P-pictures** or **P-frames:** Pictures that are coded with respect to the nearest *previous* I or P-picture. This technique is termed *forward prediction*. P-pictures provide more compression than I-pictures and serve as a reference for future P-pictures or B-pictures. P-pictures can propagate coding errors when P-pictures (or B-pictures) are predicted from prior P-pictures where the prediction is flawed.

presentation time-stamp (PTS): A field that may be present in a PES packet header that indicates the time that a presentation unit is presented in the system target decoder.

presentation unit (PU): A decoded audio access unit or a decoded picture.

profile: A defined subset of the syntax specified in the MPEG-2 video coding specification

program clock reference (PCR): A time stamp in the transport stream from which decoder timing is derived.

program element: A generic term for one of the elementary streams or other data streams that may be included in the program.

program specific information (PSI): PSI consists of normative data which is necessary for the demultiplexing of transport streams and the successful regeneration of programs.

program: A program is a collection of program elements. Program elements may be elementary streams. Program elements need not have any defined time base; those that do have a common time base and are intended for synchronized presentation.

PSI: See program specific information.

PTS: See presentation time-stamp.

PU: See presentation unit.

quantizer: A processing step which intentionally reduces the precision of DCT coefficients

random access: The process of beginning to read and decode the coded bit stream at an arbitrary point.

reserved: This term, when used in clauses defining the coded bit stream, indicates that the value may be used in the future for Digital Television Standard extensions. Unless otherwise specified within this Standard, all reserved bits shall be set to "1".

SCR: See system clock reference.

scrambling: The alteration of the characteristics of a video, audio or coded data stream in order to prevent unauthorized reception of the information in a clear form. This alteration is a specified process under the control of a conditional access system.

SDTV: See standard definition television.

slice: A series of consecutive macroblocks.

SMPTE: Society of Motion Picture and Television Engineers.

source stream: A single, non-multiplexed stream of samples before compression coding.

splicing: The concatenation performed on the system level or two different elementary streams. It is understood that the resulting stream must conform totally to the Digital Television Standard.

standard definition television (SDTV): This term is used to signify a *digital* television system in which the quality is approximately equivalent to that of NTSC. This equivalent quality may be achieved from pictures sourced at the 4:2:2 level of ITU-R Recommendation 601 and subjected to processing as part of the bit rate compression. The results should be such that when judged across a representative sample of program material, subjective equivalence with NTSC is achieved. Also called standard digital television. See also *conventional definition television* and ITU-R Recommendation 1125.

start codes: 32-bit codes embedded in the coded bit stream that are unique. They are used for several purposes including identifying some of the layers in the coding syntax. Start codes consist of a 24 bit prefix (0x000001) and an 8 bit stream_id.

STD input buffer: A first-in, first-out buffer at the input of a system target decoder for storage of compressed data from elementary streams before decoding.

STD: See system target decoder.

still picture: A coded still picture consists of a video sequence containing exactly one coded picture which is intra-coded. This picture has an associated PTS and the presentation time of succeeding pictures, if any, is later than that of the still picture by at least two picture periods.

system clock reference (SCR): A time stamp in the program stream from which decoder timing is derived.

system header: The system header is a data structure that carries information summarizing the system characteristics of the Digital Television Standard multiplexed bit stream.

system target decoder (STD): A hypothetical reference model of a decoding process used to describe the semantics of the Digital Television Standard multiplexed bit stream.

time-stamp: A term that indicates the time of a specific action such as the arrival of a byte or the presentation of a presentation unit.

TOV: Threshold of visibility.

Transport Stream packet header: The leading fields in a Transport Stream packet up to and including the continuity_counter field.

variable bit rate: Operation where the bit rate varies with time during the decoding of a compressed bit stream.

VBV: See video buffering verifier.

Video buffering verifier (VBV): A hypothetical decoder that is conceptually connected to the output of an encoder. Its purpose is to provide a constraint on the variability of the data rate that an encoder can produce.

video sequence: A video sequence is represented by a sequence header, one or more groups of pictures, and an end_of_sequence code in the data stream.

8 VSB: Vestigial sideband modulation with 8 discrete amplitude levels.

16 VSB: Vestigial sideband modulation with 16 discrete amplitude levels.

3.5 Symbols, abbreviations, and mathematical operators

3.5.1 Introduction

The symbols, abbreviations, and mathematical operators used to describe the Digital Television Standard are those adopted for use in describing MPEG-2 and are similar to those used in the "C" programming language. However, integer division with truncation and rounding are specifically defined. The bitwise operators are defined assuming two's-complement representation of integers. Numbering and counting loops generally begin from 0.

3.5.2 Arithmetic operators

+	Addition.
-	Subtraction (as a binary operator) or negation (as a unary operator).
++	Increment.
- -	Decrement.
* or ×	Multiplication.
^	Power.
/	Integer division with truncation of the result toward 0. For example, 7/4 and -7/-4 are truncated to 1 and -7/4 and 7/-4 are truncated to -1.
//	Integer division with rounding to the nearest integer. Half-integer values are rounded away from 0 unless otherwise specified. For example 3//2 is rounded to 2, and -3//2 is rounded to -2.
DIV	Integer division with truncation of the result towards -∞.
%	Modulus operator. Defined only for positive numbers.
Sign( )	Sign(x) = 1 x > 0 0 x == 0 -1 x < 0
NINT ( )	Nearest integer operator. Returns the nearest integer value to the real-valued argument. Half-integer values are rounded away from 0.
sin	Sine.
cos	Cosine.
exp	Exponential.
√	Square root.
$\log_{10}$	Logarithm to base ten.
$\log_e$	Logarithm to base e.

3.5.3 Logical operators

||	Logical OR.
&&	Logical AND.
!	Logical NOT.

3.5.4 Relational operators

>	Greater than.
≥	Greater than or equal to.
<	Less than.
≤	Less than or equal to.
==	Equal to.
!=	Not equal to.
max [,...,]	The maximum value in the argument list.
min [,...,]	The minimum value in the argument list.

3.5.5 Bitwise operators

&	AND.
|	OR.
>>	Shift right with sign extension.
<<	Shift left with 0 fill.

3.5.6 Assignment

=	Assignment operator.

3.5.7 Mnemonics

The following mnemonics are defined to describe the different data types used in the coded bit stream.

bslbf	Bit string, left bit first, where "left" is the order in which bit strings are written in the Standard. Bit strings are written as a string of 1s and 0s within single quote marks, e.g. '1000 0001'. Blanks within a bit string are for ease of reading and have no significance.
uimsbf	Unsigned integer, most significant bit first.

The byte order of multi-byte words is most significant byte first.

3.5.8 Constants

π	3.14159265359...
e	2.71828182845...

3.5.9 Method of describing bit stream syntax

Each data item in the coded bit stream described below is in bold type. It is described by its name, its length in bits, and a mnemonic for its type and order of transmission.

The action caused by a decoded data element in a bit stream depends on the value of that data element and on data elements previously decoded. The decoding of the data elements and definition of the state variables used in their decoding are described in the clauses containing the semantic description of the syntax. The following constructs are used to express the conditions when data elements are present, and are in normal type.

Note this syntax uses the "C" code convention that a variable or expression evaluating to a non-zero value is equivalent to a condition that is true.

```
while ( condition ) {
    data_element
    . . .
}
```

If the condition is true, then the group of data elements occurs next in the data stream. This repeats until the condition is not true.

```
do {
    data_element
    . . . }
while ( condition )
```

The data element always occurs at least once. The data element is repeated until the condition is not true.

```
if ( condition) {
    data_element
    . . .
}
```

If the condition is true, then the first group of data elements occurs next in the data stream.

```
else {
    data_element
    . . .
}
```

If the condition is not true, then the second group of data elements occurs next in the data stream.

```
for (i = 0;i<n;i++) {
    data_element
    . . .
}
```

The group of data elements occurs n times. Conditional constructs within the group of data elements may depend on the value of the loop control variable i, which is set to zero for the first occurrence, incremented to 1 for the second occurrence, and so forth.

As noted, the group of data elements may contain nested conditional constructs. For compactness, the {} are omitted when only one data element follows.

data_element [ ]	data_element [ ] is an array of data. The number of data elements is indicated by the context.
data_element [n]	data_element [n] is the n+1th element of an array of data.
data_element [m][n]	data_element [m][n] is the m+1,n+1 th element of a two-dimensional array of data.
data_element [l][m][n]	data_element [l][m][n] is the l+1,m+1,n+1 th element of a three-dimensional array of data.
data_element [m..n]	data_element [m..n] is the inclusive range of bits between bit m and bit n in the data_element.

Decoders must include a means to look for start codes and sync bytes (transport stream) in order to begin decoding correctly, and to identify errors, erasures or insertions while decoding. The methods to identify these situations, and the actions to be taken, are not standardized.

3.5.9.1 Definition of bytealigned function

The function bytealigned( ) returns 1 if the current position is on a byte boundary; that is, the next bit in the bit stream is the first bit in a byte. Otherwise it returns 0.

3.5.9.2 Definition of nextbits function

The function nextbits( ) permits comparison of a bit string with the next bits to be decoded in the bit stream.

3.5.9.3 Definition of next_start_code function

The next_start_code( ) function removes any zero bit and zero byte stuffing and locates the next start code.

This function checks whether the current position is byte-aligned. If it is not, 0 stuffing bits are present. After that any number of 0 bytes may be present before the start-code. Therefore start-codes are always byte-aligned and may be preceded by any number of 0 stuffing bits.

Table 3.1 Next Start Code

Syntax	No. of bits	Mnemonic
next_start_code( ) {		
while (!bytealigned( ))		
zero_bit	1	'0'
while (nextbits( )!='0000 0000 0000 0000 0000 0001')		
zero_byte	8	'00000000'
}		

4. BACKGROUND

4.1 Advanced Television Systems Committee (ATSC)

The Advanced Television Systems Committee, chaired by James C. McKinney, was formed by the member organizations of the Joint Committee on InterSociety Coordination (JCIC)[1] for the purpose of exploring the need for and, where appropriate, to coordinate development of the documentation of Advanced Television Systems. Documentation is understood to include voluntary technical standards, recommended practices, and engineering guidelines.

[1] The JCIC is presently composed of: the Electronic Industries Association (EIA), the Institute of Electrical and Electronics Engineers (IEEE), the National Association of Broadcasters (NAB), the National Cable Television Association (NCTA), and the Society of Motion Picture and Television Engineers (SMPTE).

Proposed documentation may be developed by the ATSC, by member organizations of the JCIC, or by existing standards committees. The ATSC was established recognizing that the prompt, efficient and effective development of a coordinated set of national standards is essential to the future development of domestic television services.

On June 5, 1992 ATSC provided information to the Federal Communications Commission (FCC) outlining proposed industry actions to fully document the advanced television system standard. The FCC has recognized the importance of prompt disclosure of the system technical specifications to the mass production of advanced television system professional and consumer equipment in a timely fashion. The FCC has further noted its appreciation of the diligence with which the ATSC and the other groups participating in the standardization are pursuing these matters.[2]

Supporting this activity, the ATSC Executive Committee requested that the T3/S1 Specialist Group on Macro Systems Approach meet and suggest which portions of an advanced television system broadcasting standard might require action by the FCC and which portions should be voluntary.

Subsequently, T3/S1 held meetings and developed recommendations in two areas:

1. Principles upon which documentation of the advanced television system should be based; and
2. A list of characteristics of an advanced television system that should be documented.

The list tentatively identified the industry group(s) that would provide the documentation information and the document where the information would likely appear.

The recommendations developed by the T3/S1 Specialist Group were modified by T3 to accommodate information and knowledge about advanced television systems developed in the period since June 1992. Some of the modifications to the recommendations ensued from the formation of the Grand Alliance. The modified guidelines were approved at the March 31, 1994 meeting of the T3 Technology Group on Distribution and are described in Section 4.5.

4.2 Advisory Committee on Advanced Television Service (ACATS)

A "Petition for Notice of Inquiry" was filed with the FCC on February 21, 1987 by 58 broadcasting organizations and companies requesting that the Commission initiate a proceeding to explore the issues arising from the introduction of advanced television technologies and their possible impact on the television broadcasting service. At that time, it was generally believed that High Definition Television (HDTV) could not be broadcast using 6 MHz terrestrial broadcasting channels. The broadcasting organizations were concerned that the alternative media would be able to deliver HDTV to the viewing public placing terrestrial broadcasting at a severe disadvantage.

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[2] FCC 92-438, MM Docket No. 87-268, "Memorandum Opinion and Order/Third Report and Order/Third Further Notice of Proposed Rule Making," Adopted: September 17, 1992, pp. 59-60.

The FCC agreed that this was a subject of utmost importance and initiated a proceeding (MM Docket No. 87-268) to consider the technical and public policy issues of advanced television systems. The Advisory Committee on Advanced Television Service was empaneled by the Federal Communications Commission in 1987 with Richard E. Wiley as chairman to develop information that would assist the FCC in establishing an advanced television standard for the United States. The objective given to the Advisory Committee in its Charter by the FCC was:

> "The Committee will advise the Federal Communications Commission on the facts and circumstances regarding advanced television systems for Commission consideration of technical and public policy issues. In the event that the Commission decides that adoption of some form of advanced broadcast television is in the public interest, the Committee would also recommend policies, standards and regulations that would facilitate the orderly and timely introduction of advanced television services in the United States."

The Advisory Committee established a series of subgroups to study the various issues concerning services, technical parameters, and testing mechanisms required to establish an Advanced television system standard. The Advisory Committee also established a system evaluation, test and analysis process that began with over twenty proposed systems, reducing them to four final systems for consideration.

4.3 Digital HDTV Grand Alliance (Grand Alliance)

On May 24, 1993 the three groups that had developed the four final digital systems agreed to produce a single, best-of-the best system to propose as the standard. The three groups (AT&T and Zenith Electronics Corporation; General Instrument Corporation and the Massachusetts Institute of Technology; and Philips Consumer Electronics, Thomson Consumer Electronics, and the David Sarnoff Research Center) have been working together as the "Digital HDTV Grand Alliance." The system described in this Standard is based on the Digital HDTV Grand Alliance proposal to the Advisory Committee.

4.4 Organization for documenting the Digital Television Standard

The ATSC Executive Committee assigned the work of documenting the advanced television system standards to T3 specialist groups dividing the work into five areas of interest: **Video** (including input signal format and source coding), **Audio** (including input signal format and source coding), **Transport** (including data multiplex and channel coding), **RF/Transmission**, (including the modulation subsystem) and **Receiver** characteristics. A steering committee consisting of the chairs of the five specialist groups, the chair and vice-chairs of T3, and liaison among the ATSC, the FCC, and ACATS was established to coordinate the development of the documents. The members of the steering committee and areas of interest were as follows:

Stanley Baron	T3 chair
Jules Cohen	T3 vice-chair
Brian James	T3 vice-chair

Larry Pearlstein	T3/S6 (Video systems characteristics), chair
Graham S. Stubbs	T3/S7 (Audio systems characteristics), chair
Bernard J. Lechner	T3/S8 (Service multiplex and transport systems characteristics), chair
Lynn D. Claudy	T3/S9 (RF/Transmission systems characteristics), chair
Werner F. Wedam	T3/S10 (Receiver characteristics), chair
Robert M. Rast	Grand Alliance facilitator
Robert Hopkins	ATSC
Robert M. Bromery	FCC Office of Engineering and Technology
Gordon Godfrey	FCC Mass Media Bureau
Paul E. Misener	ACATS

4.5 Principles for documenting the Digital Television Standard

T3 adopted the following principles for documenting the advanced television system standard:

1. The Grand Alliance was recognized as the principal supplier of information for documenting the advanced television system, supported by the ATSC and others. Other organizations seen as suppliers of information: EIA, FCC, IEEE, MPEG, NCTA, and SMPTE.
2. The Grand Alliance was encouraged to begin drafting the essential elements of system details as soon as possible to avoid delays in producing the advanced television system documentation.
3. FCC requirements for the advanced television system standard were to be obtained as soon as possible.
4. Complete functional system details (permitting those skilled in the art to construct a working system) were to be made publicly available.
5. Protection of any intellectual property made public must be by patent or copyright as appropriate.
6. The advanced television system documentation shall include the necessary system information such that audio and video encoders may be manufactured to deliver the system's full demonstrated performance quality.
7. The advanced television system documentation shall point to existing standards, recommended practices or guideline documents. These documents shall be referenced in one of two ways as deemed appropriate for the application. In the first instance, a specific revision shall be specified where review of changes to the referenced document is required before changes might be incorporated into the advanced television system document. The second instance references the document without specificity to revision and allows any changes to the referenced documents to be automatically incorporated.

8. System specifications shall explain how future, compatible improvements may be achieved.

9. As ongoing improvements take place in the advanced television system, manufacturers of encoders and decoders should coordinate their efforts to insure compatibility.

10. The advanced television system standard must support backward compatibility of future improvements with all generations of advanced television system receivers and inherently support production of low cost receivers (not withstanding that cost reduction through reduced performance quality may also be used to achieve inexpensive products).

11. The advanced television system standard should not foreclose flexibility in implementing advanced television system receivers at different price and performance levels.

12. The advanced television system standard should not foreclose flexibility in implementing program services or in data stream modification or insertion of data packets by down-stream (local) service providers.

13. The advanced television system documentation shall address interoperability with non-broadcast delivery systems including cable.

14. The advanced television system standard shall identify critical system parameters and shall provide information as to the range of acceptable values, the method of measurement, and the location in the system where measurement takes place.

5. SYSTEM OVERVIEW

5.1 Objectives

The Digital Television Standard describes a system designed to transmit high quality video and audio and ancillary data over a single 6 MHz channel. The system can deliver reliably about 19 Mbps of throughput in a 6 MHz terrestrial broadcasting channel and about 38 Mbps of throughput in a 6 MHz cable television channel. This means that encoding a video source whose resolution can be as high as five times that of conventional television (NTSC) resolution requires a bit rate reduction by a factor of 50 or higher. To achieve this bit rate reduction, the system is designed to be efficient in utilizing available channel capacity by exploiting complex video and audio compression technology.

The objective is to maximize the information passed through the data channel by minimizing the amount of data required to represent the video image sequence and its associated audio. The objective is to represent the video, audio, and data sources with as few bits as possible while preserving the level of quality required for the given application.

Although the RF/Transmission subsystems described in this Standard are designed specifically for terrestrial and cable applications, the objective is that the video, audio, and service multiplex/transport subsystems be useful in other applications.

5.2 System block diagram

A basic block diagram representation of the system is shown in Figure 5.1. This representation is based on one adopted by the International Telecommunication Union, Radiocommunication Sector (ITU-R), Task Group 11/3 (Digital Terrestrial Television Broadcasting). According to this model, the digital television system can be seen to consist of three subsystems.[3]

1. Source coding and compression,
2. Service multiplex and transport, and
3. RF/Transmission.

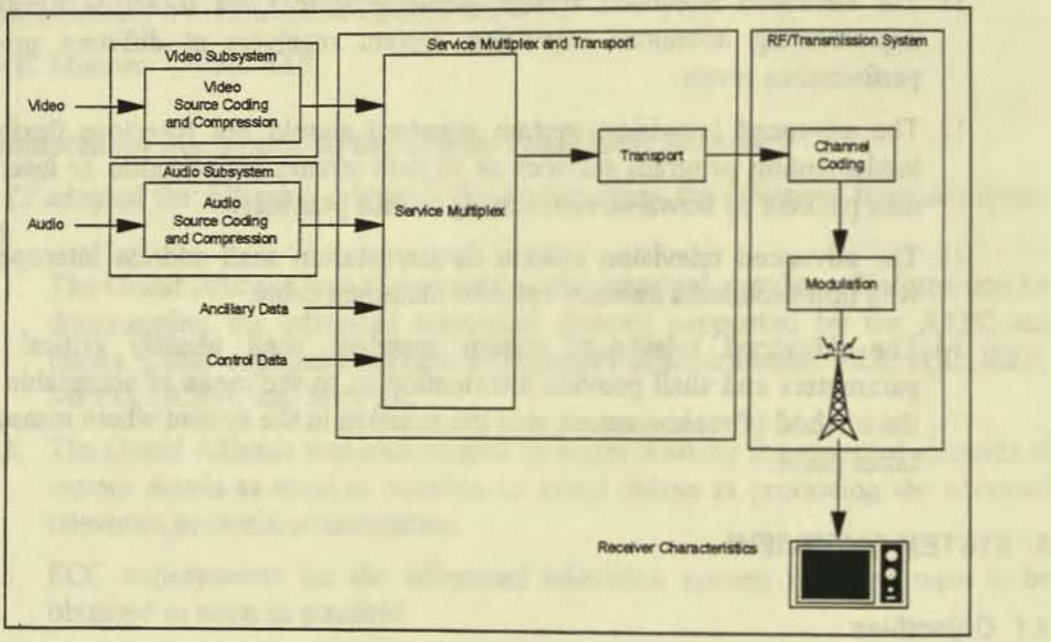


Figure 5.1. ITU-R digital terrestrial television broadcasting model.

"Source coding and compression" refers to the bit rate reduction methods, also known as data compression, appropriate for application to the video, audio, and ancillary digital data streams. The term "ancillary data" includes control data, conditional access control data, and data associated with the program audio and video services, such as closed captioning. "Ancillary data" can also refer to independent program services. The purpose of the coder is to minimize the number of bits needed to represent the audio and video information. The digital television system employs the MPEG-2 video stream syntax for the coding of video and the Digital Audio Compression (AC-3) Standard for the coding of audio.

"Service multiplex and transport" refers to the means of dividing the digital data stream into "packets" of information, the means of uniquely identifying each packet or packet type,

[3] ITU-R Document TG11/3-2, "Outline of Work for Task Group 11/3, Digital Terrestrial Television Broadcasting," June 30, 1992.

and the appropriate methods of multiplexing video data stream packets, audio data stream packets, and ancillary data stream packets into a single data stream. In developing the transport mechanism, interoperability among digital media, such as terrestrial broadcasting, cable distribution, satellite distribution, recording media, and computer interfaces, was a prime consideration. The digital television system employs the MPEG-2 transport stream syntax for the packetization and multiplexing of video, audio, and data signals for digital broadcasting systems.[4] The MPEG-2 transport stream syntax was developed for applications where channel bandwidth or recording media capacity is limited and the requirement for an efficient transport mechanism is paramount. It was designed also to facilitate interoperability with the ATM transport mechanism.

"RF/Transmission" refers to channel coding and modulation. The channel coder takes the data bit stream and adds additional information that can be used by the receiver to reconstruct the data from the received signal which, due to transmission impairments, may not accurately represent the transmitted signal. The modulation (or physical layer) uses the digital data stream information to modulate the transmitted signal. The modulation subsystem offers two modes: a terrestrial broadcast mode (8 VSB), and a high data rate mode (16 VSB).

Figure 5.2 illustrates a high level view of encoding equipment. This view is not intended to be complete, but is used to illustrate the relationship of various clock frequencies within the encoder. There are two domains within the encoder where a set of frequencies are related, the source coding domain and the channel coding domain.

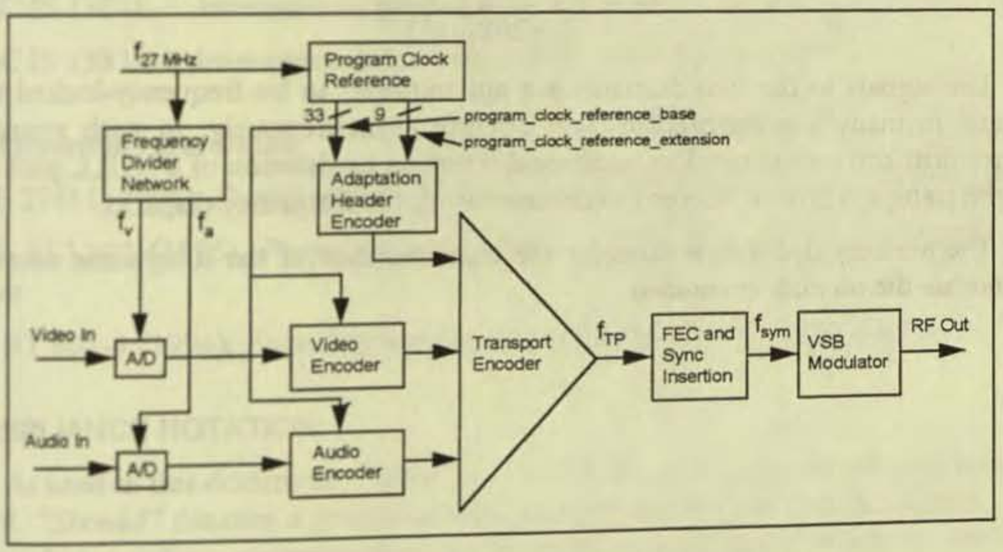


Figure 5.2. High level view of encoding equipment.

The source coding domain, represented schematically by the video, audio and transport encoders, uses a family of frequencies which are based on a 27 MHz clock (f_{27MHz}). This clock is used to generate a 42-bit sample of the frequency which is

[4] Chairman, ITU-R Task Group 11/3, "Report of the Second Meeting of ITU-R Task Group 11/3, Geneva, October 13-19, 1993," January 5, 1994, p. 40.

partitioned into two parts defined by the MPEG-2 specification. These are the 33-bit program_clock_reference_base and the 9-bit program_clock_reference_extension. The former is equivalent to a sample of a 90 kHz clock which is locked in frequency to the 27 MHz clock, and is used by the audio and video source encoders when encoding the presentation time stamp (PTS) and the decode time stamp (DTS). The audio and video sampling clocks, f_a and f_v respectively, must be frequency-locked to the 27 MHz clock. This can be expressed as the requirement that there exist two pairs of integers, (n_a, m_a) and (n_v, m_v), such that:

$$f_a = \left(\frac{n_a}{m_a}\right) x\ 27MHz$$

and

$$f_v = \left(\frac{n_v}{m_v}\right) x\ 27MHz$$

The channel coding domain is represented by the FEC/Sync Insertion subsystem and the VSB modulator. The relevant frequencies in this domain are the VSB symbol frequency (f_{sym})and the frequency of the transport stream (f_{TP}) which is the frequency of transmission of the encoded transport stream. These two frequencies must be locked, having the relation:

$$f_{TP} = 2\ x \left(\frac{188}{208}\right)\left(\frac{312}{313}\right) f_{sym}$$

The signals in the two domains are not required to be frequency-locked to each other, and in many implementations will operate asynchronously. In such systems, the frequency drift can necessitate the occasional insertion or deletion of a NULL packet from within the transport stream, thereby accommodating the frequency disparity.

The annexes that follow consider the characteristics of the subsystems necessary to accommodate the services envisioned.

ANNEX A

(Normative)

VIDEO SYSTEMS CHARACTERISTICS

1. SCOPE

This Annex describes the characteristics of the video subsystem of the Digital Television Standard. The input formats and bit stream characteristics are described in separate sections.

2. REFERENCES

2.1 Normative references

The following documents contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreement based on this standard are encouraged to investigate the possibility of applying the most recent editions of the documents listed below.

ISO/IEC IS 13818-1, International Standard (1994), *MPEG-2 Systems.*

ISO/IEC IS 13818-2, International Standard (1994), *MPEG-2 Video.*

2.2 Informative references

SMPTE 274M (1995), *Standard for television, 1920 x 1080 Scanning and Interface.*

SMPTE S17.392 (1995), *Proposed Standard for television, 1280 x 720 Scanning and Interface.*

ITU-R BT.601-4 (1994), *Encoding parameters of digital television for studios.*

3. COMPLIANCE NOTATION

As used in this document, *"shall"* or *"will"* denotes a mandatory provision of the standard. *"Should"* denotes a provision that is recommended but not mandatory. *"May"* denotes a feature whose presence does not preclude compliance, that may or may not be present at the option of the implementor.

4. POSSIBLE VIDEO INPUTS

While not required by this standard, there are certain television production standards, shown in Table 1, that define video formats that relate to compression formats specified by this standard.

Table 1 Standardized Video Input Formats

Video standard	Active lines	Active samples/ line
SMPTE 274M	1080	1920
SMPTE S17.392	720	1280
ITU-R BT.601-4	483	720

The compression formats may be derived from one or more appropriate video input formats. It may be anticipated that additional video production standards will be developed in the future that extend the number of possible input formats.

5. SOURCE CODING SPECIFICATION

The ATV video compression algorithm shall conform to the Main Profile syntax of ISO/IEC 13818-2. The allowable parameters shall be bounded by the upper limits specified for the Main Profile at High Level.[1] Additionally, ATV bit streams shall meet the constraints and specifications described in Sections 5.1 and 5.2.

5.1 Constraints with respect to ISO/IEC 13818-2 Main Profile

The following tables list the allowed values for each of the ISO/IEC 13818-2 syntactic elements which are restricted beyond the limits imposed by MP@HL.

In these tables conventional numbers denote decimal values, numbers preceded by **0x** are to be interpreted as hexadecimal values and numbers within single quotes (e.g., '10010100') are to be interpreted as a string of binary digits.

5.1.1 Sequence header constraints

Table 2 identifies parameters in the sequence header of a bit stream that shall be constrained by the video subsystem and lists the allowed values for each.

Table 2 Sequence Header Constraints

Sequence header syntactic element	Allowed value
horizontal_size_value	see Table 3
vertical_size_value	see Table 3
aspect_ratio_information	see Table 3
frame_rate_code	see Table 3
bit_rate_value (≤ 19.4 Mbps)	≤ 48500
bit_rate_value (≤ 38.8 Mbps)	≤ 97000
vbv_buffer_size_value	≤ 488

The allowable values for the field bit_rate_value are application dependent. In the primary application of terrestrial broadcast, this field shall correspond to a bit rate which is less than or equal to 19.4 Mbps. In the high data rate mode, the corresponding bit rate is less than or equal to 38.8 Mbps.

[1] See ISO/IEC 13818-2, Section 8 for more information regarding profiles and levels.

5.1.2 Compression format constraints

Table 3 lists the allowed compression formats.

Table 3 Compression Format Constraints

vertical_size_ value	horizontal_size_ value	aspect_ratio_ information	frame_rate_ code	progressive_ sequence
1080[2]	1920	1,3	1,2,4,5	1
			4,5	0
720	1280	1,3	1,2,4,5,7,8	1
480	704	2,3	1,2,4,5,7,8	1
			4,5	0
	640	1,2	1,2,4,5,7,8	1
			4,5	0

Legend for MPEG-2 coded values in Table 3
aspect_ratio_information 1 = square samples 2 = 4:3 display aspect ratio 3 = 16:9 display aspect ratio
frame_rate_code 1 = 23.976 Hz 2 = 24 Hz 4 = 29.97 Hz 5 = 30 Hz 7 = 59.94 Hz 8 = 60 Hz
progressive_sequence 0 = interlaced scan 1 = progressive scan

5.1.3 Sequence extension constraints

Table 4 identifies parameters in the sequence extension part of a bit stream that shall be constrained by the video subsystem and lists the allowed values for each. A sequence_extension structure is required to be present after every sequence_header structure.

Table 4 Sequence Extension Constraints

Sequence extension syntactic element	Allowed values
progressive_sequence	see Table 3
profile_and_level_indication	see Note
chroma_format	'01'
horizontal_size_extension	'00'
vertical_size_extension	'00'
bit_rate_extension	'0000 0000 0000'
vbv_buffer_size_extension	'0000 0000'
frame_rate_extension_n	'00'
frame_rate_extension_d	'0000 0'

Note: The profile_and_level_indication field shall indicate the lowest profile and level defined in ISO/IEC 13818-2, Section 8, that is consistent with the parameters of the video elementary stream.

[2] Note that 1088 lines are actually coded in order to satisfy the MPEG-2 requirement that the coded vertical size be a multiple of 16 (progressive scan) or 32 (interlaced scan).

5.1.4 Sequence display extension constraints

Table 5 identifies parameters in the sequence display extension part of a bit stream that shall be constrained by the video subsystem and lists the allowed values for each.

Table 5 Sequence Display Extension Constraints

Sequence display extension syntactic element	Allowed values
video_format	'000'

The preferred and default values for color_primaries, transfer_characteristics, and matrix_coefficients are defined to be SMPTE 274M[3] (value 0x01 in all three cases). While all values described by MPEG-2 are allowed in the transmitted bit stream, it is noted that SMPTE 170M values (0x06 in all three cases) will be the most likely alternate in common use.

5.1.5 Picture header constraints

In all cases other than when vbv_delay has the value 0xFFFF, the value of vbv_delay shall be constrained as follows:

vbv_delay $\leq$ 45000

5.2 Bit stream specifications beyond MPEG-2

This section covers the extension and user data part of the video syntax. These data are inserted at the sequence, GOP, and picture level. The syntax used for the insertion of closed captioning in picture user data is described.[4]

5.2.1 Picture extension and user data syntax

Table 6 describes the syntax used for picture extension and user data.

Table 6 Picture Extension and User Data Syntax

	No. of bits	Mnemonic
extension_and_user_data(2) {		
while ((nextbits( ) == extension_start_code) || (nextbits() == user_data_start_code)) {		
if (nextbits()== extension_start_code)		
extension_data(2)		
if (nextbits() == user_data_start_code)		
user_data(2)		
}		
}		

[3] At some point in the future, the color gamut may be extended by allowing negative values of RGB and defining the transfer characteristics for negative RGB values.

[4] In order to decode the user data, the decoder should properly recognize the 32-bit ATSC registration identifier at the PSI stream level (see ISO/IEC 13818-1).

5.2.2 Picture user data syntax

Table 7 describes the picture user data syntax.

Table 7 Picture User Data Syntax[5]

	No. of bits	Mnemonic
user_data( ) {		
user_data_start_code	32	bslbf
ATSC_identifier	32	bslbf
user_data_type_code	8	uimsbf
if (user_data_type_code == '0x03') {		
process_em_data_flag	1	bslbf
process_cc_data_flag	1	bslbf
additional_data_flag	1	bslbf
cc_count	5	uimsbf
em_data	8	bslbf
for (i=0 ; i < cc_count ; i++) {		
marker_bits	5	'1111 1'
cc_valid	1	bslbf
cc_type	2	bslbf
cc_data_1	8	bslbf
cc_data_2	8	bslbf
}		
marker_bits	8	'1111 1111'
if (additional_data_flag) {		
while(nextbits() != '0000 0000 0000 0000 0000 0001') {		
additional_user_data	8	
}		
}		
}		
next_start_code()		
}		

5.2.3 Picture user data semantics

user_data_start_code — This is set to 0x0000 01B2.

ATSC_identifier — This is a 32 bit code that indicates that the video user data conforms to this specification. The value ATSC_identifier shall be 0x4741 3934.

user_data_type_code — The 8-bit code is set to 0x03.

[5] Shaded cells in this table indicate syntactic and semantic additions to the ISO/IEC 13818-2 standard.

process_em_data_flag — This flag is set to indicate whether it is necessary to process the em_data. If it is set to 1, the em_data has to be parsed and its meaning has to be processed. When it is set to 0, the em_data can be discarded.

process_cc_data_flag — This flag is set to indicate whether it is necessary to process the cc_data. If it is set to 1, the cc_data has to be parsed and its meaning has to be processed. When it is set to 0, the cc_data can be discarded.

additional_data_flag — This flag is set to 1 to indicate the presence of additional user data.

cc_count — This 5-bit integer indicates the number of closed caption constructs following this field. It can have values 0 through 31. The value of cc_count shall be set according to the frame rate and coded picture structure (field or frame) such that a fixed bandwidth of 9600 bits per second is maintained for the closed caption payload data. Sixteen (16) bits of closed caption payload data are carried in each pair of the fields cc_data_1 and cc_data_2.

em_data — Eight bits for representing emergency message.[6]

cc_valid — This flag is set to '1' to indicate that the two closed caption data bytes that follow are valid. If set to '0' the two data bytes are invalid.

cc_type — Denotes the type of the two closed caption data bytes that follow.[7]

cc_data_1 — The first byte of a closed caption data pair.

cc_data_2 — The second byte of a closed caption data pair.

additional_user_data — Any further demand for picture user data could be met by defining this part of the bit stream.

[6] Syntax and semantics to be specified by EIA.

[7] EIA, *Recommended Practice for Advanced Television Closed Captioning*, draft, July 1, 1994.

ANNEX B

(Normative)

AUDIO SYSTEMS CHARACTERISTICS

1. SCOPE

This Annex describes the audio system characteristics and normative specifications of the Digital Television Standard.

2. NORMATIVE REFERENCES

The following documents contain provisions which in whole or part, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision and amendment, and parties to agreement based on this standard are encouraged to investigate the possibility of applying the most recent editions of the documents listed below.

ATSC Standard A/52 (1995), *Digital Audio Compression (AC-3)*.

AES 3-1992 (ANSI S4.40-1992), *AES Recommended Practice for digital audio engineering — Serial transmission format for two-channel linearly represented digital audio data*.

ANSI S1.4-1983, *Specification for Sound Level Meters*.

IEC 651 (1979), *Sound Level Meters*.

IEC 804 (1985), Amendment 1 (1989) *Integrating/Averaging Sound Level Meters*.

3. COMPLIANCE NOTATION

As used in this document, *"shall"* or *"will"* denotes a mandatory provision of the standard. *"Should"* denotes a provision that is recommended but not mandatory. *"May"* denotes a feature whose presence does not preclude compliance, that may or may not be present at the option of the implementor.

4. SYSTEM OVERVIEW

As illustrated in Figure 1, the audio subsystem comprises the audio encoding/decoding function and resides between the audio inputs/outputs and the transport subsystem. The audio encoder(s) is (are) responsible for generating the audio elementary stream(s) which are encoded representations of the baseband audio input signals. At the receiver, the audio subsystem is responsible for decoding the audio elementary stream(s) back into baseband audio.

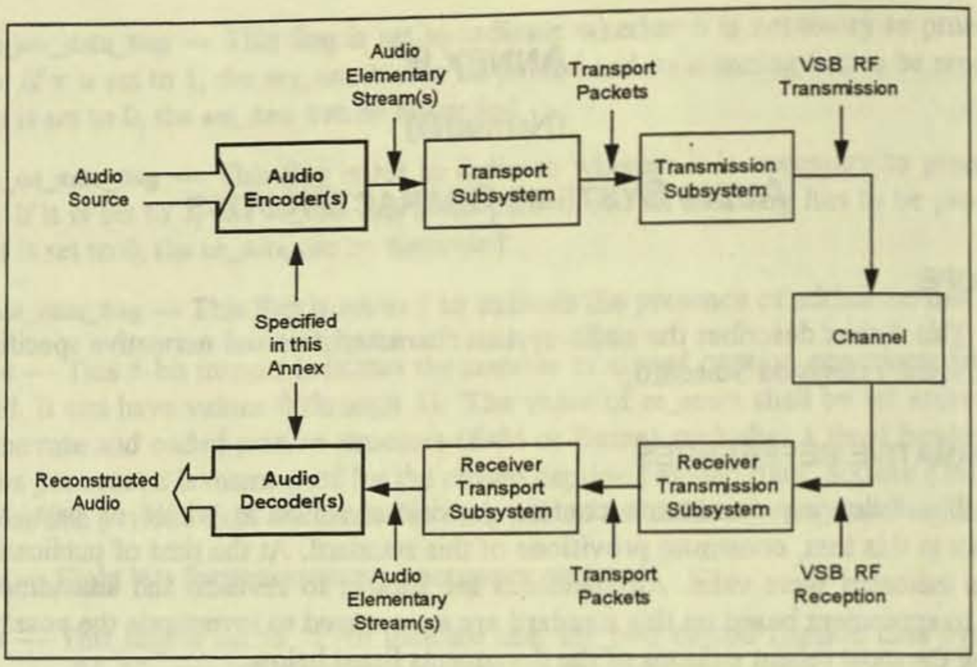


Figure 1. Audio subsystem in the digital television system.

5. SPECIFICATION

This Section forms the normative specification of the audio system. The audio compression system conforms with the Digital Audio Compression (AC-3) Standard, subject to the constraints outlined in this Section.

5.1 Constraints with respect to ATSC Standard A/52

The digital television audio coding system is based on the Digital Audio Compression (AC-3) Standard specified in the body of ATSC Doc. A/52 (the annexes are not included). Constraints on the system are shown in Table 1 which shows permitted values of certain syntactical elements. These constraints are described in Sections 5.2 - 5.4.

Table 1 Audio Constraints

AC-3 syntactical element	Comment	Allowed value
fscod	Indicates sampling rate	'00' (indicates 48 kHz)
frmsizecod	Main audio service or associated audio service containing all necessary program elements	≤ '011100' (indicates ≤ 384 kbps)
frmsizecod	Single channel associated service containing a single program element	≤ '010000' (indicates ≤ 128 kbps)
frmsizecod	Two channel dialogue associated service	≤ '010100' (indicates ≤ 192 kbps)
(frmsizecod)	Combined bit rate of a main and an associated service intended to be simultaneously decoded	(total ≤ 512 kbps)
acmod	Indicates number of channels	≥ '001'

5.2 Sampling frequency

The system conveys digital audio sampled at a frequency of 48 kHz, locked to the 27 MHz system clock. The 48 kHz audio sampling clock is defined as:

(1) 48 kHz audio sample rate = (2 ÷1125) × (27 MHz system clock)

If analog signal inputs are employed, the A/D converters should sample at 48 kHz. If digital inputs are employed, the input sampling rate shall be 48 kHz, or the audio encoder shall contain sampling rate converters which convert the sampling rate to 48 kHz.

5.3 Bit rate

A main audio service, or an associated audio service which is a complete service (containing all necessary program elements) shall be encoded at a bit rate less than or equal to 384 kbps. A single channel associated service containing a single program element shall be encoded at a bit rate less than or equal to 128 kbps. A two channel associated service containing only dialogue shall be encoded at a bit rate less than or equal to 192 kbps. The combined bit rate of a main service and an associated service which are intended to be decoded simultaneously shall be less than or equal to 512 kbps.

5.4 Audio coding modes

Audio services shall be encoded using any of the audio coding modes specified in A/52, with the exception of the 1+1 mode. The value of acmod in the AC-3 bit stream shall have a value in the range of 1-7, with the value 0 prohibited.

5.5 Dialogue level

The value of the dialnorm parameter in the AC-3 elementary bit stream shall indicate the level of average spoken dialogue within the encoded audio program. Dialogue level may be measured by means of an "A" weighted integrated measurement (LAeq). (Receivers use the value of dialnorm to adjust the reproduced audio level so as to normalize the dialogue level.)

5.6 Dynamic range compression

Each encoded audio block may contain a dynamic range control word (dynrng) which is used by decoders (by default) to alter the level of the reproduced audio. The control words allow the decoded signal level to be increased or decreased by up to 24 dB. In general, elementary streams may have dynamic range control words inserted or modified without affecting the encoded audio. When it is necessary to alter the dynamic range of audio programs which are broadcast, the dynamic range control word should be used.

6. MAIN AND ASSOCIATED SERVICES

6.1 Overview

An AC-3 elementary stream contains the encoded representation of a single audio service. Multiple audio services are provided by multiple elementary streams. Each elementary stream is conveyed by the transport multiplex with a unique PID. There are a number of audio service types which may (individually) be coded into each elementary stream. Each AC-3 elementary stream is tagged as to its service type using the bsmod bit field. There are two types of *main service* and six types of *associated service*. Each associated service may be tagged (in the AC-3 audio descriptor in the transport PSI data) as being associated with one or more main audio services. Each AC-3 elementary stream may also be tagged with a language code.

Associated services may contain complete program mixes, or may contain only a single program element. Associated services which are complete mixes may be decoded and used as is. They are identified by the full_svc bit in the AC-3 descriptor (see A/52, Annex A). Associated services which contain only a single program element are intended to be combined with the program elements from a main audio service.

This Section specifies the meaning and use of each type of service. In general, a complete audio program (what is presented to the listener over the set of loudspeakers) may consist of a main audio service, an associated audio service which is a complete mix, or a main audio service combined with an associated audio service. The capability to simultaneously decode one main service and one associated service is required in order to form a complete audio program in certain service combinations described in this Section. This capability may not exist in some receivers.

6.2 Summary of service types

The audio service types are listed in Table 2.

Table 2 Audio Service Types

bsmod	Type of service
000 (0)	Main audio service: complete main (CM)
001 (1)	Main audio service: music and effects (ME)
010 (2)	Associated service: visually impaired (VI)
011 (3)	Associated service: hearing impaired (HI)
100 (4)	Associated service: dialogue (D)
101 (5)	Associated service: commentary (C)
110 (6)	Associated service: emergency (E)
111 (7)	Associated service: voice-over (VO)

6.3 Complete main audio service (CM)

The CM type of main audio service contains a complete audio program (complete with dialogue, music, and effects). This is the type of audio service normally provided.

The CM service may contain from 1 to 5.1 audio channels. The CM service may be further enhanced by means of the VI, HI, C, E, or VO associated services described below. Audio in multiple languages may be provided by supplying multiple CM services, each in a different language.

6.4 Main audio service, music and effects (ME)

The ME type of main audio service contains the music and effects of an audio program, but not the dialogue for the program. The ME service may contain from 1 to 5.1 audio channels. The primary program dialogue is missing and (if any exists) is supplied by simultaneously encoding a D associated service. Multiple D associated services in different languages may be associated with a single ME service.

6.5 Visually impaired (VI)

The VI associated service typically contains a narrative description of the visual program content. In this case, the VI service shall be a single audio channel. The simultaneous reproduction of both the VI associated service and the CM main audio service allows the visually impaired user to enjoy the main multi-channel audio program, as well as to follow (by ear) the on-screen activity.

The dynamic range control signal in this type of VI service is intended to be used by the audio decoder to modify the level of the main audio program. Thus the level of the main audio service will be under the control of the VI service provider, and the provider may signal the decoder (by altering the dynamic range control words embedded in the VI audio elementary stream) to reduce the level of the main audio service by up to 24 dB in order to assure that the narrative description is intelligible.

Besides providing the VI service as a single narrative channel, the VI service may be provided as a complete program mix containing music, effects, dialogue, and the narration. In this case, the service may be coded using any number of channels (up to 5.1), and the dynamic range control signal applies only to this service. The fact that the service is a complete mix shall be indicated in the AC-3 descriptor (see A/52, Annex A).

6.6 Hearing impaired (HI)

The HI associated service typically contains only dialogue which is intended to be reproduced simultaneously with the CM service. In this case, the HI service shall be a single audio channel. This dialogue may have been processed for improved intelligibility by hearing impaired listeners. Simultaneous reproduction of both the CM and HI services allows the hearing impaired listener to hear a mix of the CM and HI services in order to emphasize the dialogue while still providing some music and effects.

Besides providing the HI service as a single dialogue channel, the HI service may be provided as a complete program mix containing music, effects, and dialogue with enhanced intelligibility. In this case, the service may be coded using any number of channels (up to 5.1). The fact that the service is a complete mix shall be indicated in the AC-3 descriptor (see A/52, Annex A).

6.7 Dialogue (D)

The D associated service contains program dialogue intended for use with an ME main audio service. The language of the D service is indicated in the AC-3 bit stream, and in the audio descriptor. A complete audio program is formed by simultaneously decoding the D service and the ME service and mixing the D service into the center channel of the ME main service (with which it is associated).

If the ME main audio service contains more than two audio channels, the D service shall be monophonic (1/0 mode). If the main audio service contains two channels, the D service may also contain two channels (2/0 mode). In this case, a complete audio program is formed by simultaneously decoding the D service and the ME service, mixing the left channel of the ME service with the left channel of the D service, and mixing the right channel of the ME service with the right channel of the D service. The result will be a two channel stereo signal containing music, effects, and dialogue.

Audio in multiple languages may be provided by supplying multiple D services (each in a different language) along with a single ME service. This is more efficient than providing multiple CM services, but, in the case of more than two audio channels in the ME service, requires that dialogue be restricted to the center channel.

Some receivers may not have the capability to simultaneously decode an ME and a D service.

6.8 Commentary (C)

The commentary associated service is similar to the D service, except that instead of conveying essential program dialogue, the C service conveys optional program commentary. The C service may be a single audio channel containing only the commentary content. In this case, simultaneous reproduction of a C service and a CM service will allow the listener to hear the added program commentary.

The dynamic range control signal in the single channel C service is intended to be used by the audio decoder to modify the level of the main audio program. Thus the level of the main audio service will be under the control of the C service provider, and the provider may signal the decoder (by altering the dynamic range control words embedded in the C audio elementary stream) to reduce the level of the main audio service by up to 24 dB in order to assure that the commentary is intelligible.

Besides providing the C service as a single commentary channel, the C service may be provided as a complete program mix containing music, effects, dialogue, and the commentary. In this case the service may be provided using any number of channels (up to 5.1). The fact that the service is a complete mix shall be indicated in the AC-3 descriptor (see A/52, Annex A).

6.9 Emergency (E)

The E associated service is intended to allow the insertion of emergency or high priority announcements. The E service is always a single audio channel. An E service is given priority in transport and in audio decoding. Whenever the E service is present, it will be delivered to the audio decoder. Whenever the audio decoder receives an E type associated service, it will stop reproducing any main service being received and only reproduce the E service out of the center channel (or left and right channels if a center loudspeaker does not exits). The E service may also be used for non-emergency applications. It may be used whenever the broadcaster wishes to force all decoders to quit reproducing the main audio program and reproduce a higher priority single audio channel.

6.10 Voice-over (VO)

The VO associated service is a single channel service intended to be reproduced along with the main audio service in the receiver. It allows typical voice-overs to be added to an already encoded audio elementary stream without requiring the audio to be decoded back to baseband and then re-encoded. It is always a single audio channel. It has second priority (only the E service has higher priority). It is intended to be simultaneously decoded and mixed into the center channel of the main audio service. The dynamic range control signal in the VO service is intended to be used by the audio decoder to modify the level of the main audio program. Thus the level of the main audio service may be controlled by the broadcaster, and the broadcaster may signal the decoder (by altering the dynamic range control words embedded in the VO audio elementary stream) to reduce the level of the main audio service by up to 24 dB during the voice-over.

Some receivers may not have the capability to simultaneously decode and reproduce a voice-over service along with a program audio service.

7. AUDIO ENCODER INTERFACES

7.1 Audio encoder input characteristics

Audio signals which are input to the digital television system may be in analog or digital form. Audio signals should have any DC offset removed before being encoded. If the audio encoder does not include a DC blocking high pass filter, the audio signals should be high pass filtered before being applied to the encoder. In general, input signals should be quantized to at least 16-bit resolution. The audio compression system can convey audio signals with up to 24-bit resolution. Physical interfaces for the audio inputs to the encoder may be defined as voluntary industry standards by the AES, SMPTE, or other standards organizations.

7.2 Audio encoder output characteristics

Conceptually, the output of the audio encoder is an elementary stream which is formed into PES packets within the transport subsystem. It is possible that systems will be implemented wherein the formation of audio PES packets takes place within the audio encoder. In this case, the output(s) of the audio encoder(s) would be PES packets. Physical interfaces for these outputs (elementary streams and/or PES packets) may be defined as voluntary industry standards by SMPTE or other standards organizations.

ANNEX C

(Normative)

SERVICE MULTIPLEX AND TRANSPORT SYSTEMS CHARACTERISTICS

1. SCOPE

This Annex describes the transport layer characteristics and normative specifications of the Digital Television Standard.

2. NORMATIVE REFERENCES

The following documents contain provisions which in whole or in part, through reference in this text, constitute provisions of this Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision and amendment, and parties to agreements based on this Standard are encouraged to investigate the possibility of applying the most recent editions of the documents listed below.

ATSC Standard A/52 (1995), *Digital Audio Compression (AC-3)*.

ISO/IEC IS 13818-1, International Standard (1994), *MPEG-2 Systems*.

ISO/IEC IS 13818-2, International Standard (1994), *MPEG-2 Video*.

ISO/IEC CD 13818-4, MPEG Committee Draft (1994), *MPEG-2 Compliance*.

The normative reference for the Program Guide will be the standard developed from ATSC document T3/S8-050, "Program Guide for Digital Television".

The normative reference for System Information will be the standard developed from ATSC document T3/S8-079, "System Information for Digital Television".

3. COMPLIANCE NOTATION

As used in this document, "*shall*" or "*will*" denotes a mandatory provision of the standard. "*Should*" denotes a provision that is recommended but not mandatory. "*May*" denotes a feature whose presence does not preclude compliance, that may or may not be present at the option of the implementor.

4. SYSTEM OVERVIEW

The transport format and protocol for the Digital Television Standard is a compatible subset of the MPEG-2 Systems specification defined in ISO/IEC 13818-1. It is based on a fixed-length packet transport stream approach which has been defined and optimized for digital television delivery applications.

As illustrated in Figure 1, the transport function resides between the application (e.g., audio or video) encoding and decoding functions and the transmission subsystem. The encoder's transport subsystem is responsible for formatting the coded elementary streams and multiplexing the different components of the program for transmission. At the receiver, it is responsible for recovering the elementary streams for the individual application decoders and for the corresponding error signaling. The transport subsystem also incorporates other higher protocol layer functionality related to synchronization of the receiver.

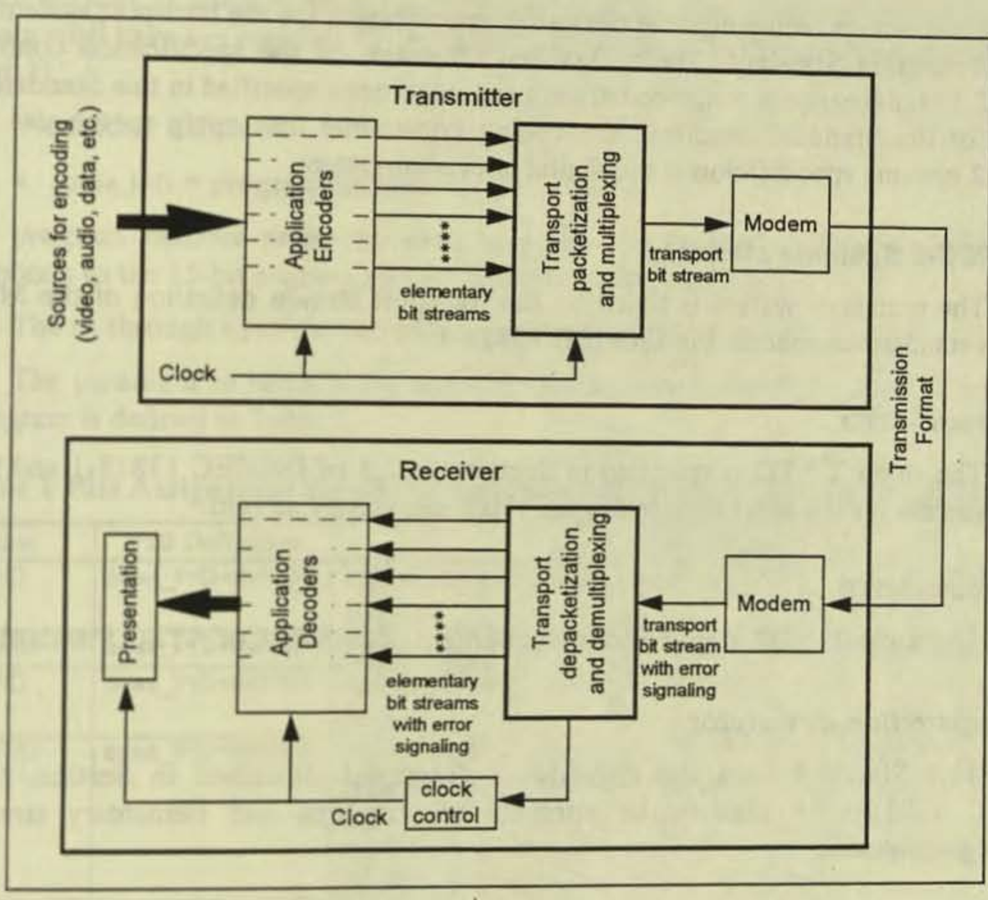


Figure 1. Sample organization of functionality in a transmitter-receiver pair for a single program.

The overall system multiplexing approach can be thought of as a combination of multiplexing at two different layers. In the first layer, single program transport bit streams are formed by multiplexing transport packets from one or more Packetized Elementary Stream (PES) sources. In the second layer, many single program transport bit streams are combined to form a system of programs. The Program Specific Information (PSI) streams contain the information relating to the identification of programs and the components of each program.

Not shown explicitly in Figure 1, but essential to the practical implementation of this Standard, is a control system that manages the transfer and processing of the elementary streams from the application encoders. The rules followed by this control system are not a part of this Standard but must be established as recommended practices by the users of the Standard. The control system implementation shall adhere to the requirements of the MPEG-2 transport system as specified in ISO/IEC 13818-1 with the additional constraints specified in this Standard. These constraints may go beyond the constraints imposed by the application encoders.

5. SPECIFICATION

This Section constitutes the normative specification for the transport system of the Digital Television Standard. The syntax and semantics of the specification conform to ISO/IEC 13818-1 subject to the constraints and conditions specified in this Standard. This Section of the Standard describes the coding constraints that apply to the use of the MPEG-2 systems specification in the digital television system.

5.1 MPEG-2 Systems standard

The transport system is based on the transport stream definition of the MPEG-2 Systems standard as specified in ISO/IEC 13818-1.

5.1.1 Video T-STD

The video T-STD is specified in Section 2.4.2.3 of ISO/IEC 13818-1 and follows the constraints for the level encoded in the video elementary stream.

5.1.2 Audio T-STD

The audio T-STD is specified in Section 3.6 of Annex A of ATSC Standard A/52.

5.2 Registration descriptor

This Standard uses the registration descriptor described in Section 2.6.8 of ISO/IEC 13818-1 to identify the contents of programs and elementary streams to decoding equipment.

5.2.1 Program identifier

Programs which conform to this specification will be identified by the 32-bit identifier in the section of the Program Map Table (PMT) detailed in Section 2.4.4.8 of ISO/IEC 13818-1. The identifier will be coded according to Section 2.6.8, and shall have a value of 0x4741 3934.

5.2.2 Audio elementary stream identifier

Audio elementary streams which conform to this specification will be identified by the 32-bit identifier in the section of the Program Map Table (PMT) detailed in Section 2.4.4.8 of ISO/IEC 13818-1. The identifier will be coded according to Section 2.6.8, and shall have a value of 0x4143 2D33.

5.3 The program paradigm

The program paradigm specifies the method that shall be used for allocating the values of the Packet Identifier (PID) field of the transport packet header in a systematic manner. Within one transport multiplex, television programs that follow the program paradigm are assigned a program number ranging from 1 to 255. The binary value of the program number is used to form b_{11} through b_4 of the PID. Programs adhering to the paradigm shall have b_{12} equal to '0'. Programs not adhering to the paradigm shall have b_{12} equal to '1'.

We further define:

- base_PID = program number << 4

where program number refers to each program within one transport multiplex and corresponds to the 16-bit program_number identified in PAT and PMT.

The b_0 through b_3 of the PID are assigned according to Table 1.

The paradigm to identify the transport bit streams containing certain elements of the program is defined in Table 1.

Table 1 PID Assignment for the Constituent Elementary Streams of a Program

Name	PID Definition	Description
PMT_PID	base_PID+0x0000	PID for the bit stream containing the program_map_table for the program.
Video_PID	base_PID+0x0001	PID for the bit stream containing the video for the program.
PCR_PID	base_PID+0x0001	Implies the video bit stream also carries the PCR values for the program
Audio_PID	base_PID+0x0004	PID for the bit stream containing the primary audio for the program. The primary audio shall be a complete main audio service (CM) as defined by ATSC Standard A/52 and shall contain the complete primary audio of the program including all required voice-overs and emergency messages.
Data_PID	base_PID+0x000A	PID for the bit stream containing the data for the program.

The program_map_table must be decoded to obtain the PIDs for services not defined by the paradigm but included within the program (such as a second data channel). According to the program paradigm, every 16th PID is a PMT_PID and may be assigned to a program. If a PMT_PID is assigned to a program by the program paradigm, the next 15 PIDs after that PMT_PID are reserved for elements of that program and shall not be otherwise assigned.

5.4 Constraints on PSI

The program constituents for all programs, including television programs that follow the program paradigm and other programs or services that do not follow the program paradigm, are described in the PSI. There are the following constraints on the PSI information:

- Only one program is described in a PSI transport bit stream corresponding to a particular PMT_PID value. A transport bit stream containing a program_map_table shall not be used to transmit any other kind of PSI table (identified by a different table_id).
- The maximum spacing between occurrences of a program_map_table containing television program information shall be 400 ms.
- The program numbers are associated with the corresponding PMT_PIDs in the PID0 Program Association Table. The maximum spacing between occurrences of section 0 of the program_association_table is 100 ms.
- The video elementary stream section shall contain the Data stream alignment descriptor described in Section 2.6.10 of ISO/IEC 13818-1. The alignment_type field shown in Table 2-47 of ISO/IEC 13818-1 shall be 0x02.
- Adaptation headers shall not occur in transport packets of the PMT_PID for purposes other than for signaling with the discontinuity_indictor that the version_number (Section 2.4.4.5 of ISO/IEC 13818-1) may be discontinuous.
- Adaptation headers shall not occur in transport packets of the PAT_PID for purposes other than for signaling with the discontinuity_indicator that the version_number (Section 2.4.4.5 of ISO/IEC 13818-1) may be discontinuous.

5.5 PES constraints

Packetized Elementary Stream syntax and semantics shall be used to encapsulate the audio and video elementary stream information. The Packetized Elementary Stream syntax is used to convey the Presentation Time-Stamp (PTS) and Decoding Time-Stamp (DTS) information required for decoding audio and video information with synchronism. This Section describes the coding constraints for this system layer.

Within the PES packet header, the following restrictions apply:

- PES_scrambling_control shall be coded as '00'.
- ESCR_flag shall be coded as '0'.
- ES_rate_flag shall be coded as '0'.
- PES_CRC_flag shall be coded as '0'.

Within the PES packet extension, the following restrictions apply.

- PES_private_data_flag shall be coded as '0'.
- pack_header_field_flag shall be coded as '0'.
- program_packet_sequence_counter_flag shall be coded as '0'.
- P-STD_buffer_flag shall be coded as '0'.

5.5.1 Video PES constraints

Each PES packet shall begin with a video access unit, as defined in Section 2.1.1 of ISO/IEC 13818-1, which is aligned with the PES packet header. The first byte of a PES packet payload shall be the first byte of a video access unit. Each PES header shall contain a PTS. Additionally, it shall contain a DTS as appropriate. For terrestrial broadcast, the PES packet shall not contain more than one coded video frame, and shall be void of video picture data only when transmitted in conjunction with the discontinuity_indicator to signal that the continuity_counter may be discontinuous.

Within the PES packet header, the following restrictions apply:

- The PES_packet_length shall be coded as '0x0000'.
- data_alignment_indicator shall be coded as '1'.

5.5.2 Audio PES constraints

The audio decoder may be capable of simultaneously decoding more than one elementary stream containing different program elements, and then combining the program elements into a complete program. In this case, the audio decoder may sequentially decode audio frames (or audio blocks) from each elementary stream and do the combining (mixing together) on a frame or (block) basis. In order to have the audio from the two elementary streams reproduced in exact sample synchronism, it is necessary for the original audio elementary stream encoders to have encoded the two audio program elements frame synchronously; i.e., if audio program 1 has sample 0 of frame n at time t0, then audio program 2 should also have frame n beginning with its sample 0 at the identical time t0. If the encoding is done frame synchronously, then matching audio frames should have identical values of PTS.

If PES packets from two audio services that are to be decoded simultaneously contain identical values of PTS then the corresponding encoded audio frames contained in the PES packets should be presented to the audio decoder for simultaneous synchronous decoding. If the PTS values do not match (indicating that the audio encoding was not frame synchronous) then the audio frames which are closest in time may be presented to the audio decoder for simultaneous decoding. In this case the two services may be reproduced out of sync by as much as 1/2 of a frame time (which is often satisfactory, e.g., a voice-over does not require precise timing).

The value of stream_id for AC-3 shall be 1011 1101 (private_stream_1).

5.6 Services and features

5.6.1 Program guide

5.6.1.1 Master program guide PID

At the option of broadcasters, an interactive program guide database may be transmitted in the transport stream. If present, the master program guide data stream shall be transported in PID 0x1FFD. This PID shall be reserved exclusively for the program guide. The program guide shall be formatted according to the structure and syntax described in the standard developed from ATSC document T3/S8-050, "Program Guide for Digital Television". The program guide database allows a receiver to build an on-screen grid of program information and contains control information to facilitate navigation.

5.6.1.2 Program guide STD model

Each program guide bit stream shall adhere to an STD model that can be described by an MPEG smoothing buffer descriptor (Section 2.6.30 in ISO/IEC 13818-1) with the following constraints:

- sb_leak_rate shall be 250 (indicating a leak rate of 100,000 bps)
- sb_size shall be 1024 (indicating a smoothing buffer size of 1024 bytes)

Note that the smoothing buffer descriptor is referred to here to describe the STD model for the program guide, and does not imply that a smoothing buffer descriptor for the program guide is to be included in the PMT.

5.6.2 System information

5.6.2.1 System information PID

At the option of broadcasters, certain system information may be transmitted in the transport stream. If present, the system information data stream shall be transported in PID 0x1FFC. This PID shall be reserved exclusively for the system information. The system information shall be formatted according to the structure and syntax described in the standard developed from ATSC document T3/S8-079, "System Information for Digital Television". Constraints applying to specific transmission media are given in that standard.

5.6.2.2 System information STD model

The system information bit stream shall adhere to an STD model that can be described by an MPEG smoothing buffer descriptor (Section 2.6.30 in ISO/IEC 13818-1) with the following constraints:

- sb_leak_rate shall be 50 (indicating a leak rate of 20,000 bps)
- sb_size shall be 1024 (indicating a smoothing buffer size of 1024 bytes)

Note that the smoothing buffer descriptor is referred to here to describe the STD model for the system information, and does not imply that a smoothing buffer descriptor for the system information is to be included in the PMT.

5.6.3 Specification of private data services

Private data provides a means to add new ancillary services to the basic digital television service specified in this standard. Private data is supported in two bit stream locations.

1. Private data can be transmitted within the adaptation header of transport packets (Sections 2.4.3.4 and 2.4.3.5 of ISO/IEC 13818-1).
2. Private data can be transmitted as a separate transport stream with its own PID. The contents can be identified as being ATSC private by using the private_data_indicator_descriptor (Section 2.6.29 of ISO/IEC 13818-1) within the PMT.

In either case, it is necessary that the standards which specify the characteristics of such private_streams be consistent with the Digital Television Standard. Standards for private_streams shall precisely specify the semantics of the transmitted syntax as described in Sections 5.6.3.1 and 5.6.3.1.1.

5.6.3.1 Verification model

The standard shall be specified in terms of a verification model by defining the characteristics of the transmitted syntax and an idealized decoder. In ISO/IEC 13818-1 and 13818-2, this is accomplished by using the T-STD and VBV models, respectively. The elements required for specification by this Standard are described in the following Sections.

5.6.3.1.1 Syntax and semantics

The syntax and semantics of the transmitted bit stream that implements the ancillary service shall be completely and unambiguously specified. The decoding process shall also be completely and unambiguously specified.

5.6.3.1.2 Ancillary service target decoder (ASTD)

An idealized decoder model must be precisely defined for the service. Figure 2 introduces a concrete model for pedagogic purposes. It is modeled after the T-STD.

The salient features of the model are the size of the transport demultiplexing buffer (TB), the minimum transfer rate out of the transport demultiplex buffer (R_{leak}), the required System buffering (BS_{sys}), and optionally the partitioning of BS_{sys} between the smoothing portion and the decoder portion. The decoding process, represented as the decoding times T_decode(i), must be completely specified. The behavior of the BS_{sys} buffer must be completely modeled with respect to its input process and its output process. Certain parameters of the service such as bit rate, etc., should also be specified.

5.6.3.2 Stream type and PMT descriptors

A new ancillary service shall be described as a program or elementary stream through documented Program Specific Information.

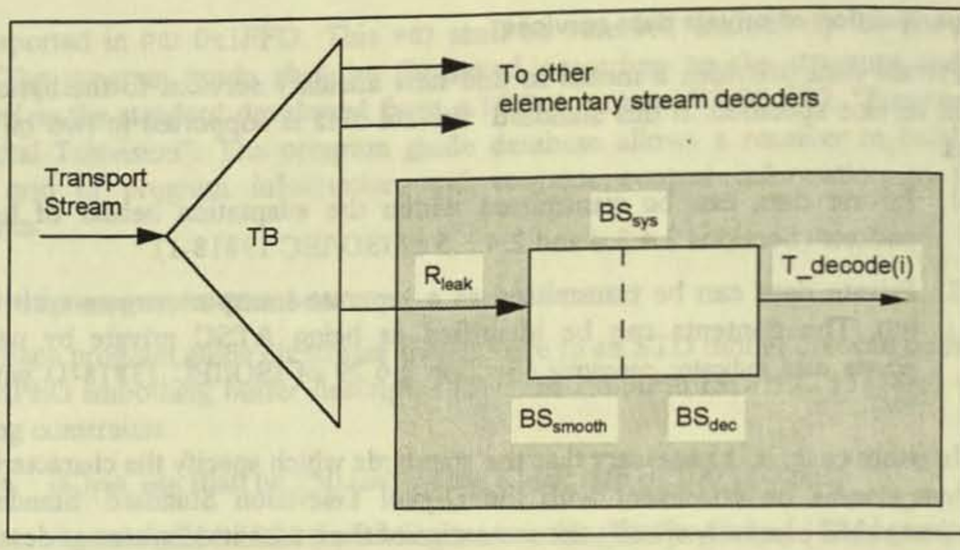


Figure 2. Ancillary service target decoder.

5.6.3.2.1 Stream type

Several identifiers that are part of the transport section of the Digital Television Standard may be used to identify either the signal or constituent parts thereof; however, the fundamental identifier is the User Private stream type. The stream_type codes shall be unambiguously assigned within the range 0x80 to 0xAF. 0x81 has already been assigned within the Digital Television Standard (see Section 5.7.1).

5.6.3.2.2 PMT descriptors

The Ancillary Service specification shall include all pertinent descriptors that are found within the Program Map Table. Specifically, it is recommended that either the private_stream_identifier or the registration_descriptor, or both, be included. Although this is not required for a stream with a unique stream_type code within this Standard, it will enhance interoperability in the case where the stream is stored outside this Standard, or transmitted in some other network that has its own set of stream_type codes.

5.7 Assignment of identifiers

In this Section, those Identifiers and codes which shall have a fixed value are summarized. These include PES Stream IDs and Descriptors. Stream_type codes from 0x80 to 0xAF shall be reserved for assignment as needed within the Digital Television Standard. Descriptor_tag codes from 0x40 to 0xAF shall be reserved for assignment as needed within the Digital Television Standard.

5.7.1 Stream type

The AC-3 audio stream_type shall have the value 0x81.

5.7.2 Descriptors

5.7.2.1 AC-3 audio descriptor

In the digital television system the AC-3 audio descriptor shall be included in the TS_program_map_section. The syntax is given in Table 2 of Annex A of ATSC Standard A/52. There are the following constraints on the AC-3 audio descriptor:

- The value of the descriptor_tag shall be 0x81.
- If textlen exists, it shall have a value of '0x00'.

5.7.2.2 Program smoothing buffer descriptor.

The Program Map Table of each program shall contain a smoothing buffer descriptor pertaining to that program in accordance with Section 2.6.30 of ISO/IEC 13818-1. During the continuous existence of a program, the value of the elements of the smoothing buffer descriptor shall not change.

The fields of the smoothing buffer descriptor shall meet the following constraints:

- The field sb_leak_rate shall be allowed to range up to the maximum transport rates specified in Section 7.2.
- The field sb_size shall have a value less than or equal to 2048. The size of the smoothing buffer is thus ≤ 2048 bytes.

5.8 Extensions to the MPEG-2 Systems specification

This Section covers extensions to the MPEG-2 Systems specification.

5.8.1 Scrambling control

The scrambling control field within the packet header allows all states to exist in the digital television system as defined in Table 2.

Table 2 Transport Scrambling Control Field

transport_ scrambling_ control	Function
00	packet payload not scrambled
01	not scrambled, state may be used as a flag for private use defined by the service provider.
10	packet payload scrambled with "even" key
11	packet payload scrambled with "odd" key

Elementary Streams for which the transport_scrambling_control field does not exclusively have the value of '00' for the duration of the program, must carry a CA_descriptor in accordance with Section 2.6.16 of ISO/IEC 13818-1.

The implementation of a digital television delivery system that employs conditional access will require the specification of additional data streams and system constraints.

6. FEATURES OF 13818-1 NOT SUPPORTED BY THIS STANDARD

The transport definition is based on the MPEG-2 Systems standard, ISO/IEC 13818-1; however, it does not implement all parts of the standard. This Section describes those elements which are omitted from this Standard.

6.1 Program streams

This Standard does not include those portions of ISO/IEC 13818-1 and Annex A of ATSC Standard A/52 which pertain exclusively to Program Stream specifications.

6.2 Still pictures

This Standard does not include those portions of ISO/IEC 13818-1 Transport Stream specification which pertain to the Still Picture model.

7. TRANSPORT ENCODER INTERFACES AND BIT RATES

7.1 Transport encoder input characteristics

The MPEG-2 Systems standard specifies the inputs to the transport system as MPEG-2 elementary streams. It is also possible that systems will be implemented wherein the process of forming PES packets takes place within the video, audio or other data encoders. In such cases, the inputs to the Transport system would be PES packets. Physical interfaces for these inputs (elementary streams and/or PES packets) may be defined as voluntary industry standards by SMPTE or other standardizing organizations.

7.2 Transport output characteristics

Conceptually, the output from the transport system is a continuous MPEG-2 transport stream as defined in this Annex at a constant rate of T_r Mbps when transmitted in an 8 VSB system and $2T_r$ when transmitted in a 16 VSB system where:

$$T_r = 2\,x\left(\frac{188}{208}\right)\left(\frac{312}{313}\right)\left(\frac{684}{286}\right)\,x\,4.5 = 19.39...\,Mbps$$

and

$$\left(\frac{684}{286}\right)x\,4.5$$

is the symbol rate S_r in Msymbols per second for the transmission subsystem (see Section 4.1 of Annex D). T_r and S_r shall be locked to each other in frequency.

All transport streams conforming to this Standard shall conform to the ISO/IEC 13818-1 model.

Details of the interface for this output, including its physical characteristics, may be defined as a voluntary industry standard by SMPTE , or other standardizing organizations.

ANNEX D

(Normative)

RF/TRANSMISSION SYSTEMS CHARACTERISTICS

1. SCOPE

This Annex describes the characteristics of the RF/Transmission subsystem, which is referred to as the VSB subsystem, of the Digital Television Standard. The VSB subsystem offers two modes: a terrestrial broadcast mode (8 VSB), and a high data rate mode (16 VSB). These are described in separate sections of this document.

2. NORMATIVE REFERENCES

There are no Normative References.

3. COMPLIANCE NOTATION

As used in this document, *"shall"* or *"will"* denotes a mandatory provision of the standard. *"Should"* denotes a provision that is recommended but not mandatory. *"May"* denotes a feature whose presence does not preclude compliance, that may or may not be present at the option of the implementor.

4. TRANSMISSION CHARACTERISTICS FOR TERRESTRIAL BROADCAST

4.1 Overview

The terrestrial broadcast mode (known as 8 VSB) will support a payload data rate of 19.28... Mbps in a 6 MHz channel. A functional block diagram of a representative 8 VSB terrestrial broadcast transmitter is shown in Figure 1. The input to the transmission subsystem from the transport subsystem is a 19.39... Mbps serial data stream comprised of 188-byte MPEG-compatible data packets (including a sync byte and 187 bytes of data which represent a payload data rate of 19.28... Mbps).

The incoming data is randomized and then processed for forward error correction (FEC) in the form of Reed-Solomon (RS) coding (20 RS parity bytes are added to each packet), 1/6 data field interleaving and 2/3 rate trellis coding. The randomization and FEC processes are not applied to the sync byte of the transport packet, which is represented in transmission by a Data Segment Sync signal as described below. Following randomization and forward error correction processing, the data packets are formatted into Data Frames for transmission and Data Segment Sync and Data Field Sync are added.

Figure 2 shows how the data are organized for transmission. Each Data Frame consists of two Data Fields, each containing 313 Data Segments. The first Data Segment of each Data Field is a unique synchronizing signal (Data Field Sync) and includes the training sequence used by the equalizer in the receiver. The remaining 312 Data Segments each carry the equivalent of the data from one 188-byte transport packet plus its associated FEC overhead. The actual data in each Data Segment comes from several transport packets because of data interleaving. Each Data Segment consists of 832 symbols. The first 4 symbols are transmitted in binary form and provide segment synchronization. This Data Segment Sync signal also represents the sync byte of the 188-byte MPEG-compatible transport packet. The remaining 828 symbols of each Data Segment carry data equivalent to the remaining 187 bytes of a transport packet and its associated FEC overhead. These 828 symbols are transmitted as 8-level signals and therefore carry three bits per symbol. Thus, 828 x 3 = 2484 bits of data are carried in each Data Segment, which exactly matches the requirement to send a protected transport packet:

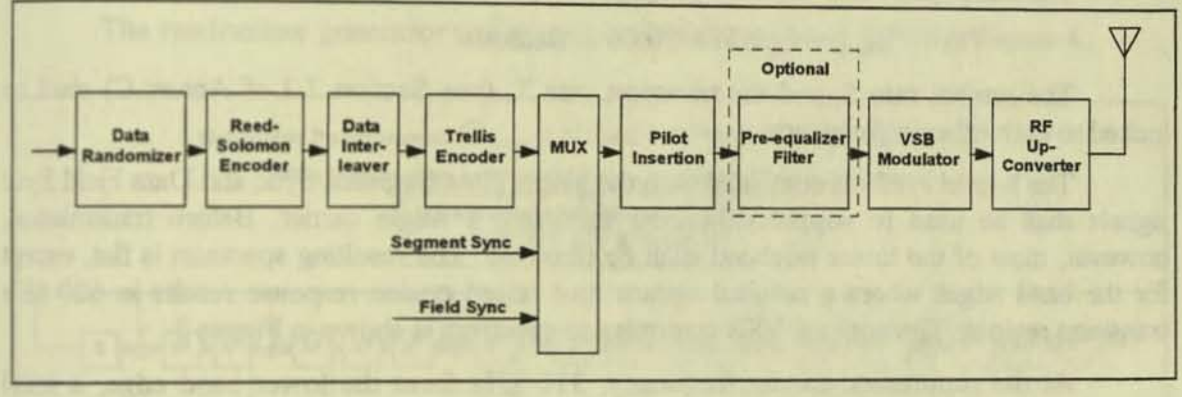


Figure 1. VSB transmitter.

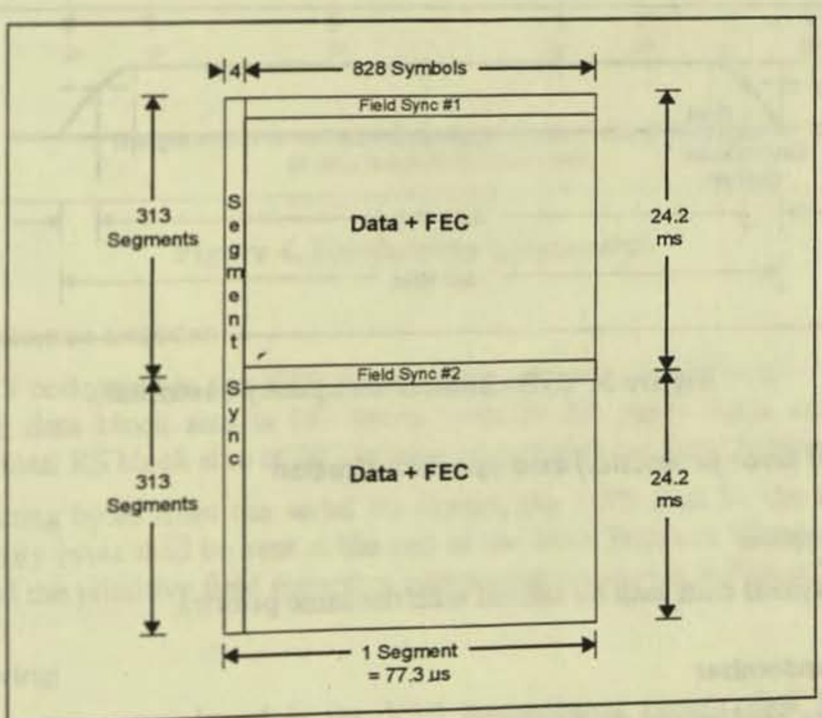


Figure 2. VSB data frame.

187 data bytes + 20 RS parity bytes = 207 bytes
207 bytes x 8 bits/byte = 1656 bits
2/3 rate trellis coding requires 3/2 x 1656 bits = 2484 bits.

The exact symbol rate is given by equation 1 below:

(1) S_r (MHz) = 4.5/286 x 684 = 10.76... MHz

The frequency of a Data Segment is given in equation 2 below:

(2) $f_{seg} = S_r / 832 = 12.94... \times 10^3$ Data Segments/s.

The Data Frame rate is given by equation (3) below:

(3) $f_{frame} = f_{seg}/626 = 20.66$ ... frames/s.

The symbol rate S_r and the transport rate T_r (see Section 7.2 of Annex C) shall be locked to each other in frequency.

The 8-level symbols combined with the binary Data Segment Sync and Data Field Sync signals shall be used to suppressed-carrier modulate a single carrier. Before transmission, however, most of the lower sideband shall be removed. The resulting spectrum is flat, except for the band edges where a nominal square root raised cosine response results in 620 kHz transition regions. The nominal VSB transmission spectrum is shown in Figure 3.

At the suppressed-carrier frequency, 310 kHz from the lower band edge, a small pilot shall be added to the signal.

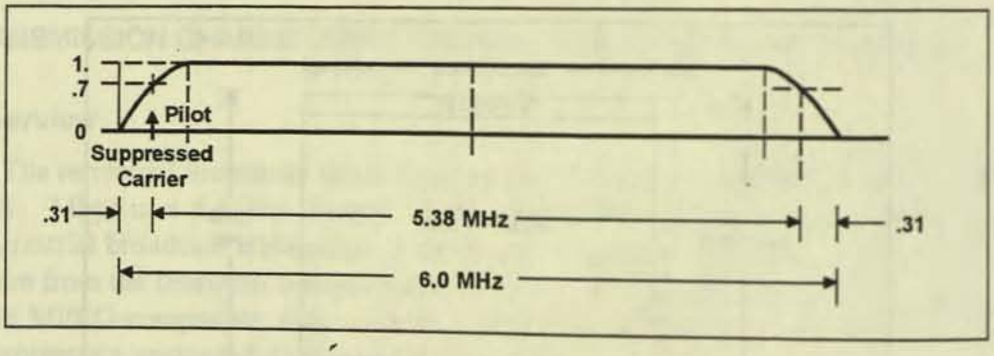


Figure 3. VSB channel occupancy (nominal).

4.2 Channel error protection and synchronization

4.2.1 Prioritization

All payload data shall be carried with the same priority.

4.2.2 Data randomizer

A data randomizer shall be used on all input data to randomize the data payload (not including Data Field Sync or Data Segment Sync, or RS parity bytes). The data randomizer XORs all the incoming data bytes with a 16-bit maximum length pseudo random binary sequence (PRBS) which is initialized at the beginning of the Data Field. The PRBS is generated in a 16-bit shift register that has 9 feedback taps. Eight of the shift register outputs are selected as the fixed randomizing byte, where each bit from this byte is used to individually XOR the corresponding input data bit. The data bits are XORed MSB to MSB ... LSB to LSB.

The randomizer generator polynomial is as follows:

$$G_{(16)} = X^{16} + X^{13} + X^{12} + X^{11} + X^{7} + X^{6} + X^{3} + X + 1$$

The initialization (pre-load) to F180 hex (load to 1) occurs during the Data Segment Sync interval prior to the first Data Segment.

The randomizer generator polynomial and initialization is shown in Figure 4.

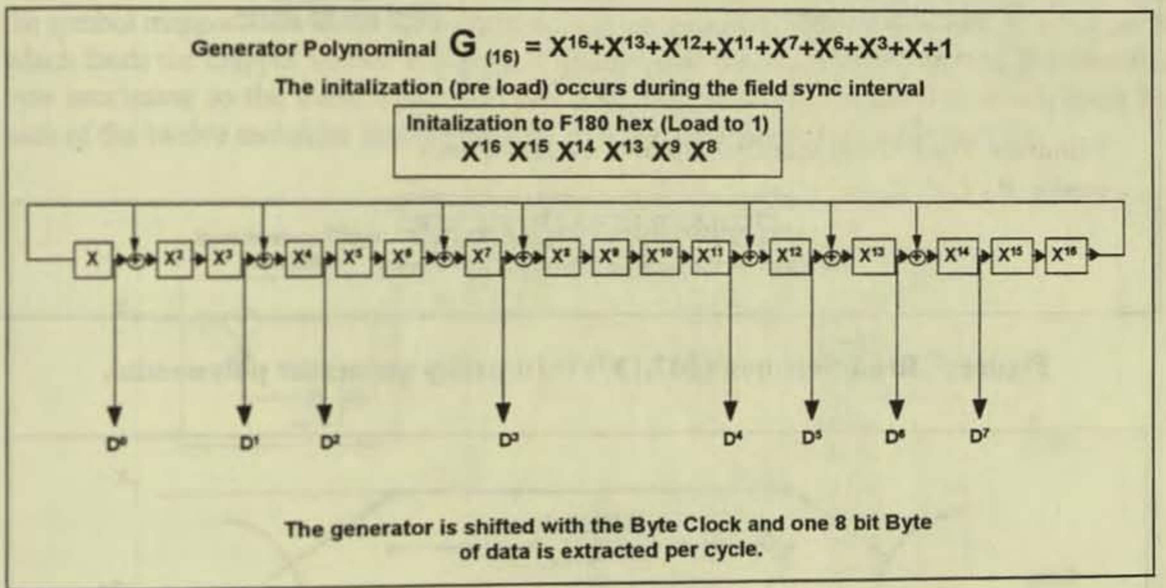


Figure 4. Randomizer polynomial.

4.2.3 Reed-Solomon encoder

The RS code used in the VSB transmission subsystem shall be a t = 10 (207,187) code. The RS data block size is 187 bytes, with 20 RS parity bytes added for error correction. A total RS block size of 207 bytes is transmitted per Data Segment.

In creating bytes from the serial bit stream, the MSB shall be the first serial bit. The 20 RS parity bytes shall be sent at the end of the Data Segment. The parity generator polynomial and the primitive field generator polynomial are shown in Figure 5.

4.2.4 Interleaving

The interleaver employed in the VSB transmission system shall be a 52 data segment (intersegment) convolutional byte interleaver. Interleaving is provided to a depth of about 1/6 of a data field (4 ms deep). Only data bytes shall be interleaved. The interleaver shall be synchronized to the first data byte of the data field. Intrasegment interleaving is also performed for the benefit of the trellis coding process.

The convolutional interleaver is shown in Figure 6.

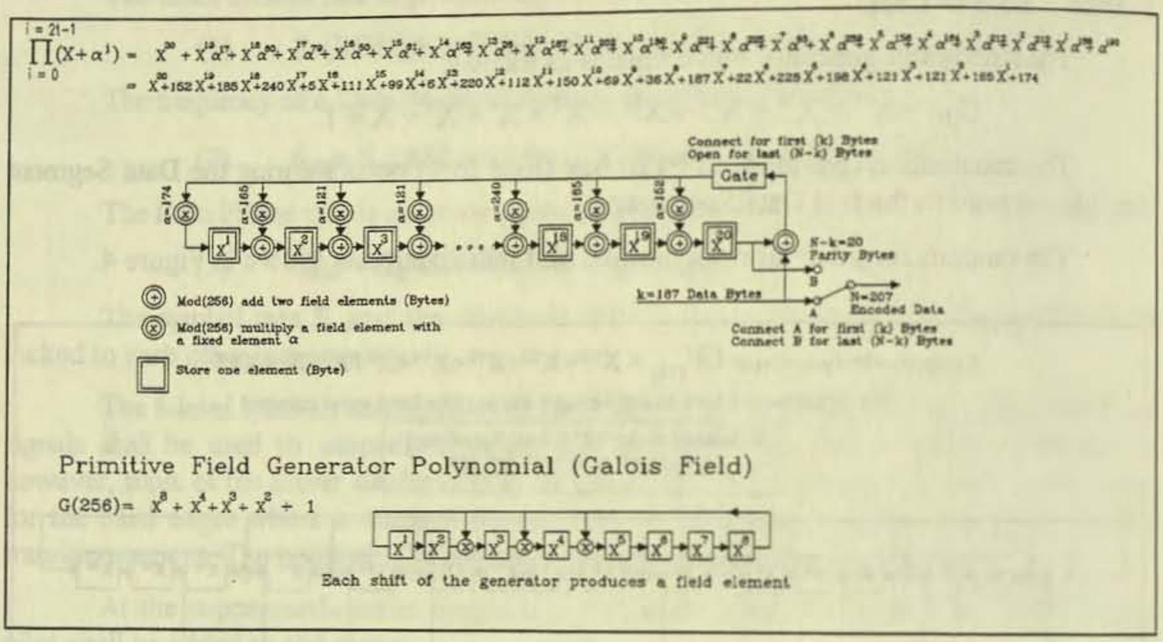


Figure 5. Reed-Solomon (207,187) t=10 parity generator polynomial.

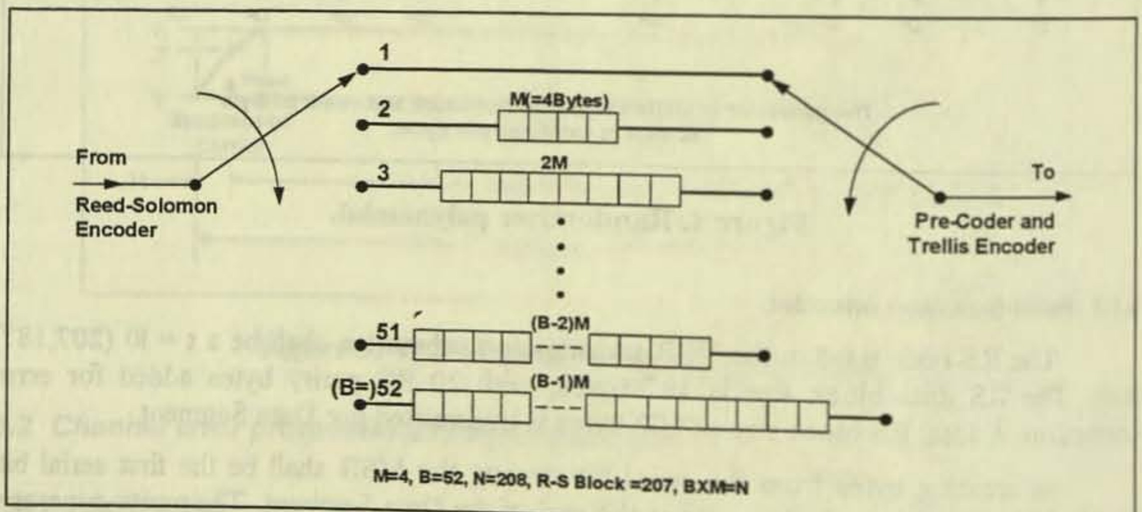


Figure 6. Convolutional interleaver (byte shift register illustration).

4.2.5 Trellis coding

The 8 VSB transmission sub-system shall employ a 2/3 rate (R=2/3) trellis code (with one unencoded bit which is precoded). That is, one input bit is encoded into two output bits using a 1/2 rate convolutional code while the other input bit is precoded. The signaling waveform used with the trellis code is an 8-level (3 bit) one-dimensional constellation. The transmitted signal is referred to as 8 VSB. A 4-state trellis encoder shall be used.

Trellis code intrasegment interleaving shall be used. This uses twelve identical trellis encoders and precoders operating on interleaved data symbols. The code interleaving is accomplished by encoding symbols (0, 12, 24, 36 ...) as one group, symbols (1, 13, 25, 37, ...) as a second group, symbols (2, 14, 26, 38, ...) as a third group, and so on for a total of 12 groups.

In creating serial bits from parallel bytes, the MSB shall be sent out first: (7, 6, 5, 4, 3, 2, 1, 0). The MSB is precoded (7, 5, 3, 1) and the LSB is feedback convolutional encoded (6, 4, 2, 0). Standard 4-state optimal Ungerboeck codes shall be used for the encoding. The trellis code utilizes the 4-state feedback encoder shown in Figure 7. Also shown is the precoder and the symbol mapper. The trellis code and precoder intrasegment interleaver is shown in Figure 8 which feeds the mapper shown in Figure 7. Referring to Figure 8, data bytes are fed from the byte interleaver to the trellis coder and precoder, and they are processed as whole bytes by each of the twelve encoders. Each byte produces four symbols from a single encoder.

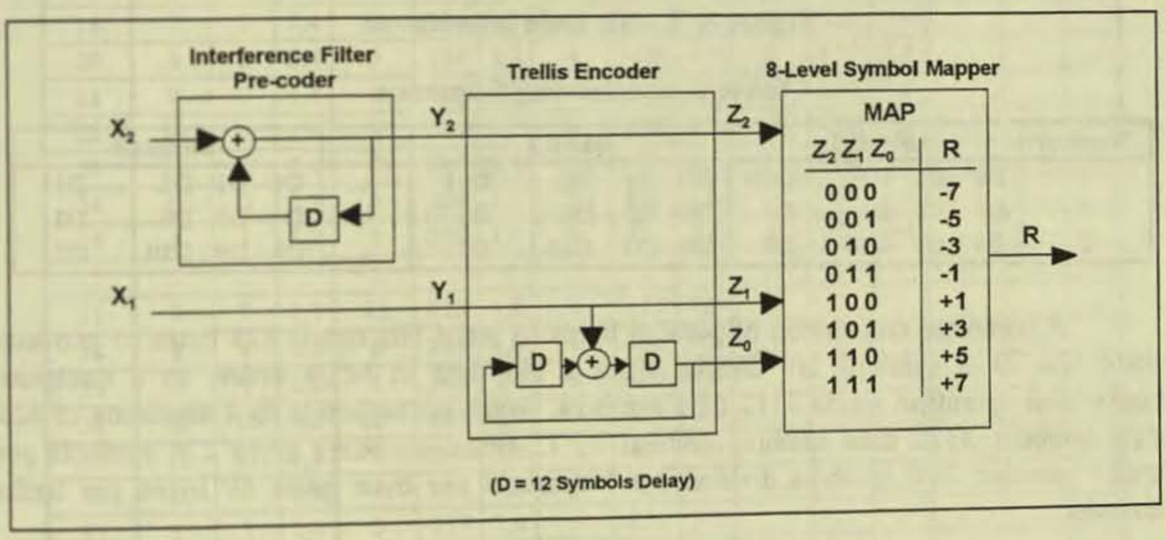


Figure 7. 8 VSB trellis encoder, precoder, and symbol mapper.

The output multiplexer shown in Figure 8 shall advance by four symbols on each segment boundary. However, the state of the trellis encoder shall not be advanced. The data coming out of the multiplexer shall follow normal ordering from encoder 0 through 11 for the first segment of the frame, but on the second segment the order changes and symbols are read from encoders 4 through 11, and then 0 through 3. The third segment reads from encoder 8 through 11 and then 0 through 7. This three-segment pattern shall repeat through the 312 Data Segments of the frame. Table 1 shows the interleaving sequence for the first three Data Segments of the frame.

After the Data Segment Sync is inserted, the ordering of the data symbols is such that symbols from each encoder occur at a spacing of twelve symbols.

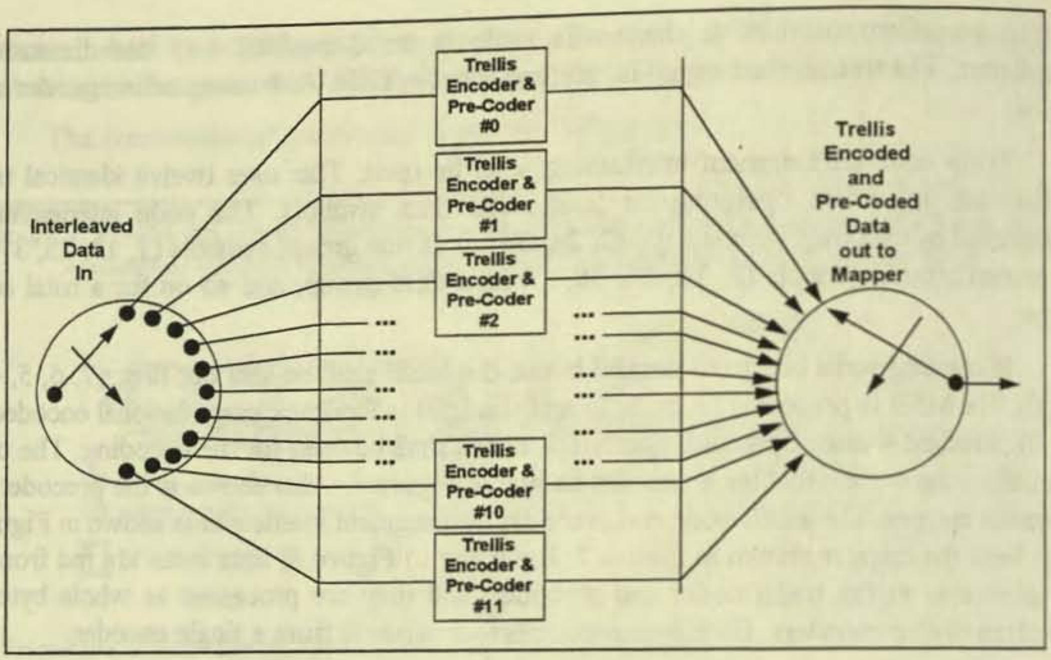


Figure 8. Trellis code interleaver.

Table 1 Interleaving Sequence

Segment	Block 0	Block 1	...	Block 68
0	D0 D1 D2 ... D11	D0 D1 D2 ... D11	...	D0 D1 D2 ... D11
1	D4 D5 D6 ... D3	D4 D5 D6 ... D3	...	D4 D5 D6 ... D3
2	D8 D9 D10 ... D7	D8 D9 D10 ... D7	...	D8 D9 D10 ... D7

A complete conversion of parallel bytes to serial bits needs 828 bytes to produce 6624 bits. Data symbols are created from 2 bits sent in MSB order, so a complete conversion operation yields 3312 data symbols, which corresponds to 4 segments of 828 data symbols. 3312 data symbols divided by 12 trellis encoders gives 276 symbols per trellis encoder. 276 symbols divided by 4 symbols per byte gives 69 bytes per trellis encoder.

The conversion starts with the first segment of the field and proceeds with groups of 4 segments until the end of the field. 312 segments per field divided by 4 gives 78 conversion operations per field.

During segment sync the input to 4 encoders is skipped and the encoders cycle with no input. The input is held until the next multiplex cycle and then fed to the correct encoder.

Table 2 details the byte to symbol conversion and the associated multiplexing of the trellis encoders. Segment 0 is the first segment of the field. The pattern repeats every 12 segments; segments 5 through 11 are not shown.

Table 2 Byte to Symbol Conversion, Multiplexing of Trellis Encoders

Symbol	Segment 0			Segment 1			Segment 2			Segment 3			Segment 4		
	Trellis	Byte	Bits	Trellis	Byte	Bits	Trellis	Byte	Bits	Trellis	Byte	Bits	Trellis	Byte	Bits
0	0	0	7,6	4	208	5,4	8	412	3,2	0	616	1,0	4	828	7,6
1	1	1	7,6	5	209	5,4	9	413	3,2	1	617	1,0	5	829	7,6
2	2	2	7,6	6	210	5,4	10	414	3,2	2	618	1,0	6	830	7,6
3	3	3	7,6	7	211	5,4	11	415	3,2	3	619	1,0	...	...	...
4	4	4	7,6	8	212	5,4	0	416	3,2	4	620	1,0	...	...	...
5	5	5	7,6	9	213	5,4	1	417	3,2	5	621	1,0	...	...	...
6	6	6	7,6	10	214	5,4	2	418	3,2	6	622	1,0	...	...	...
7	7	7	7,6	11	215	5,4	3	419	3,2	7	623	1,0	...	...	...
8	8	8	7,6	0	204	5,4	4	408	3,2	8	612	1,0	...	...	...
9	9	9	7,6	1	205	5,4	5	409	3,2	9	613	1,0	...	...	...
10	10	10	7,6	2	206	5,4	6	410	3,2	10	614	1,0	...	...	...
11	11	11	7,6	3	207	5,4	7	411	3,2	11	615	1,0	...	...	...
12	0	0	5,4	4	208	3,2	8	412	1,0	0	624	7,6	...	...	...
13	1	1	5,4	5	209	3,2	9	413	1,0	1	625	7,6	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
19	7	7	5,4	11	215	3,2	3	419	1,0	7	631	7,6	...	...	...
20	8	8	5,4	0	204	3,2	4	408	1,0	8	632	7,6	...	...	...
21	9	9	5,4	1	205	3,2	5	409	1,0	9	633	7,6	...	...	...
22	10	10	5,4	2	206	3,2	6	410	1,0	10	634	7,6	...	...	...
23	11	11	5,4	3	207	3,2	7	411	1,0	11	635	7,6	...	...	...
24	0	0	3,2	4	208	1,0	8	420	7,6	0	624	5,4	...	...	...
25	1	1	3,2	5	209	1,0	9	421	7,6	1	625	5,4	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
31	7	7	3,2	11	215	1,0	3	427	7,6	...	...	...	...	...	...
32	8	8	3,2	0	204	1,0	4	428	7,6	...	...	...	...	...	...
33	9	9	3,2	1	205	1,0	5	429	7,6	...	...	...	...	...	...
34	10	10	3,2	2	206	1,0	6	430	7,6	...	...	...	...	...	...
35	11	11	3,2	3	207	1,0	7	431	7,6	...	...	...	...	...	...
36	0	0	1,0	4	216	7,6	8	420	5,4	...	...	...	...	...	...
37	1	1	1,0	5	217	7,6	9	421	5,4	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
47	11	11	1,0	3	227	7,6	...	...	...	...	...	...	...	...	...
48	0	12	7,6	4	216	5,4	...	...	...	...	...	...	...	...	...
49	1	13	7,6	5	217	5,4	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
95	11	23	1,0	...	...	...	...	...	...	...	...	...	...	...	...
96	0	24	7,6	...	...	...	...	...	...	...	...	...	...	...	...
97	1	25	7,6	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
767	11	191	1,0	...	...	...	...	...	...	...	...	...	...	...	...
768	0	192	7,6	...	...	...	...	...	...	...	...	...	...	...	...
769	1	193	7,6	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Symbol	Segment 0			Segment 1			Segment 2			Segment 3			Segment 4		
	Trellis	Byte	Bits	Trellis	Byte	Bits	Trellis	Byte	Bits	Trellis	Byte	Bits	Trellis	Byte	Bits
815	11	203	1,0	3	419	7,6	7	623	5,4	11	827	3,2	...	...	...
816	0	204	7,6	4	408	5,4	8	612	3,2	0	816	1,0	...	...	...
817	1	205	7,6	5	409	5,4	9	613	3,2	1	817	1,0	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
827	11	215	7,6	3	419	5,4	7	623	3,2	11	827	1,0	...	...	...

4.2.6 Data segment sync

The encoded trellis data shall be passed through a multiplexer that inserts the various synchronization signals (Data Segment Sync and Data Field Sync).

A two-level (binary) 4-symbol Data Segment Sync shall be inserted into the 8-level digital data stream at the beginning of each Data Segment. (The MPEG sync byte shall be replaced by Data Segment Sync.) The Data Segment Sync embedded in random data is illustrated in Figure 9.

A complete segment shall consist of 832 symbols: 4 symbols for Data Segment Sync, and 828 data plus parity symbols. The Data Segment Sync is binary (2-level). The same sync pattern occurs regularly at 77.3 μs intervals, and is the only signal repeating at this rate. Unlike the data, the four symbols for Data Segment Sync are not Reed-Solomon or trellis encoded, nor are they interleaved. The Data Segment Sync pattern shall be a 1001 pattern, as shown in Figure 9.

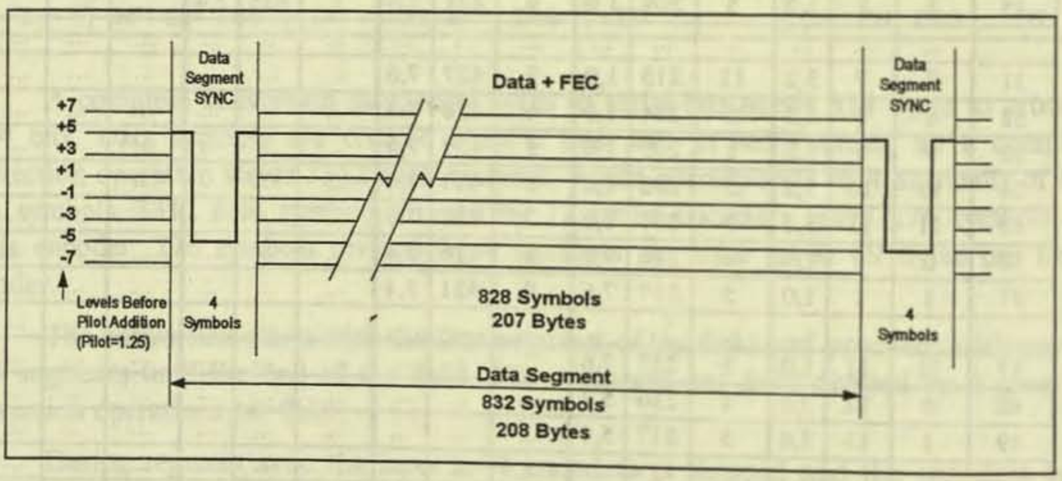


Figure 9. 8 VSB data segment.

4.2.7 Data field sync

The data are not only divided into Data Segments, but also into Data Fields, each consisting of 313 segments. Each Data Field (24.2 ms) shall start with one complete Data Segment of Data Field Sync, as shown in Figure 10. Each symbol represents one bit of data (2-level). The 832 symbols in this segment are defined below. Refer to Figure 10.

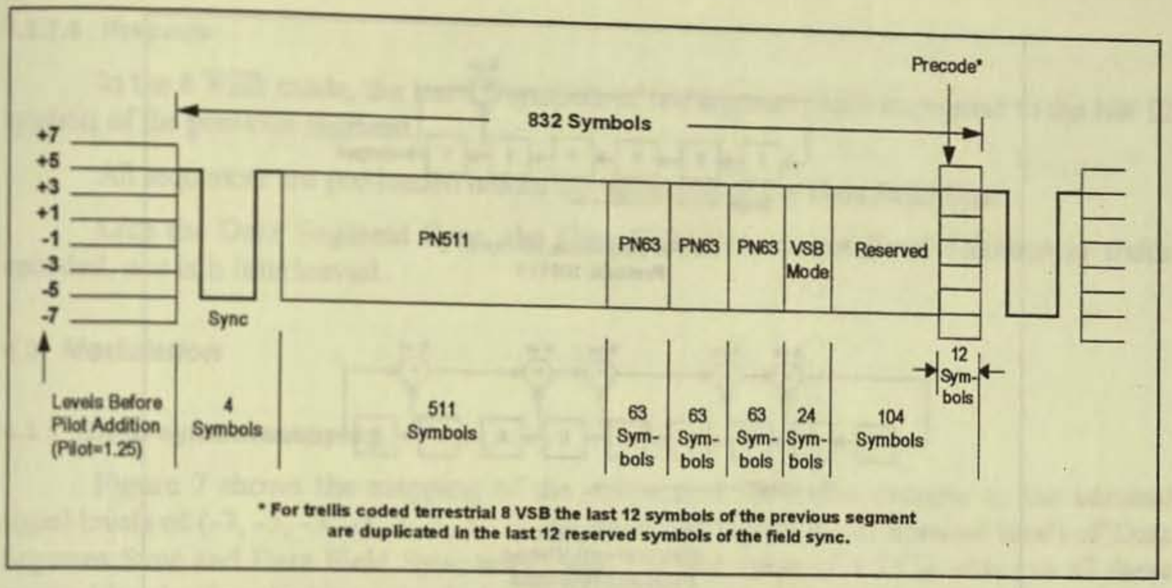


Figure 10. VSB data field sync.

4.2.7.1 Sync

This corresponds to Data Segment Sync and is defined as 1001.

4.2.7.2 PN511

This pseudo-random sequence is defined as $X^9 + X^7 + X^6 + X^4 + X^3 + X + 1$ with a pre-load value of 010000000. The sequence is:

0000 0001 0111 1111 1100 1010 1010 1110 0110 0110 1000 1000 1001 1110 0001 1101
0111 1101 0011 0101 0011 1011 0011 1010 0100 0101 1000 1111 0010 0001 0100 0111
1100 1111 0101 0001 0100 1100 0011 0001 0000 0100 0011 1111 0000 0101 0100 0000
1100 1111 1110 1110 1010 1001 0110 0110 0011 0111 0111 1011 0100 1010 0100 1110
0111 0001 0111 0100 0011 0100 1111 1011 0001 0101 1011 1100 1101 1010 1110 1101
1001 0110 1101 1100 1001 0010 1110 0011 1001 0111 1010 0011 0101 1000 0100 1101
1111 0001 0010 1011 1100 0110 0101 0000 1000 1100 0001 1110 1111 1101 0110 1010
1100 1001 1001 0001 1101 1100 0010 1101 0000 0110 1100 0000 1001 0000 0001 110

4.2.7.3 PN63

This pseudo-random sequence is repeated three times. It is defined as $X^6 + X + 1$ with a pre-load value of 100111. The middle PN63 is inverted on every other Data Field Sync. The sequence is:

1110 0100 1011 0111 0110 0110 1010 1111 1100 0001 0000 1100 0101 0011 1101 000

The generators for the PN63 and PN511 sequences are shown in Figure 11.

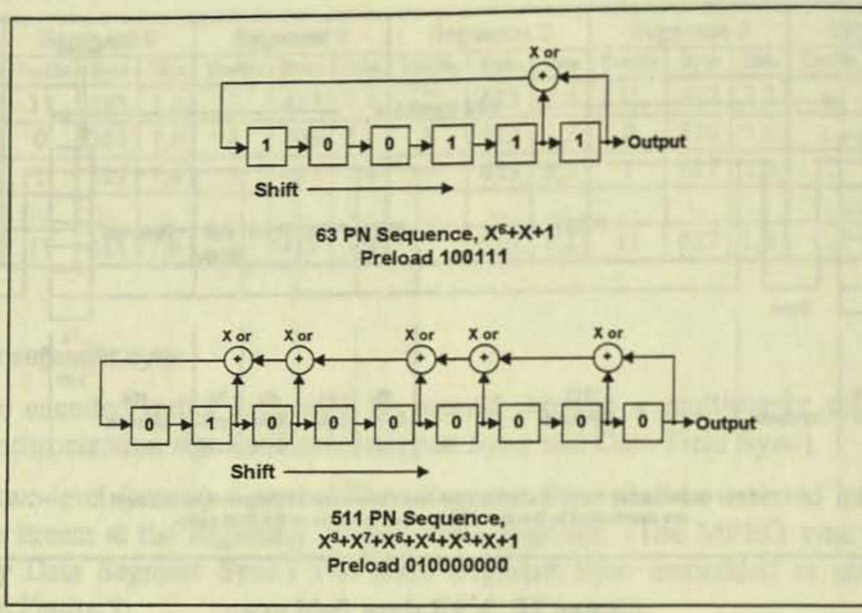


Figure 11. Field sync PN sequence generators.

4.2.7.4 VSB mode

These 24 bits determine the VSB mode for the data in the frame. The first two bytes are reserved. The suggested fill pattern is 0000 1111 0000 1111. The next byte is defined as:

P A B C $\overline{\text{P A B C}}$

where P is the even parity bit, the MSB of the byte, and A,B, C are the actual mode bits.

P A B C	
0 0 0 0	Reserved
1 0 0 1	Reserved
1 0 1 0	Reserved
0 0 1 1	Reserved
1 1 0 0	16 VSB
0 1 0 1	8 VSB*
0 1 1 0	Reserved
1 1 1 1	Reserved

* In the 8 VSB mode, the preceding bits are defined as :

0 0 0 0 $\overline{\text{P A B C}}$ P A B C 1 1 1 1

4.2.7.5 Reserved

The last 104 bits shall be reserved space. It is suggested that this be filled with a continuation of the PN63 sequence. In the 8 VSB mode, 92 bits are reserved followed by the 12 symbol definition below.

4.2.7.6 Precode

In the 8 VSB mode, the last 12 symbols of the segment shall correspond to the last 12 symbols of the previous segment.

All sequences are pre-loaded before the beginning of the Data Field Sync.

Like the Data Segment Sync, the Data Field Sync is not Reed-Solomon or trellis encoded, nor is it interleaved.

4.3 Modulation

4.3.1 Bit-to-symbol mapping

Figure 7 shows the mapping of the outputs of the trellis decoder to the nominal signal levels of (-7, -5, -3, -1, 1, 3, 5, 7). As shown in Figure 9, the nominal levels of Data Segment Sync and Data Field Sync are -5 and +5. The value of 1.25 is added to all these nominal levels after the bit-to-symbol mapping function for the purpose of creating a small pilot carrier.

4.3.2 Pilot addition

A small in-phase pilot shall be added to the data signal. The frequency of the pilot shall be the same as the suppressed-carrier frequency as shown in Figure 3. This may be generated in the following manner. A small (digital) DC level (1.25) shall be added to every symbol (data and sync) of the digital baseband data plus sync signal (±1, ±3, ±5, ±7). The power of the pilot shall be 11.3 dB below the average data signal power.

4.3.3 8 VSB modulation method

The VSB modulator receives the 10.76 Msymbols/s, 8-level trellis encoded composite data signal (pilot and sync added). The ATV system performance is based on a linear phase raised cosine Nyquist filter response in the concatenated transmitter and receiver, as shown in Figure 12. The system filter response is essentially flat across the entire band, except for the transition regions at each end of the band. Nominally, the roll-off in the transmitter shall have the response of a linear phase root raised cosine filter.

5. TRANSMISSION CHARACTERISTICS FOR HIGH DATA RATE MODE

5.1 Overview

The high data rate mode trades off transmission robustness (28.3 dB signal-to-noise threshold) for payload data rate (38.57 Mbps). Most parts of the high data rate mode VSB system are identical or similar to the terrestrial system. A pilot, Data Segment Sync, and Data Field Sync are all used to provide robust operation. The pilot in the high data rate mode also is 11.3 dB below the data signal power. The symbol, segment, and field signals and rates are all the same, allowing either receiver to lock up on the other's transmitted signal. Also, the data frame definitions are identical. The primary difference is the number of transmitted levels (8 versus 16) and the use of trellis coding and NTSC interference rejection filtering in the terrestrial system.

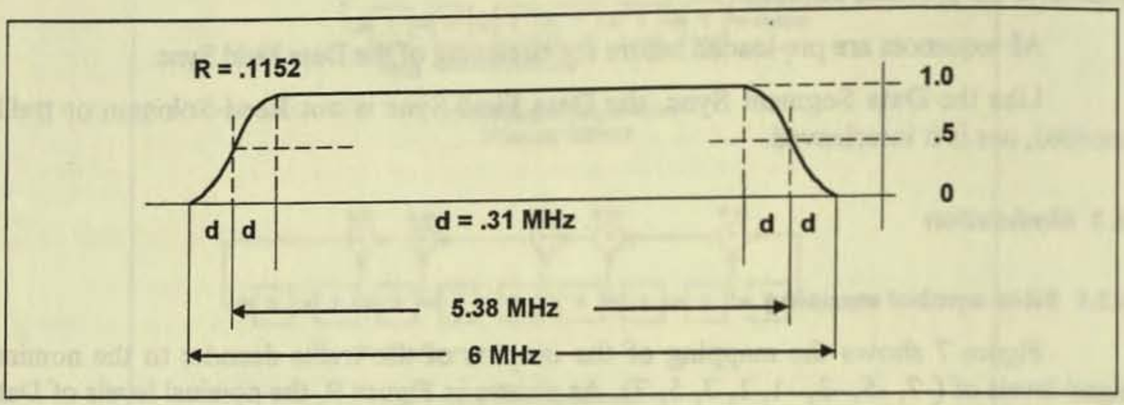


Figure 12. Nominal VSB system channel response (linear phase raised cosine Nyquist filter).

The RF spectrum of the high data rate modem transmitter looks identical to the terrestrial system, as illustrated in Figure 3. Figure 13 illustrates a typical data segment, where the number of data levels is seen to be 16 due to the doubled data rate. Each portion of 828 data symbols represents 187 data bytes and 20 Reed-Solomon bytes followed by a second group of 187 data bytes and 20 Reed-Solomon bytes (before convolutional interleaving).

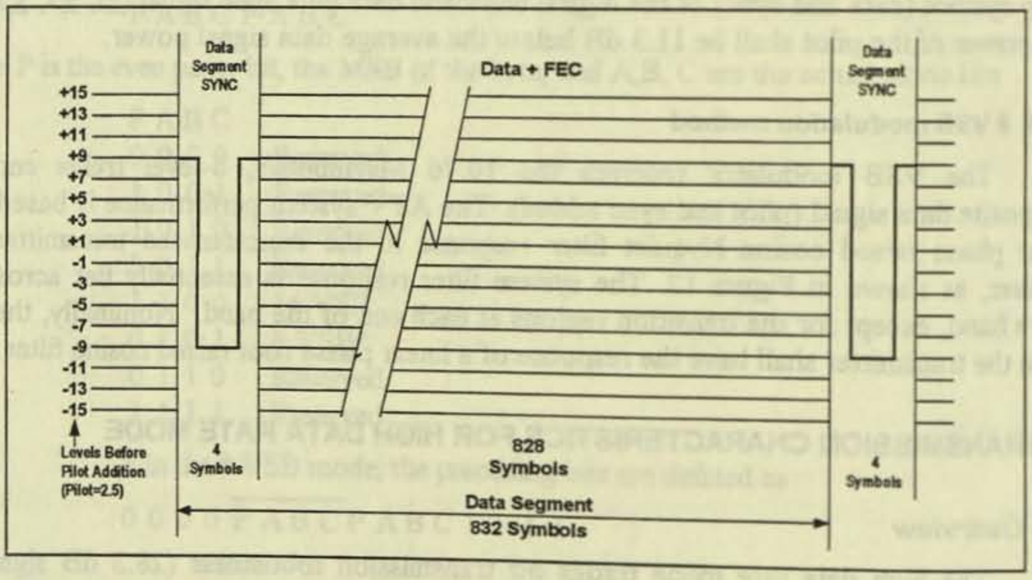


Figure 13. 16 VSB data segment.

Figure 14 shows the block diagram of the transmitter. It is identical to the terrestrial VSB system except the trellis coding shall be replaced with a mapper which converts data to multi-level symbols. See Figure 15.

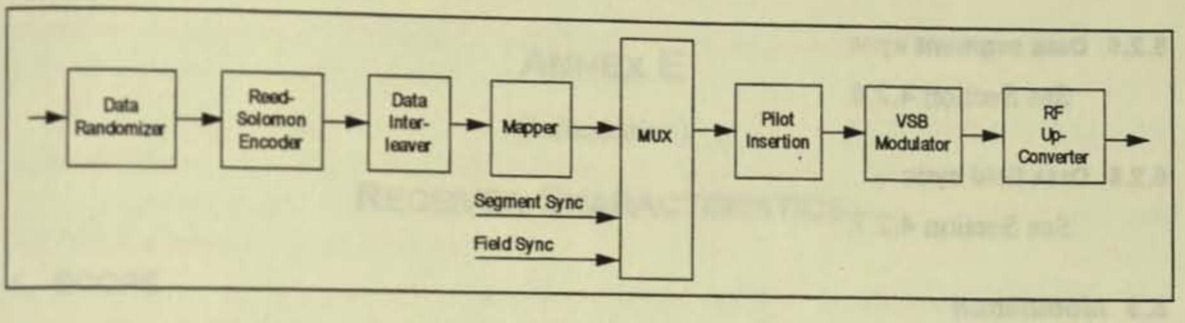
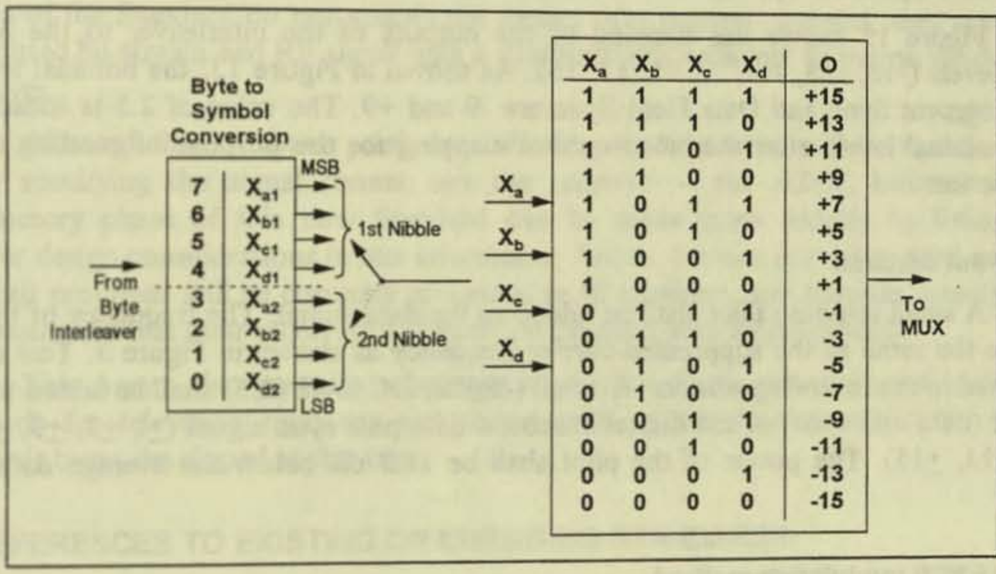


Figure 14. 16 VSB transmitter.



X_a	X_b	X_c	X_d	O
1	1	1	1	+15
1	1	1	0	+13
1	1	0	1	+11
1	1	0	0	+9
1	0	1	1	+7
1	0	1	0	+5
1	0	0	1	+3
1	0	0	0	+1
0	1	1	1	-1
0	1	1	0	-3
0	1	0	1	-5
0	1	0	0	-7
0	0	1	1	-9
0	0	1	0	-11
0	0	0	1	-13
0	0	0	0	-15

Figure 15. 16 VSB mapper.

5.2 Channel error protection and synchronization

5.2.1 Prioritization

See Section 4.2.1.

5.2.2 Data randomizer

See Section 4.2.2.

5.2.3 Reed-Solomon encoder

See Section 4.2.3.

5.2.4 Interleaving

The interleaver shall be a 26 data segment inter-segment convolutional byte interleaver. Interleaving is provided to a depth of about 1/12 of a data field (2 ms deep). Only data bytes shall be interleaved.

5.2.5 Data segment sync

See Section 4.2.6.

5.2.6 Data field sync

See Section 4.2.7.

5.3 Modulation

5.3.1 Bit-to-symbol mapping

Figure 15 shows the mapping of the outputs of the interleaver to the nominal signal levels (-15, -13, -11, ..., 11, 13, 15). As shown in Figure 13, the nominal levels of Data Segment Sync and Data Field Sync are -9 and +9. The value of 2.5 is added to all these nominal levels after the bit-to-symbol mapping for the purpose of creating a small pilot carrier.

5.3.2 Pilot addition

A small in-phase pilot shall be added to the data signal. The frequency of the pilot shall be the same as the suppressed-carrier frequency as shown in Figure 3. This may be generated in the following manner. A small (digital) DC level (2.5) shall be added to every symbol (data and sync) of the digital baseband data plus sync signal (±1, ±3, ±5, ±7, ±9, ±11, ±13, ±15). The power of the pilot shall be 11.3 dB below the average data signal power.

5.3.3 16 VSB modulation method

The modulation method shall be identical to that in Section 4, except the number of transmitted levels shall be 16 instead of 8.

ANNEX E

(Informative)

RECEIVER CHARACTERISTICS

1. SCOPE

This informative Annex provides material to help readers understand and implement the normative portions of the Digital Television Standard. The normative clauses of the Standard do not specify the design of a receiver. Instead, they specify the transmitted bit stream and RF signal with a thoroughness sufficient to permit the design of a receiver.

Although the normative portions of the Standard are written in the traditional way — by specifying the signal format, not the receiver — the ATSC believes that the introductory phase of this new Standard can be made more orderly by listing some receiver design considerations in this informative Annex. Service providers need assurance that their programs will be correctly processed in all receivers, and receiver manufacturers need assurance that their receivers will function properly with all broadcasts.

This Annex also contains references to existing (both voluntary and mandatory) standards for television receivers and notes work in progress on voluntary industry standards being developed at this time.

2. REFERENCES TO EXISTING OR EMERGING STANDARDS

47 CFR Part 15, *FCC Rules.*

EIA IS-132, *EIA Interim Standard for Channelization of Cable Television.*

EIA IS-23, *EIA Interim Standard for RF Interface Specification for Television Receiving Devices and Cable Television Systems.*

EIA IS-105, *EIA Interim Standard for a Decoder Interface Specification for Television Receiving Devices and Cable Television Decoders.*

3. COMPLIANCE NOTATION

Compliance with mandatory or voluntary standards and recommended practices for digital television receivers can be inferred only from previous experience with NTSC. Actual standards for digital television receivers have not been developed at this time. As used in this document "appropriate" means that the existing rules for NTSC which are referenced contain most elements of future rules for digital television. Furthermore, the rules may be expanded to cover digital television.

4. STATUS OF RECEIVER STANDARDIZATION ACTIVITIES

4.1 Tuner performance

The FCC Rules under 47 CFR Part 15 which are applicable to conventional television receivers are expected to be appropriate for digital television receivers.

4.1.1 Noise figure

The 10 dB noise figure used as a planning factor has been reviewed considering the needs of digital television reception and has been found appropriate.

4.1.2 Channelization plan for broadcast and cable

The cable channelization plan specified in the FCC Rules under 47 CFR Part 15 which are applicable to conventional television receivers are expected to be appropriate for digital television receivers. Broadcast channelization is specified in the FCC Rules under 47 CFR Part 73.

4.1.3 Direct pickup

The FCC Rules under 47 CFR Part 15 which are applicable to conventional television receivers may be appropriate for digital television receivers, as well. Performance characteristics for reception of digital signals, whether standard or high definition, have not been developed by the industry. It is expected that direct pickup of a given level will have less effect on digital signals than on NTSC.

4.2 Transport

Significant work for identification of multiple programs within a single digital television channel has not taken place in the industry. It is recommended that a digital television receiver provide appropriate features to assist users in the selection of the desired video program service, if multiple video programs within one channel are offered.

4.3 Decoder interface

The FCC Rules which are to be adopted for a decoder interface on NTSC receiver advertised as "cable-ready" or "cable-compatible" are expected to be appropriate for digital television receivers. Much work has been done on this interface standard (IS-105) by the Joint Engineering Committee of EIA and NCTA. Although that interface standard is not intended to apply to digital television receivers, it will almost certainly provide a basis for a decoder interface standard applicable to them.

4.4 Digital data interface

Work on a digital data interface is being performed by the EIA's R-4.1 subcommittee on ATV Receiver Interfaces. R-4.1 intends to define a baseband serial digital interface so that devices may exchange packetized data, for example, when a digital VCR is connected to a digital television receiver.

It is recommended that manufacturers of digital television receivers wishing to include a digital data interface give consideration to the interface developed by R4.1.

4.5 Conditional access interface

The National Renewable Security System (NRSS) Subcommittee of the Joint Engineering Committee of EIA and NCTA has the responsibility to develop a standard for a plug-in security module. The NRSS standard may be applied in either a standard definition or high definition environment.

It is recommended that manufacturers of digital television receivers wishing to include a conditional access interface give consideration to the NRSS standard developed by the JEC.

4.6 Closed captioning

Closed captioning for television is covered by the FCC Rules under 47 CFR Part 15 which are presently applied to conventional television receivers. These rules are expected to be appropriate for digital television receivers.

Work on defining the technical standard for closed captioning for the digital television system is being performed by the EIA's R-4.3 subcommittee.

5. RECEIVER FUNCTIONALITY

5.1 Video

It is recommended that a digital television receiver be capable of appropriately decoding and displaying the video scanning formats defined in the Digital Television Standard and described in Table 3 "Compression Format Constraints" in Annex A of this Standard.

5.2 Audio

It is recommended that a digital television receiver be capable of selecting and decoding any audio service described in Section 6 of Annex B of this Standard, subject to the bit rate constraints in Section 5.3 of Annex B of this Standard.

It is recommended that a digital television receiver be capable of normalizing audio levels based on the value of the syntactical element dialnorm which is contained in the audio elementary stream.

It is recommended that a digital television receiver be capable of altering reproduced audio levels based on the value of the syntactical element dynrng which is contained in the audio elementary stream.

It is recommended that a digital television receiver provide appropriate features to assist users in the selection of program related audio services.

ANNEX

Record of Test Results
October 1995

For copies of the Record of Test Results, contact:

Advanced Television Test Center
1330 Braddock Place
Suite 200
Alexandria, VA 22314-1650
703-739-3850