ATV SYSTEM RECOMMENDATION

Federal Communications Commission

Advisory Committee on Advanced Television Service

Preface

This report, adopted by the Advisory Committee on Advanced Television Service on February 24, 1993, is based on the efforts of hundreds of firms and individuals involved in this project to bring advanced television service to the American public. As a result of the Advisory Committee process, under the leadership of the Federal Communications Commission, it has become apparent that digital HDTV service is achievable for the United States. Indeed, the four digital systems developed under this process lead the world in this technology.

The Advisory Committee wishes to thank all those persons who have played a role in drafting this report and especially wishes to thank the members of the Special Panel for their extraordinary effort in completing the report.

Respectfully submitted,

FCC ADVISORY COMMITTEE ON
ADVANCED TELEVISION SERVICE

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

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Appendices

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1. EXECUTIVE SUMMARY

This document represents the work conducted to date under the auspices of the Advisory Committee on Advanced Television Service, which was formed in 1987 to advise the Federal Communications Commission on various aspects of advanced television. Through the efforts of hundreds of Advisory Committee participants, particularly those groups which have proposed systems for the Committee's consideration, extraordinary achievements in advanced television have been realized in a very short period. As a result of the Advisory Committee process, under the Commission's leadership, it has become apparent that digital high definition television service is achievable for the United States.

Testing and data analysis recently were completed on five high definition television systems. Previously, in its Fifth Interim Report to the FCC, the Advisory Committee approved a set of ten "Selection Criteria" for use in analyzing the performance of the systems tested. The criteria are grouped into three general categories: spectrum utilization, economics, and technology. In the same report, the Advisory Committee created a Special Panel that would use these criteria to evaluate the performance of tested ATV systems.

The Special Panel met on February 8 - 11, 1993, to consider these matters and to pass a report to the Parent Committee for its consideration. The resulting findings, the bases of which are set forth in Chapter 14 of this document, are as follows:

SPECTRUM UTILIZATION

1. The analysis conducted by the Advisory Committee clearly demonstrates that a substantial difference exists in spectrum utilization performance between Narrow-MUSE and the four all-digital systems. The differences among the four digital systems generally are far less pronounced, however. Based on this analysis, it would appear that Narrow-MUSE will not prove to be a suitable terrestrial broadcasting ATV system for the United States.

2. The Special Panel notes that many system proponents have proposed improvements to their systems in the area of spectrum utilization. The Special Panel finds that the system improvements, primarily those identified by its Technical Subgroup as ready for implementation in time for testing, may lead to improvements in spectrum utilization and should be subjected to testing as soon as possible.

3. The Special Panel finds that the degree of interference from ATV into NTSC, as reflected in the test results and the PS/WP3 report, is recognized as an area of concern in certain markets. The Special Panel finds that the issue of ATV into NTSC interference, including interference to BTSC audio, should be addressed in the remaining stages of the system selection process, including the examination of refined allotment/assignment techniques, the study of possible beneficial effects of system improvements, and the consideration of any mitigations which might be achieved by transitional implementation policies.

ECONOMICS

1. No significant cost differences among the five proponent systems, either in costs to consumers or to broadcasters, are evident. Thus, based on cost alone, there is no basis to discriminate among systems. However, the additional benefits offered to broadcasters and others by the digital systems were noted as significant.

TECHNOLOGY

1. As a result of the testing process, the Advisory Committee is confident that a digital terrestrial advanced television system can provide excellent picture and sound quality. All of the system proponents have proposed refinements that are likely to enhance the audio and video quality beyond that measured in the testing process.

2. A variety of transmission formats was evaluated. The transmission robustness analysis conducted by the Advisory Committee clearly reveals that an all-digital approach is both feasible and desirable. All of the system proponents have proposed refinements that are likely to enhance robustness beyond that measured in the testing process.

3. An all-digital system approach is important to the scope of ATV services and features and in the areas of extensibility and interoperability. All four digital proponents have committed to a flexible packetized data transport structure and universal headers/ descriptors; design and implementation are subject to verification. Progressive-scan/ square-pixel transmission is considered beneficial to creating synergy between terrestrial ATV and national information initiatives. As well, scalability at the transmission data stream would permit trade-offs in “bandwidth on demand” network environments.

RECOMMENDATIONS

While all the proponents produced advanced television systems, the Special Panel notes that there are major advantages in the performance of digital HDTV systems in the United States environment and recommends that no further consideration be given to analog-based systems. The proponents of all four digital HDTV systems — DigiCipher, DSC-HDTV, AD-HDTV, and CCDC — have provided practical digital HDTV systems that lead the world in this technology. Because all four systems would benefit significantly from further development, the Special Panel does not recommend any one of these systems for adoption as a United States terrestrial ATV transmission standard at this time. Rather, the Special Panel recommends that these four finalist proponents be authorized to implement their improvements as submitted to the Advisory Committee and approved by the Special Panel’s Technical Subgroup.

The Special Panel further recommends that the approved system improvements be ready for testing not later than March 15, 1993, and that these improvements be laboratory and field tested as expeditiously as possible. The results of the supplemental tests, along with the already planned field tests, would provide the necessary additional data needed to select a single digital system for recommendation as a United States terrestrial ATV transmission standard.

2. INTRODUCTION

The Advisory Committee on Advanced Television Service was empaneled by the Federal Communications Commission in 1987 to develop information that would assist the FCC in establishing an advanced television ("ATV") standard for the United States.[1] 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.

This report is the Advisory Committee's ATV System Recommendation to the FCC.

The United States is on the verge of establishing a new technical standard for television broadcasting, a standard that will last many years if we have done our work well. Our current standard has stood the test of time — the United States monochrome television standard was adopted by the FCC in 1941; in 1953 it was modified by the FCC to add color. That standard is still in use and will be for a number of years. In both of these cases, an industry committee developed the technical standards which were then adopted by the FCC. It seems fitting that this historical information be noted in this report — it can be found in Chapter 3.

Chapter 3 also gives background information on the work of the Advisory Committee. Key findings of the Advisory Committee in its five interim reports are listed.

The substantive work of the Advisory Committee has been performed by three subcommittees: Planning, Systems, and Implementation. The subcommittees were organized into the following sub-groups:

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[1] The Advisory Committee on Advanced Television Service is chaired by Richard E. Wiley. Other members of the Advisory Committee at the time of the adoption of this report are Frank Biondi, Joel Chaseman, Bruce Christensen, Joseph Collins, William Connolly, Martin Davis, James Dowdle, Craig I. Fields, Stanley S. Hubbard, Donald F. Johnstone, James Kennedy, James C. McKinney, Rupert Murdock, Thomas S. Murphy, Jerry K. Pearlman, F. Jack Pluckhan, Ward Quaal, Richard D. Roberts, Burton Staniar, Laurence Tisch, Robert Wright, and subcommittee chairs Joseph Flaherty, Irwin Dorros, and James Tietjen. Ex officio members are one representative each from the State Department and NTIA, John Abel, Wendell Bailey, Henry L. Baumann, Tyrone Brown, Brenda Fox, George Vradenburg III, Margita White, Joseph Donahue, Robert Graves, Keiichi Kubota, Jae S. Lim, and Donald Rumsfeld.

Planning Subcommittee
- PS/WP1 - Technology Attributes and Assessment
- PS/WP2 - Testing and Evaluation Specifications
- PS/WP3 - Spectrum Utilization and Alternatives
- PS/WP4 - Alternative Media Technology and Broadcast Interface
- PS/WP5 - Economic Factors and Market Penetration
- PS/WP6 - Systems Subjective Assessment
- PS/WP7 - Audience Research
- PS/AG1 - Creative Issues
- PS/AG2 - Consumer/Trade Issues

Systems Subcommittee
- SS/WP1 - Systems Analysis
- SS/WP2 - System Evaluation and Testing
- SS/WP3 - Economic Assessment
- SS/WP4 - System Standards

Implementation Subcommittee
- IS/WP1 - Policy and Regulation
- IS/WP2 - Transition Scenarios

The work of the Planning Subcommittee is summarized in Chapter 4 of this report. The work of the Systems Subcommittee is summarized in Chapter 5. The work of the Implementation Subcommittee is summarized in Chapter 6.

The Advisory Committee, in its fifth interim report, approved a procedure for recommending an ATV system. The first step in the process is the determination of the “Selection Criteria.” The Selection Criteria constitute the key issues that must be examined in order to recommend an ATV system. Also in the fifth interim report, the Advisory Committee agreed to a list of ten Selection Criteria. The Selection Criteria are separated into three areas. These areas and the ten criteria are:

Spectrum Utilization Criteria
- — Service Area
- — Accommodation Percentage

Economics Criteria
- — Cost to Broadcasters
- — Cost to Alternative Media
- — Cost to Consumers

Technology Criteria
- — Audio/Video Quality
- — Transmission Robustness
- — Scope of Services and Features
- — Extensibility
- — Interoperability Considerations

Chapter 7 of this report elaborates on these ten issues, defining them and explaining how proposed systems were measured against the ten criteria. Chapter 8 gives technical details that are necessary for understanding the reported test results on individual proposed systems.

The second step in the recommendation process is the analysis of the proposed systems according to the Selection Criteria. In the subsequent five chapters, each of the proposed five systems is examined according to these criteria. The test information for the examinations came from laboratory testing at the Advanced Television Test Center, Inc. (ATTC), the Cable Television Laboratories, Inc. (CableLabs), and the Advanced Television Evaluation Laboratory (ATEL). Test data was analyzed by the Planning Subcommittee Working Party 3 (Spectrum Utilization Criteria) and the Systems Subcommittee Working Party 4 (Audio/Video Quality and Transmission Robustness). Other substantive information for the examinations came from the Planning Subcommittee Working Party 4 (Scope of Services and Features, Extensibility, and Interoperability Considerations) and the Systems Subcommittee Working Party 3 (Economics Criteria). Information related to improvements which could be made to each of the proposed systems was provided by the Technical Sub-Group of the Special Panel. The system examinations, in the order of testing, can be found in the following chapters:

Chapter 9	Narrow-MUSE
Chapter 10	DigiCipher
Chapter 11	Digital Spectrum Compatible HDTV
Chapter 12	Advanced Digital HDTV
Chapter 13	Channel Compatible DigiCipher

Other steps in the recommendation process are the comparison of proposed systems, the determination of a superior system, and the recommendation of a system. The Advisory Committee, in approving the fifth interim report, appointed a Special Panel to make a thorough technical analysis and comparison of the ATV proponent systems and assist the Advisory Committee in preparing its system recommendation. The analyses and comparisons made by the Special Panel[2] appear in Chapter 14 of this report. In Chapter 14, systems are always listed in the order of testing if no distinction was made in performance. ATV systems that were found to perform in a superior manner are identified in Chapter

[2] The Special Panel was chaired by Dr. Robert Hopkins. The Vice-Chair was Alex D. Felker. Other members of the Special Panel were Wendell Bailey, Birney D. Dayton, Irwin Dorros, Richard Ducey, Joseph Flaherty, James Gaspar, Branko J. Gerovac, Reggie Gilliam, George Hanover, Dale Hatfield, Edward D. Horowitz, Charles Jackson, Bronwen Jones, Renville H. McMann Jr., Robert Niles, Mark Richer, Robert Sanderson, Rupert Stow, Richard J. Stumpf, Craig Tanner, Victor Tawil, Laurence J. Thorpe, and George Vradenburg III. *Ex officio* participants were the Chairman of the Advisory Committee (Richard E. Wiley), FCC Mass Media Bureau (Roy Stewart), FCC Office of Engineering and Technology (Thomas Stanley), NTIA (Tom Sugrue), Department of State (Richard Beaird), Canadian Liaison (Kenneth Davies), Mexican Liaison (Victor Rojas), ATTC (Peter Fannon), CableLabs (Brian James), ATEL (Paul Hearty), Field Test Technical Oversight Committee (Howard Miller), System-Specific Task Force (John Henderson), Narrow-MUSE proponent (Keiichi Kubota), DigiCipher proponent (Robert Rast), DSC-HDTV proponent (Wayne Luplow), AD-HDTV proponent (Glenn Reitmeier), and CCDC proponent (Jae Lim).

14 along with an explanation supporting that finding. Finally, the recommendations made by the Special Panel appear in Chapter 14.

Chapter 15 outlines future work, including field testing and documentation of the recommended ATV system. A glossary, the ATEL comparative report, and the System-Specific Task Force comparative report appear at the end. There are a number of appendices to this report, some of which are rather lengthy. They are available separately.

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3. BACKGROUND AND HISTORY

The United States began a proceeding in 1987 which will lead eventually to a new television broadcasting standard. It will be the third American television broadcasting standard. In this Chapter, all three processes are reviewed. For the Monochrome Television Standard and the Color Television Standard, the full process can be reviewed. For the Advanced Television Service, the events that led to the formation of the Advisory Committee on Advanced Television Service and key findings from the five interim reports of the Advisory Committee are reviewed.

3.1 MONOCHROME TELEVISION STANDARD[1]

In the late 1930's, as television was nearing the point of commercialization, the members of the FCC insisted that the standards for television, as well as for other services, be set only when the industry was in substantial agreement on the form the standards should take. The FCC had already decided that the channel bandwidth for television would be 6 MHz. The Chairman of the FCC was James Lawrence Fly.

The concept of the National Television System Committee (NTSC) arose in a meeting between Chairman Fly and Dr. W.R.G. Baker, a General Electric executive and director of engineering of the Radio Manufacturers Association (RMA). The NTSC was formed as a private sector organization and placed under the sponsorship of the RMA. The deliberations were open to all members of the industry that were technically qualified to participate whether or not they were members of the RMA.

The original record of the NTSC was 11 volumes totaling approximately 2,000 pages. The first meeting was held July 31, 1940. The final meeting was held March 8, 1941. Dr. Baker served as Chairman of the NTSC. The work of the NTSC was organized into nine panels.

A progress report was presented to the FCC on January 27, 1941. The members of the FCC were satisfied that substantial agreement had been obtained on all parts of the standard except for two points — the specification of 441 scanning lines per frame and amplitude modulation for the synchronization signals.

At its final meeting on March 8, 1941 the NTSC agreed to specify 525 scanning lines per frame and rewrote the portion of the standard concerning synchronization to permit also the use of frequency modulation.

The final report of the NTSC was delivered to the FCC on March 20, 1941 recommending adoption of the NTSC standard. The only opposition given to the standard at that time was put forward by the DuMont Laboratories which urged that a variable number of lines and frames per second should be

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[1] All the information in this section has been taken from Television Standards and Practice (Selected Papers from the Proceedings of the National Television System Committee and Its Panels), edited by Donald G. Fink, McGraw-Hill Book Company Inc., NY, 1943.

used. Effective April 30, 1941 the FCC officially adopted the standard and ruled that commercial television broadcasting based on the standard would be permitted on and after July 1, 1941.

Key elements of the standard were the use of a 6 MHz RF channel with the picture carrier 1.25 MHz above the bottom of the channel, the sound carrier 4.5 MHz above the picture carrier, VSB modulation of the picture carrier with negative modulation and preservation of the DC component, frequency modulation of the sound carrier, 525 scanning lines per frame with 2:1 interlace, 30 frames or 60 fields per second, and 4:3 aspect ratio.

3.2 COLOR TELEVISION STANDARD[2]

The first NTSC was formed to perform a service specifically requested by the FCC and its advent was welcomed by the FCC. When the second NTSC was formed, a much less favorable situation existed. A non-compatible color system was approved by the FCC in 1950 against the advice of a great majority of the industry's technical experts. Because of the controversy, Dr. Baker reactivated the NTSC in January 1950.

The panel structure was reorganized around the particular problems of color television. The membership was greatly expanded. The work of the second NTSC was contained in 18 volumes of about 4,100 pages. Dr. Baker served as Chairman. The work of the second NTSC was divided among 8 panels.

Progress by several companies on color television research was rapid. Because of the rapid progress, on November 20, 1950 the activity of the eight panels was temporarily suspended and an Ad Hoc Committee was appointed to recommend a future course of action. The Ad Hoc Committee reported on April 19, 1951. Its recommendations were accepted and the second NTSC was reorganized into ten new panels. The first meeting of the reorganized NTSC was held June 18, 1951. By July 1953, when the Committee approved the final draft of the color signal specifications, all traces of the earlier controversy had disappeared and the industry was able to present a truly united front.

The color standard was adopted by the NTSC on July 21, 1953 and transmitted to the FCC the following day. Demonstrations were performed for the FCC on October 15, 1953. On December 17, 1953 the FCC approved the color standard. Color service was authorized after January 22, 1954. The second NTSC was officially disbanded on February 4, 1954.

Only a few changes were made to the monochrome standard to include color. Of the key elements noted above for the monochrome standard, only the frame/field rate changed and that was by the ratio of 1000/1001.[3] A modulated subcarrier containing the color information was added. The color burst was added to the synchronizing waveform. Some signal tolerances were made tighter.

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[2] All the information in this section has been taken from Color Television Standards (Selected Papers and Records of the National Television System Committee), edited by Donald G. Fink, McGraw-Hill Book Company Inc., NY, 1955.

[3] The color subcarrier was specified to be 1/2 an odd multiple (455) of the horizontal frequency to minimize the visibility of the subcarrier in the picture. To minimize beats between the sound carrier and the color subcarrier, the

(continued...)

3.3 ADVANCED TELEVISION SERVICE

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.

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 ATV. On November 17, 1987 the FCC formed the Advisory Committee on Advanced Television Service. The Advisory Committee has filed five interim reports with the FCC. Key findings in those reports are summarized in this section.

3.3.1 First Interim Report, June 16, 1988

The first interim report was based primarily on the work of the Planning Subcommittee. The report noted that proposals to implement improvements in the existing NTSC television standard ranged from simply enhancing the current standard all the way to HDTV. The spectrum requirements for these proposals fell into three categories: 6 MHz, 9 MHz, and 12 MHz. Advocates of a 12 MHz approach suggested using two channels in one of two ways: 1) an existing NTSC-compatible channel supplemented by a 6 MHz augmentation channel (either contiguous or non-contiguous), or 2) an existing NTSC-compatible channel, unchanged, and a separate 6 MHz channel containing an independent non-NTSC-compatible HDTV signal. It was pointed out that both of these methods would be "compatible" in the sense that existing television receivers could continue to be serviced by an NTSC signal.

Just as rapid progress was seen by the second NTSC, rapid progress was seen by the Advisory Committee. In the first interim report, it was stated: "Based on current bandwidth compression techniques, it appears that full HDTV will require greater spectrum than 6 MHz." The report went on to say: "The Advisory Committee believes that efforts should be focused on establishing, at least ultimately, an HDTV standard for terrestrial broadcasting." The report also stated: "One advantage to [simulcasting], it should be noted, is that at some point in the future — after the NTSC standard and NTSC-equipped receivers are retired — part of the spectrum being utilized might be reemployed for other uses." On the basis of preliminary engineering studies, the Advisory Committee stated that it

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sound carrier was specified to be 1/2 an even multiple of the horizontal frequency. To ensure compatibility with monochrome receivers, the sound carrier remained the same as it was for monochrome, 4.5 MHz. For monochrome, the ratio of the sound carrier to the horizontal frequency was close to, but not precisely, 286. For color, it was set precisely to 286. As a result, the horizontal frequency was changed slightly and thus the vertical frequency was changed slightly. This gave rise to NTSC's infamous vertical frequency of 59.94 Hz, or 1000/1001 times 60 Hz.

believed that sufficient spectrum capacity in the current TV allocations might be available to allow all existing stations to provide ATV through either an augmentation or simulcast approach.

3.3.2 Second Interim Report, April 26, 1989

The Advisory Committee suggested its life be extended from November 1989 to November 1991. It also suggested that the FCC should be in a position to establish a single terrestrial ATV standard sometime in 1992.

The Advisory Committee noted that work was ongoing in defining tests to be performed on proponent systems. An issue was raised relating to subjective tests and whether source material required for testing should be produced in only one format and transcoded into the formats used by different systems to be tested, or whether source material should be produced in all required formats.

The Advisory Committee also sought guidance from the FCC on the minimum number of audio channels that an ATV system would be expected to provide.

3.3.3 Third Interim Report, March 21, 1990

In the third interim report, it was noted that subjective assessment material would soon be shot. The Advisory Committee approved the test plans and agreed that complete systems, including audio, would be required for testing. It was also agreed that proposed systems must be pre-certified by SS/WP1 by June 1, 1990.

Because it was a deadline, the date of June 1, 1990 became quite significant. It is noteworthy that the first all-digital proposal was submitted shortly before June 1, 1990.

Other items mentioned in the third interim report were that the psychophysical tests of advanced television systems would be conducted in Canada; that the Planning Subcommittee, through its Working Party 3, would undertake the development of preliminary ATV channel allotment plans and assignment options; and that the Advisory Committee was not in a position to fund testing of consumer reactions to various aspects of ATV although PS/WP7 efforts to find other financing sources for such research projects was endorsed.

3.3.4 Fourth Interim Report, April 1, 1991

The Advisory Committee noted that there had been changes in proponents and proposed systems. Most significant was that there were four all-digital proposals. It was reported that testing of proponent systems would begin in the near future; changes had been required in the test procedures because of the introduction of all-digital systems. It was reported also that the System Standards Working Party had defined a process for recommending an ATV system and that PS/WP3 was working toward the goal of providing essentially all existing broadcasters with a simulcast channel whose coverage characteristics are equivalent to NTSC service.

The fourth interim report stated: “Ultimately, it is the Advisory 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. It is anticipated that the Committee will find that one of the ATV proponent systems best fulfills this description. However, in 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."

3.3.5 Fifth Interim Report, March 24, 1992

It was noted that there were five proponent systems, all simulcast, one analog and four all-digital. The Planning Subcommittee reported that it had reconstituted its Working Party 4 to study issues related to harmonizing an ATV broadcast transmission standard with other advanced imaging and transmission schemes that will be used in other television and non-broadcast applications.

The Systems Subcommittee reported that its Working Party 2 had developed procedures for field testing an ATV system. It was noted that the intent of the Advisory Committee is to field test only the system recommended to the FCC by the Advisory Committee based on the laboratory tests (or, possibly, a "winning" system and a "runner-up"). It was reported that Charlotte, North Carolina, had been selected as the site for the field tests and that FCC staff had concurred in this site selection. The Advisory Committee established a field test technical oversight committee.

It was reported that the Systems Subcommittee Working Party 4 had developed a process for recommending an ATV system and had agreed to a list of ten Selection Criteria. It was also reported that Working Party 4 would draft the bulk of the "ATV System Recommendation" report. The draft report would be completed by a Special Panel, composed of knowledgeable and experienced Advisory Committee participants not affiliated with any system proponent, who would make a thorough technical analysis and comparison of the ATV proponent systems and assist the Advisory Committee in preparing its system recommendation to the FCC.

A review of current technology progress showed that there were no new concepts "sufficiently concrete so as to be tested contemporaneously with the pre-certified systems." The Advisory Committee stated that it believed that the five HDTV proponent systems then under consideration represented the state-of-available-technology.

The Advisory Committee noted that it was formed to counsel the FCC and proffer a recommendation on the best available ATV system. It said that other organizations are better suited to develop a completely specified technical standard. It also said it was the Committee's understanding that relevant discussions were underway among standards organizations and that an appropriate organization would volunteer to conduct this important assignment.

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4. CONTRIBUTIONS FROM THE PLANNING SUBCOMMITTEE

The Planning Subcommittee had the following Objective and Scope of Activity:

> *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 broadcasters/consumers/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.*

The Planning Subcommittee was Chaired by Joseph A. Flaherty. The Vice Chairs were Wendell Bailey and Margita White.

The work of the Planning Subcommittee was divided among seven working parties and two advisory groups. The work of these groups is described in the following sections.

4.1 PS/WP1 - WORKING PARTY ON TECHNOLOGY ATTRIBUTES AND ASSESSMENT

The primary responsibility of PS/WP1 was to construct a framework for the investigation of advanced television services for the United States. This framework was to provide the other working parties with a structure upon which they would fulfill their individual assignments. PS/WP1, therefore, was required to complete its work early in the process, meeting occasionally thereafter to respond to specific questions raised by the other working parties.

The scope or statement of work and objectives of PS/WP1 were adopted at the first meeting of the working party on 12 January 1988. The scope stated:

> *This Working Party will define the desirable attributes of terrestrial transmission systems for ATV.*

The statement of objectives stated:

> *The objective of the Working Party shall be to determine the desirable technical characteristics of ATV systems and to arrange and present this information in a form useful to the Planning Subcommittee and its Working Party. The Working*

Party will also work with and advise the Subjective Assessment and the Testing and Evaluation Working Parties on areas of particular interest for detailed examination. It will not be an objective of this Working Party to characterize or select any given system for recommendation to the Advisory Committee on Advanced Television Service for possible implementation.

The major contribution of the working party was an Attributes/Systems Matrix defining the attributes of an advanced television system that must be considered in selecting a terrestrial transmission advanced television service. The attributes matrix with explanatory notes is found as Annex I of the PS/WP1 final report.

The working party met several times with PS/WP2 (Working Party on Testing and Evaluation Specifications) in order to ensure that PS/WP2 was correctly interpreting the Attributes/Systems Matrix while defining their test plan.

The working party was Chaired by Renville H. McMann. The Vice Chairs were Stanley Baron, Thomas Keller, and Robert Niles. Forty-nine individuals participated in one or more of the meetings.

4.2 PS/WP2 - WORKING PARTY ON TESTING AND EVALUATION SPECIFICATIONS

PS/WP2 was charged with the development of objective test specifications for the ATV system attributes identified by PS/WP1 and to develop a draft schedule for the actual testing and evaluation of proposed ATV systems to be performed by the Systems Subcommittee.

PS/WP2 identified two types of testing which were subsequently adopted by the Advisory Committee:

Laboratory Testing to compare proponent system performance.

Field Testing to permit further investigation after laboratory tests are completed.

The completed conceptual test plan was forwarded to the Chairman of SS/WP2 on March 18, 1989. Necessary revisions since then were incorporated in the PS/WP2 final report as were documents created by the working party or submitted to it.

The working party was Chaired by Richard Green. The Vice Chairs were Edward Miller, Steve Flanagan, and William F. Schreiber.

4.3 PS/WP3 - WORKING PARTY ON SPECTRUM UTILIZATION AND ALTERNATIVES

PS/WP3 was given the responsibility for carrying out studies on the availability of spectrum to support various alternatives and systems for advanced television service.

To accomplish its mission, the working party divided its work into three fundamental parts. The first part dealt with the alternative of accommodating ATV within existing VHF and/or UHF television allocations. The second part dealt with the issues surrounding the alternative of accommodating ATV in the region of the spectrum above 1 GHz. The third and final part dealt with the possible impact of ATV on the spectrum utilization of various broadcast support and non-broadcast services.

With regard to the first part, the working party first developed and analyzed a series of spectrum scenarios reflecting various combinations of spectrum requirements. These early studies determined that existing allotments could be fully accommodated with additional ATV channels only if the minimum co-channel spacing was on the order of 160 kilometers (100 miles) and if there were no adjacent or taboo channel restrictions. The working party then developed (a) non-system-specific planning factors and (b) the methodology and computer model to permit the analyses of the service areas to be expected from each of the proposed ATV formats and the computation of further accommodation results.

Data specific to each of the proponent systems were then obtained from the testing laboratories, combined with the non-system-specific planning factors, and analyzed using the methodology/computer program noted above. These analyses produced the required accommodation and service area predictions which, in turn, provided elements necessary for the comparison of the five ATV simulcast systems.

With regard to the second part of its assigned responsibility, the working party largely suspended its investigation of the feasibility of accommodating ATV above 1 GHz when the Commission essentially ruled against such an alternative. With regard to the third part of its assigned responsibility, the working party carried out an extensive series of studies relating to the impact of ATV on spectrum requirements for the Broadcast Auxiliary Services (BAS). The working party concluded that it would be unlikely that compression techniques and fiber optic systems were feasible replacements for added BAS spectrum requirements for ATV transmission systems. It continued to urge the Commission to consider the allocation of additional spectrum for such purposes lest the advent of ATV systems be impeded.

The working party was Chaired by Dale Hatfield. The Vice Chairs were William Borman, Jules Cohen, and Donald Jansky.

4.4 PS/WP4 - WORKING PARTY ON ALTERNATIVE MEDIA TECHNOLOGY AND BROADCAST INTERFACE

The objective of PS/WP4 was to study and make recommendations regarding the relationship of terrestrial advanced television systems to alternative media, applications and standards. It was also the objective to investigate approaches for growth paths to the future while, at the same time, to support timely decisions on an ATV broadcast system with increased performance quality for the end user. PS/WP4 addressed issues related to interoperability, scalability, extensibility, and more generally, openness. Representatives of the broadcast television, cable television, program production, motion picture, computer, telecommunications, and imaging industries were active in this working party.

During 1991, PS/WP4 developed definitions of key terms such as interoperability, scalability and extensibility. Based upon a world becoming more complex and richer in alternatives (media, transmission/distribution, presentations), the working party developed the concept of image data, defined as the digital equivalent of the video information including image, sound and auxiliary data components.

Once SS/WP4 established the ten selection criteria, PS/WP4 adjusted its focus to concentrate on the three criteria that related to alternative media: Interoperability, Scope of Services and Features, and Extensibility.

An assessment of the five proponent systems in reference to the above three criteria was made by PS/WP4. The working party developed a layered architectural model[1] for ATV to aid in evaluating the proponent systems along with applications and performance questions on these criteria. Participants of PS/WP4 employed a technical consultant, StellaCom, Inc., to assist in this analysis. The assessments were based upon information supplied by each of the proponents in (1) published form, (2) response to specific PS/WP4 questions, and (3) a three-day Interoperability Review involving the proponents and a special Interoperability Review Board (convened specifically for evaluation of the proponent systems relative to the three criteria and conducted in September 1992). The Review Board consisted of experts across a broad array of relevant disciplines. The selected experts had no relationship to any of the system proponents. Results of the Review Board evaluation weighed heavily in the PS/WP4 conclusions and recommendations.

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;

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[1] Similar to the Open Systems Interconnect (OSI) model for data communications developed by the International Organization for Standardization (ISO).

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

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

Specific recommendations regarding these characteristics are included in the PS/WP4 final report.

The PS/WP4 Working Group on Satellite Testing was formed to study the compatibility of the terrestrial ATV systems with satellite transmission for broadcasting and direct-to-home applications.

The working group based its evaluation on paper studies using proponent information supplied in response to a questionnaire and “Reference Link Models” which the working group developed.

Conclusions were reached on the compatibility of ATV systems with Fixed Satellite Service (FSS) and Broadcasting Satellite Service (BSS) satellite delivery, and commercially available uplink and downlink earth station equipment.

Conclusions also were reached on delivery of ATV programming to small aperture home satellite antennas. Interference from adjacent satellites and from terrestrial Fixed Service microwave operations at C-band proved to be important issues.

The working group also concluded that some form of Automatic Transmitter Identification System (ATIS) is desirable.

The working party was Chaired by Edward D. Horowitz. The Vice Chairs were Virgil Conanan, Paul Heinerscheid, Paul Resch, and Robert L. Sanderson.

4.5 PS/WP5 - WORKING PARTY ON ECONOMIC FACTORS AND MARKET PENETRATION

The primary task of PS/WP5 was to develop a projection of the rate of growth of the market penetration of high definition equipment in television households.

Over the life of PS/WP5, four such projections were developed, each changing as new or refined assumptions were made, and as the supporting technology matured. As a starting point, the historic growth in market penetration achieved by other consumer electronic products was studied to determine whether it might be analogous to the growth of ATV.

Later work of PS/WP5 led to a refined projection of market penetration. It was based on an assessment of the perceived incremental value to the consumer of ATV compared with the present television service. High and low perceived values were projected since no comprehensive audience research program was possible for lack of funding.

Similarly, a high and low range of consumer equipment prices were developed, because no definitive prices had yet been established, pending the selection of a transmission standard.

The discretionary income of the consumer applied to the purchase of current video services was assumed to be the source of funding for HDTV purchases, becoming available over a period of years. This funding level corresponded to a high perceived value by the consumer. A lesser fund for the purchase of equipment was assumed in the event that the perceived value of HDTV was much lower.

With these projections in hand, the number of units of HDTV equipment which could be purchased was calculated for each of the ten years following the selection of a transmission standard by the FCC. In this way the growth in the number of HDTV households having one or more of the potential HDTV delivery services of broadcast, cable, home video, or DBS, could be plotted.

Year 0 is taken to be the year in which the FCC selects a transmission standard, issues a Report and Order, and publishes a table of spectrum allotments for which television stations may apply for specific channel assignment. A conservative estimate is that 5 percent market penetration will be reached by Year 5, and 37 percent by Year 10. The more optimistic projection is that 8 percent market penetration will be reached by Year 5, and 56 percent by Year 10.

The working party was initially Chaired by Michael Tyler and later by Rupert Stow. The Vice Chairs were Nancy Kowalski, Bruce Owen, and Charles Steinberg.

4.6 PS/WP6 - WORKING PARTY ON SYSTEMS SUBJECTIVE ASSESSMENT

PS/WP6 was established to conduct the planning for subjective evaluations of unimpaired video quality as well as the effect of impairments and interferences. PS/WP6 had among its members a number of experts in both psychophysics (experimental or sensory psychology and subjective testing) and social science (audience research and measurement). It became clear during the first interim period that the two disciplines had fundamentally different testing interests. Eventually, the Planning Subcommittee formed a new working party, PS/WP7, to handle separately planning for audience research. The first interim report of PS/WP6, however, was issued in June 1988 (before the establishment of PS/WP7) and contained the research proposals of both groups. After the formation of PS/WP7, PS/WP6 was free to focus on subjective assessments of basic quality, impairments and interferences.

During this first period of work general subjective test methods and procedures (pair comparisons) were agreed, along with viewing conditions (set-up of the viewing studio and displays). Four Drafting Parties were active: Test Material, Noise Weighting, Ghost Cancellation and Psychophysics.

By the end of the second period of work in February 1989, a great deal of detail had been added to the subjective test design for video, and a psychoacoustic test design had been added. A liaison with Canada had been established and an effort begun to consider running the non-expert subjective tests in Ottawa, based on an offer by the Communications Research Centre of the Canadian Department of Communications.

Going into the third interim period, the primary unresolved problem was how to produce the multiple-format test materials required. At issue was whether to transcode from the 1125-interlace format, for which production equipment was readily available, or to conduct a multi-standard shoot with a collection of one-of-a-kind cameras which scanned directly into the other formats. The test material selections were intended to provide identical picture content for each format in order that they themselves would not cause differences among system evaluations. The five formats required were:

1) 1125/60/2:1
2) 1050/59.94/2:1
3) 787.5/59.94/1:1
4) 525/59.94/1:1
5) 525/59.94/2:1 (NTSC)

While NHK and Sony had designed and constructed a “transconverter” to convert 1125/60 material to several other formats, translation to the 787.5-progressive format had not been provided. Planning of subjective test material image content, as well as characterization testing of production equipment, was the dominant area of work for the third interim period. Eventually, a multi-format production was selected.

During the third period of work, progress was made on production of still test material. Photographs were taken by the NASA Lewis Research Center, and the resulting images scanned to a computer-based format by the Eastman Kodak Corporation.

Two new test concepts were developed that proved to be of significance — Experts Observation and Commentary (EO&C) and Range Recording Only (RRO). EO&C allowed observations to be read into the test record by the expert viewer panels when unusual conditions were noted, or where full subjective measurements were not possible or needed. RRO signified a plan to make recordings of certain impairments over a specific range, with a decision to be made later regarding the need for a full subjective assessment of these tapes by panels of non-expert viewers.

A previous decision that a direct-view CRT should be used for testing was reversed, and ATTC was asked to identify a multi-scan projection display.

At the end of the third work period, PS/WP6 focused closely on the production of test materials. By the end of the fourth interim period, the test materials for still and motion segments had been completed. The still test material was delivered to the ATTC in September 1990. The motion test material was produced during early 1991. Additional material was produced for the use of the proponents in their development efforts. For a variety of reasons, the additional material was produced in 1125 interlace, 1050 interlace, and 525 progressive formats, but not in 787.5 progressive format. A number of film sequences were transferred to the various formats with equipment provided by Zenith Electronics Corporation. Eventually, a series of computer-rendered graphics still and motion sequences were also produced by AT&T Bell Labs and incorporated into the final series of test materials.

By the end of the fifth interim period, January 1992, the tests were underway and expert viewers were successfully being recruited from among those certified by a PS/WP6 sub-group.

At its July 1991 meeting, the working party agreed that an additional hour of Long-Form subjective test material would need to be produced for verification of the system selection after conclusion of the laboratory tests.

The working party was initially Chaired by Bronwen Jones, later by Craig Tanner, and finally by James Gaspar. The Vice Chairs were Jerrold Glasser and William Rubens. Craig Tanner and Bronwen Jones also served as Vice Chairs.

4.7 PS/WP7 - WORKING PARTY ON AUDIENCE RESEARCH

PS/WP7 was charged with defining, planning and executing research operations which would lead to an understanding of viewers' preferences in the field of advanced television programs viewed from the home. The scope of this work included: the type of programs most appreciated in ATV; the types of viewers who most appreciate ATV programs; the willingness of viewers who most appreciate ATV programs to pay a premium for ATV display equipment; the willingness of viewers to pay a premium for ATV services in the home; and the attributes of ATV most appreciated by viewers. PS/WP7 was essentially formed to provide a marketing input into the whole ATV standard setting process.

The plan of PS/WP7's work included but was not limited to: the types of programs to be used; sampling; the types of audience variables to be measured; the number and type of localities in which the tests would be conducted; the viewing conditions; and the types of displays to be used.

PS/WP7's main charge was to develop and then execute a research plan for investigating audience responses to ATV service. After a comprehensive process of defining research objectives, four studies were designed and Requests for Proposals (RFPs) issued to the research communities. More than twenty proposals were received. The four study designs were: Study I ("TV Store Study") — produce demand curves for HDTV, IDTV and NTSC; Study II ("Technical Study") — assess viewers' reactions to and valuation of various technical attributes of ATV; Study III ("In-Depth Study") — evaluate long-term exposure viewer evaluations of ATV programming; and Study IV ("Advanced TV Study") — investigate the contribution of other TV enhancements to ATV demand. Study III was not recommended for action by PS/WP7 due to lack of available funding. The remaining studies were estimated to cost between $725,000 and $875,000, based on the responses to the RFP.

PS/WP7 attempted to secure financial support for its research program, once it was found acceptable to the Advisory Committee. In addition, PS/WP7 was asked to seek synergies between its research program and that of SS/WP2, which was also involved in a testing program. PS/WP7 concluded that the goals, objectives and methodologies of SS/WP2 were sufficiently distinct from those of PS/WP7 that no synergies existed. Financial support was sought from government, industry, ATV proponents, and other private sources. No support was available. PS/WP7 was also asked to investigate a letter box study, possibly in association with the Advanced Television Test Center. When the ATTC decided to cancel its plans to conduct such a study, PS/WP7 concluded that such a study was not a productive use of resources.

While PS/WP7 was able to develop a comprehensive planned research program to investigate consumer reactions to advanced television systems, the research was not executed due to lack of funding. Without such support, PS/WP7's role in the standard setting process was constrained to service in an advisory capacity. PS/WP7 issued three reports, the second of which set forth a detailed research plan for investigating audience reactions to ATV.

The working party was Chaired by Richard V. Ducey. The Vice Chairs were Bruce Huber and Howard Miller.

4.8 PS/AG1 - ADVISORY GROUP ON CREATIVE ISSUES

PS/AG1 set out to assess and report on the views of the creative community in relationship to the development and implementation of a terrestrial ATV transmission system in the United States. The membership of the advisory group was drawn from the creative community and included producers, directors, writers, representatives of major studios, and industrial relations representatives.

The work of the advisory group was completed during the period covered by the first two interim reports of the Advisory Committee. Views expressed by the advisory group included the following points:

> The selected ATV transmission system should reproduce the highest quality television image and sound possible, while maintaining the artistic integrity of the creators' works.
>
> The ATV system should provide an image quality equal to that of 35 mm film.
>
> The ATV system should reproduce sound quality equal to that available on compact discs.
>
> The ATV system should enable creators to preserve the artistic integrity of works originated in other formats.

PS/AG1 also emphasized the importance of achieving a single world-wide standard for program production and program exchange. Some of the points were:

> To maintain its leadership the U.S. program producing community must continue to provide programs characterized by the highest possible image and sound quality, and advocate advanced technology that best serves program production and delivery to the public.
>
> It is essential that any program production standard adopted for use in the United States provide program producers with the highest possible picture and sound quality to offset the quality degradation inherent in post-production processing, and in down-conversion to television transmission formats.
>
> It is important that the program production standard used in the U.S. should lend itself easily to successful conversions to all existing formats including NTSC, PAL, SECAM, and 35 mm film.

The advisory group was Chaired by James Hindman. The Vice Chairs were Topper Carew, Glen Larson, and Leavitt Pope.

4.9 PS/AG2 - ADVISORY GROUP ON CONSUMER/TRADE ISSUES

In considering consumer issues, PS/AG2 devoted special attention to the importance of retaining the diversity of programming and local programming. The advisory group concluded that if ATV service were to degrade NTSC picture quality, the introduction of ATV terrestrial broadcasting would be difficult to justify. On the other hand, consumer interests might suffer if ATV terrestrial broadcasting were to lag substantially behind ATV service on VCRs or cable.

In its study of trade issues, the advisory group observed that TV set manufacturing for the U.S. consists of the output of a single major American-owned company and a number of foreign-owned companies.

While many TV receivers are assembled in the U.S., many of the components are imported from offshore sources. Nevertheless, the group believed that an opportunity may exist to establish domestic manufacturing of receivers for ATV service. If the development of ATV is successful, it could provide the stimulus for a revival of the U.S. consumer electronics industry which, unlike other U.S. electronics industries, has suffered lagging output and declining employment.

PS/AG2 completed its work at the time the Advisory Committee issued its second interim report. The last task of the advisory group was the drafting of the Advisory Committee's Report on ATV Service in response to a request for information on "the potential impact of alternative ATV policy strategies on the U.S. economy" by Representative Markey, Chairman of the House Subcommittee on Telecommunications and Finance.

The report drew upon studies conducted by the EIA, the AEA, and the NTIA. The current role of consumer electronics in the U.S. economy was presented, together with some conjectures of the potential impact of ATV service on the consumer electronics industry. Finally, policy options for the U.S. were discussed.

The advisory group was Chaired by Robert Crandall. The Vice Chairs were John Barry, Daniel L. Jaffe, and Henry Rivera.

5. CONTRIBUTIONS FROM THE SYSTEMS SUBCOMMITTEE

The Systems Subcommittee had the following Objective and Scope of Activity:

> *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).*

The Systems Subcommittee was Chaired by Irwin Dorros. The Vice Chairs were Tyrone Brown and John Abel.

The work of the Systems Subcommittee was divided among four working parties. The work of these groups is described in the following sections.

5.1 SS/WP1 - WORKING PARTY ON SYSTEMS ANALYSIS

SS/WP1 was assigned the task of analyzing proponent systems and further identifying and certifying those systems with sufficient technical merit to be recommended for test by the ATTC. The working party evaluated thirty-three proposals from twenty organizations and three consortia. Twenty-five submissions were system proposals of varying levels of completeness. Four proposals were limited to video compression techniques. Three proposals were audio only and one was a concept for a very high resolution video camera. In addition, several other organizations expressed interest in providing audio submissions. Four of the system proposals were for digital systems. A fifth digital proposal for a partially complete digital system was submitted. The remaining systems were largely analog. Many used digital processing techniques on otherwise analog systems.

Since SS/WP1's charter was to evaluate and recommend complete systems, the audio-only proponents were referred to the system proponents as possible customers. The submissions that involved video compression only were evaluated for unique ideas. Of the system proposals, six were certified for test by the ATTC. These were ACTV and AD-HDTV from the ATRC, Narrow-MUSE from NHK, DigiCipher and CCDC from the ATVA, and DSC-HDTV from Zenith/AT&T.

To provide a rigorous forum where the large number of proposed systems could be compared and evaluated on level ground, SS/WP1 initiated the concept of long meetings wherein each proponent had several hours for presentation and response to questions. This process proved effective in weeding out the proposals that were not workable and those that were not sufficiently developed to proceed. Almost all of the dropouts were ultimately voluntary after rigorous question and answer sessions shed light on the limitations or incompleteness of specific proposals.

Once the likely candidates were identified, a technical subgroup, known as the Analysis Task Force, was initiated. The task force included representatives for the systems being considered for final certification as well as experts with both signal processing and transmission backgrounds. The task force generated the final system analysis reports which, after approval by SS/WP1, were submitted to SS/WP2 and the ATTC to use as a guideline in system testing.

The working party was Chaired by Birney Dayton. The Vice Chairs were Carl Eilers, John Swanson, and David Kettler.

5.2 SS/WP2 - WORKING PARTY ON SYSTEM EVALUATION AND TESTING

SS/WP2 was established to conduct tests of proposed systems and provide information to help the Advisory Committee in its recommendations to the FCC. The working party's charter was as follows:

> *This group shall evaluate and test various ATV distribution systems based on guidelines developed by the Planning Subcommittee. Extensive subjective and objective testing shall be conducted.*

SS/WP2 developed extensive test procedures to be used to evaluate the performance of the ATV systems. These test procedures included the Test Management Plan, Objective and Transmission Tests, Cable Television Transmission Tests, Video Subjective Tests, Audio Subjective Tests, System-Specific Tests, Digital-Specific Tests, and Field Tests.

The Test Management Plan set forth the policies and procedures to conduct tests of ATV systems and to provide guidance for the laboratories, proponents, and the Advisory Committee. The Objective and Transmission Tests procedures included tests of image quality, audio performance, and terrestrial transmission. The Cable Television Transmission Tests were developed to test the performance of ATV systems in the cable television environment. The Video Subjective Tests were developed to evaluate basic quality and to establish the threshold of visibility of impairments, the point where the impairments render the signal unusable, and some steps in between. The Audio Subjective Tests were developed to evaluate basic quality and the effects of transmission impairments. The System-Specific Tests and Digital-Specific Tests were developed to test specific areas of interest not addressed by the general test plans. The Field Tests were developed to verify the performance and operability of the selected system(s) under real world conditions, and to point out flaws not uncovered through laboratory testing.

Laboratory tests of ATV transmission systems began on July 12, 1991 and were completed on November 12, 1992. Testing was planned under the aegis of the Advisory Committee, and conducted in cooperation with three laboratories (Advanced Television Test Center, Cable Television Laboratories, and the Advanced Television Evaluation Laboratory).[1] Systems were tested in the following order:[2] ACTV, Narrow-MUSE, DigiCipher, DSC-HDTV, AD-HDTV and CCDC.

A system/digital-specific testing group was established by SS/WP2 to carry out system-specific and digital-specific tests on each ATV system during the proponent's test slot at ATTC. The group produced a report of test results for each ATV system which, after review and comment by the proponent, was included in the published Record of Test Results.

The working party was initially Chaired by Benjamin Crutchfield and later by Mark Richer. The Vice Chairs were Walt Ciciora, Joel Engel, and George Hanover.

5.2.1 Advanced Television Test Center (ATTC)

The Advanced Television Test Center (also see Glossary) is a private, non-profit organization established in 1988 and developed by the television broadcasting and other industry organizations to test advanced television (ATV) transmission systems seeking to become the new North American broadcast standard.

In 1987, with the creation by the FCC of its all-industry Advisory Committee, the television broadcast industry offered to provide the means to test the various ATV proposals. Agreements were concluded between ATTC and CableLabs in 1990, and between ATTC and ATEL in 1991, which led to a cooperative testing program using test plans and test materials developed and approved by the Advisory Committee.

Working with the ATV system developers as these test plans evolved, a special-purpose laboratory was designed by ATTC to address the combination of requirements foreseen from some eight different ATV systems, all then involving analog transmission schemes (save one hybrid analog-digital submission). By the fall of 1990, laboratory construction was completed, most special-built equipment was delivered, proof-of-performance testing was started, and the test plans were largely completed. In November 1990, the newly invented ATTC/Tektronix Format Convertor successfully passed its proof-of-performance and prototype acceptance tests. The number of ATV systems reserving slots for testing had become six; testing was scheduled to begin April 12, 1991.

While one proponent had proposed an all-digital system in June 1990, by February 1991, four out of the five HDTV systems had been resubmitted as all-digital schemes. After review of these changes in March and April by the Advisory Committee, the start date for testing was moved to July 12, 1991, in order to permit modifications in ATTC systems and procedures to accommodate the amended test

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[1] The direct costs of testing at all three laboratories totaled some $26.5 million. Of this amount, $2.2 million came from test fees paid by the proponents (including both regular fees and additional amounts for certain retests); the remaining $24.3 million was funded by the sponsors of the respective laboratories.

[2] These test dates include testing of the ACTV system; those test results are not included in this report.

plans, and to conduct a partial “dry run” of the final test procedures. While testing did begin as scheduled, further test plan changes were approved in January 1992 — based on more detailed information about the digital systems — and these changes were implemented by ATTC in February 1992, just in time for use at the end of the test slot of the first of the four digital systems. Testing was completed on the final system on October 21, 1992.

The testing conducted at ATTC spanned some eight weeks per system (approximately seven weeks on broadcast-related and system-specific tests, and one week on cable-specific tests). During this period, video and audio tapes were made, as specified in the approved test plans. These tapes were used by ATEL (for video subjective tests) and, under contract to ATTC, by the Westinghouse Science and Technology Center (for audio subjective tests). In addition, before each system’s testing began, about one week was devoted to ATV system-laboratory “interface” checks and “dry-runs” of some tests.

The testing at ATTC involved nearly 200 expert viewers. It also involved — in set-up, testing, and reviews — some 75 representatives from the ATV system proponents, as well as the 21 regular staff and consultants to ATTC. The comprehensive report on each system is some 700-850 pages, compiling the results from the three laboratories, as well as comments from the proponents. There are also some 700 reels and cassettes of digital HDTV and NTSC video tape, plus more cassettes of digital audio tape, which captured the performance of the systems under test.

5.2.2 Cable Television Laboratories Inc. (CableLabs)

Cable Television Laboratories, Inc. (also see Glossary) is a research and development consortium of cable television system operators representing more than 85% of the cable subscribers in the United States and 60% of Canadian cable subscribers. CableLabs was founded in May 1988 to ensure the proper development and creation of technological initiatives for the cable television industry.

CableLabs responded to a call from the Advisory Committee for a qualified laboratory to carry out the cable portion of the Advisory Committee’s tests. The offer, in part, was to obtain necessary equipment to undertake the cable portion of the tests and, with industry input, to assist the Advisory Committee in developing test procedures, analyzing test results, and providing input to the Advisory Committee to assist in the selection of the best possible advanced television standard. CableLabs subsequently offered to undertake the cable portion of the field tests, including development of test procedures and analysis of the test results.

Over a period of a year and a half, CableLabs produced the cable portion of the test plans, designed and installed the cable television test bed and associated computer operating system and reviewed the test procedures. CableLabs commenced its tests on the first system on August 19, 1991 and completed tests of the final system on September 25, 1992. At the completion of the tests, reports were prepared, reviewed and commented on by the proponents, and submitted to the Advisory Committee for analysis.

5.2.3 Advanced Television Evaluation Laboratory (ATEL)

The Advanced Television Evaluation Laboratory (also see Glossary) is a facility of the Department of Communications, Government of Canada. Managed by the Communications Research Centre, ATEL was established to provide the special facilities needed to display pre-recorded video test materials under the rigorously controlled viewing conditions needed for sensitive and reproducible tests of advanced and conventional television systems.

In 1989, in response to a call from the Advisory Committee for qualified laboratories to carry out its advanced television test program, ATEL offered to undertake the video subjective test program. The substance of the offer was to conduct, according to the methods approved by the Advisory Committee, video subjective tests of ATV systems using pre-recorded digital videotapes prepared by ATTC and CableLabs to evaluate video quality and the performances of systems in simulated terrestrial and cable broadcast environments. This offer was accepted by the Advisory Committee in 1990.

After its offer was accepted, ATEL engaged in a 17-month period of preparation. This involved the preparation of facilities, the development of technical, operating, and scientific procedures, and a full dry run of the Advisory Committee's video subjective test procedures. The latter involved the production of test materials, examination of a satellite-based ATV system in a simulated satellite link, and conduct of formal subjective tests. The dry-run exercise was completed successfully, verifying ATEL's technical, operating, and scientific procedures as well as the methods adopted by the Advisory Committee. At the same time, ATEL was active in the Advisory Committee, contributing to the development and production of video test materials and to the development and refinement of test methods.

ATEL was ready to begin testing in August 1991. Following a short delay experienced by its partner laboratories, ATEL began its tests of the first system on September 4, 1991. ATEL completed tests of the final system on November 12, 1992. In the period from November 1992 to January 1993, ATEL completed its analyses of the data collected and finalized its reports to the Advisory Committee.

At the request of PS/WP-3, ATEL (in collaboration with ATTC) also carried out tests of Co-Channel Interference from NTSC to NTSC. These tests, which provided baseline data for PS/WP-3's analyses of ATV Service Area and Accommodation Percentage, were completed in July 1992.

Preparatory exercises, tests, and analyses and reports of the data involved about 36 months of continuous effort. More than 2,000 non-expert observers were used and more than 125,000 measurements were made.

5.3 SS/WP3 - WORKING PARTY ON ECONOMIC ASSESSMENT

SS/WP3 was assigned responsibility to make a comparative economic assessment between all contending ATV proponents and to establish technical viability of their systems.

The first phase of the work attempted a broad look at how the ATV systems would impact the terrestrial broadcasting system (at the local station level and, at the other extreme, the network); cable systems; satellite and fiber delivery systems; and the consumer's home receiver. Separate specialist groups were set up to examine all of these alternative media. Models were developed for both the terrestrial broadcast plant and a typical cable system. Spreadsheets were structured to allow total plant costs to be computed once all ATV equipments were identified and priced. During this phase, considerable preparatory work was accomplished in terms of refined, detailed, system block diagrams and flexible spreadsheets.

The second phase of the work was initiated by the presentations of CBS and PBS to SS/WP3 on the sequential phasing scenario of broadcasters conversion to ATV. This input spurred attention to developing a system block diagram that would speak to the first phase of conversion of the local station — namely, network pass through and local commercial insertion. SS/WP3 began a working liaison with IS/WP2 on ATV Transition Scenarios. SS/WP3 was already collaborating with PS/WP5 on Economic Factors and Market Penetration to seek suitable growth models — both for the broadcaster and for the home receiver. It was agreed that an early “transitional” phase local broadcast station would suffice to expose comparative cost analysis of the various ATV proposals.

The third phase began in early 1992 when the five ATV proponents began regular attendance at SS/WP3 meetings, and, more important, they began to submit substantive technical information on their systems. The primary focus was on cost to consumers and cost to broadcasters. A specialist group mobilized multinational television receiver manufacturers to assign manufacturing costing experts to the effort on cost to consumers. A highly detailed block diagram of an ATV receiver was developed by this group and an accompanying matrix was structured showing details of each ATV proponent’s version of the receiver. The ATV proponents actively participated in a procedure which assigned costs to every element of these receivers. From this, total manufacturing costs were calculated using a computer model.

On the transmission side a different approach to the cost analysis was taken. Two specialist groups, one on ATV antennas and transmitters, and a second on ATV encoders and modulators were formed. The first worked directly with all of the ATV proponents and with manufacturers of antennas and transmitters. The second specialist group was made up of seven professional broadcast equipment manufacturers who independently cost analyzed each of the ATV modulators and encoders (based upon an agreed-to “information package” provided by each ATV proponent).

The working party was Chaired by Larry Thorpe. The Vice Chairs were the late William B. Loveless, Talmadge Ball, Shellie Rosser, and Richard Grefe.

5.4 SS/WP4 - WORKING PARTY ON SYSTEM STANDARDS

In its charter, SS/WP4 was charged with recommending standards for the transmission of ATV. It was agreed that documentation of the standard would not be the responsibility of the working party or the Advisory Committee. Furthermore, the working party anticipated its recommendations would be based on information supplied by other working parties in the Advisory Committee.

The primary agenda item at the first several meetings of SS/WP4 was discussion of the process that the working party would use to recommend a standard. Voting methods were considered but abandoned because of the difficulty in determining which persons or organizations would participate in a vote. The working party consistently concluded that consensus was the best method to select a recommended standard. The working party agreed on a process which could be used to lead to consensus. The first step in that process was the determination of the "selection criteria." SS/WP4 originated that list which was subsequently approved by the Advisory Committee.

As the time for testing proponent systems approached, the emphasis turned toward analysis of the test data. A task force of SS/WP4 worked with the test laboratories to determine the format for reporting test results. The test data were divided into two categories, spectrum data and all other data. The working party asked PS/WP3 to perform the analysis on the spectrum data for SS/WP4. SS/WP4 retained responsibility for the analysis of the balance of the data.

SS/WP4 was given responsibility for organizing and drafting the final report of the Advisory Committee. The working party agreed to an outline for the report and drafted the portion defining the "selection criteria" before the first test data were available.

Once test data became available, the primary emphasis of SS/WP4 was to review and summarize the test data for each system. This work was performed by a task force in SS/WP4 and by PS/WP3. The results were integrated into the final report by another task force in SS/WP4 and approved by the full working party.

Other information for the final report was supplied by other working parties of the Advisory Committee. This information was edited and integrated into the final report and approved by the full working party.

At the time of its fifth interim report, the Advisory Committee agreed to appoint a "Special Panel" which would take the results of the analyses of the individual proponent systems in the final report and formulate recommendations for the Advisory Committee's consideration. Concerns had been expressed that the widely varying attendance witnessed in SS/WP4, along with the possibility that many of the experts may have a conflict of interest, would make it difficult to arrive at a consensus on recommendations in the working party. The Special Panel membership included "Advisory Committee staff leaders and other knowledgeable Advisory Committee members who were not affiliated with any system proponent."[3]

The responsibility of drafting the final report chapter titled "Comparisons and Recommendations" was assigned to the Special Panel. The balance of this report remained the responsibility of SS/WP4.

The working party was Chaired by Robert Hopkins. The Vice Chairs were Hugo Gaggioni, Bruce Sidran, and Louis Williamson.

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3 Fifth Interim Report of the Advisory Committee on Advanced Television Service, March 24, 1992, page 17.

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6. CONTRIBUTIONS FROM THE IMPLEMENTATION SUBCOMMITTEE

The Implementation Subcommittee had the following Objective and Scope of Activity:

> *Objective: To establish a scheme for implementation of advanced television service 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.*

The Co-Chairs of the Implementation Subcommittee were James J. Tietjen and George Vradenburg III. The Vice Chairs were Brenda Fox and Henry L. Baumann.

The work of the Implementation Subcommittee was divided between two working parties. The work of these groups is described in the following sections.

6.1 IS/WP1 - WORKING PARTY ON POLICY AND REGULATION

IS/WP1 attracted a diverse group of participants, including representatives of broadcast, cable, manufacturing, legal, policy, and regulatory interests. Although an obvious benefit to the discussion of policy issues, this diversity of interests at times made achieving consensus on particular issues difficult. IS/WP1 served as a useful forum for outlining the particular issues to be debated so that those issues could be more clearly presented to the Advisory Committee and to the Commission by the participating organizations. FCC staff also regularly and actively participated in the group's meetings. IS/WP1 adopted and submitted several policy recommendations to the Implementation Subcommittee.

Early discussions centered around defining the best role for this particular working party. The myriad of issues relevant to this subject area (policy and regulation) often indicated the need to establish separate "subgroups" to examine particular issues in depth. For example, subgroups were established to examine the FCC's role in setting standards and the importance of the <u>Ashbacker</u>[1] doctrine to HDTV allotment/assignment methodology.

IS/WP1 adopted and submitted recommendations to the Implementation Subcommittee including that: (1) the FCC has legal authority to pick a single ATV standard for terrestrial broadcasting, (2) given

[1] Ashbacker Radio Corp. v. FCC, 326 U.S. 327 (1945).

current knowledge, the choice of a single terrestrial broadcasting ATV standard would benefit the public, and (3) the FCC should announce its willingness to adopt a single broadcast standard. IS/WP1 drafted the IS/WP1 Report on Transmission Standards for ATV investigating these issues in some depth. IS/WP1 adopted two papers on the standards issue — one on standards choice by the FCC, and the other on incorporation of proprietary technology into ATV standards.

A special subgroup was established to examine the issue of assignment of spectrum. IS/WP1 generated a draft report on spectrum assignment options that discussed arguments relating to auctions, the comparative process, lotteries, and "flexible assignment" approaches. The report, IS/WP1 Report on Spectrum Assignment Options, also included a section on non-commercial reservations and assignments.

As the importance of simulcasting became apparent, it was decided to draft a paper on the definition of and options for "simulcasting" policies. The group preliminarily concluded that a flexible definition of "simulcast" would probably best serve the public interest. Later in the process, as the issue garnered increasing attention, IS/WP1 attempted to develop a paper presenting the practical policy and legal implications of different simulcasting policy options, but consensus could not be reached. The group also discussed options for a simulcasting timetable, ancillary uses of ATV spectrum, and broadcaster flexibility.

A subgroup, established to explore a comparative piece on standards and intellectual property, generated a report on Proprietary Standards in Advanced Television.

IS/WP1 also spent a significant amount of time discussing approaches to reducing the cost and delay of ATV implementation. A draft paper on reducing cost and delay of ATV implementation was prepared and circulated to the group.

The working party contributed significantly to the policy development process, especially as a forum for discussion among representatives of organizations participating in the Advisory Committee and FCC staff on important and complex issues.

The working party was Chaired by Charles Jackson. The Vice Chairs were Baryn S. Futa, Henry Geller, and Gregory M. Schmidt.

6.2 IS/WP2 - WORKING PARTY ON TRANSITION SCENARIOS

IS/WP2 was constituted to develop transition scenarios for the conversion to Advanced Television. In doing so, it sought to develop scenarios for each of the industry segments involved in the transition, to identify any potential differences in the implementations of the proposed systems, to identify potential problems in the implementation of ATV, and to respond to specific inquiries made by its parent Implementation Subcommittee.

The transition scenarios are presented as PERT and Gantt charts (together with underlying assumptions) developed by industry segment experts serving on the working party or enlisted for the task. Supporting information and answers to other implementation questions were sought by direct communications and by surveys from proponents and affected industry segments.

The scenarios identify the major work steps involved in ATV implementation and represent the shortest times in which motivated participants can be expected to implement ATV. They do not purport to show what participants will actually do in practice because, for example, IS/WP2 did not impose or account for financial or resource limitations or attempt to judge motivation.

The working party found that, in general, the time required to implement ATV is approximately the same for all industry sectors and for all proposed systems. IS/WP2 found that, in principle and subject to the limitations outlined below, stations can implement ATV within the FCC's six-year window.

The working party examined the critical path to implementation and identified key, potentially limiting tasks. First and foremost among these is the disclosure of, and agreement on full technical details of the selected system, which will underlie design and manufacture of integrated circuits and equipment for encoding, transmitting, receiving, and decoding ATV signals by parties other than the proponent. A second key item is development time for professional broadcast equipment to support several of the scenarios. IS/WP2 assumed availability within one year following the Commission's adoption of an ATV standard. Third, consumer product manufacturers pointed out that agreement on a standard consumer VCR format is an additional initiating event for that product and needs to be expedited.

A distribution standard is needed for effective interoperability among the diverse organizations within the affected industries. In addition, confirmation of the operational assumptions and techniques is required prior to a large-scale industry commitment.

IS/WP2 found and reported a potentially serious shortage in industry capacity to erect and reinforce towers and install antennas. IS/WP2 surveys indicate that, depending on the exact power requirements of systems, between one-third and one-half of television stations will require new towers. All will need new antennas.

IS/WP2 identified the need for new towers in high population centers as critical to the delivery of ATV to the largest proportion of the U.S. population. The working party established study groups in major metropolitan areas.

Expert input and a survey of all consumer manufacturers indicate that ATV receivers can be generally available in the marketplace 2-3 years following the Commission's adoption of an ATV standard. Transmitters and antennas will be available within the necessary time frame.

The working party conducted a survey that indicates software producers and users are generally in agreement that sufficient ATV software will be available by the time it is needed.

A distributed approach to transmission (multiple sites sharing the same frequency) has been suggested. Such an approach may alleviate the physical limitations encountered by some stations in achieving a single, full power, full coverage installation. IS/WP2 identified key issues that must be investigated before the implications of distributed transmission can be understood.

Specific recommendations are included in the IS/WP2 final report.

The Co-Chairs of the working party were J. Peter Bingham and Craig Tanner. The Vice Chairs were Edward J. Callahan, S. Merrill Weiss, and Daniel R. Wells.

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7. SELECTION CRITERIA

7.1 INTRODUCTION

The Selection Criteria constitute the key issues that must be examined in order to recommend an ATV system. Each of the proposed systems was measured against the Selection Criteria and compared with one another in these key areas to determine the best system. The ten selection criteria fall into three categories: Spectrum Utilization (Service Area and Accommodation Percentage), Economics (Cost to Broadcasters, Alternative Media, and Consumers), and Technology (Audio/Video Quality, Transmission Robustness, Scope of Services and Features, Extensibility, and Interoperability Considerations). Where applicable, target values of the Selection Criteria have been developed to represent the level of performance aspired to in an advanced television system.

7.2 SPECTRUM UTILIZATION CRITERIA

7.2.1 Background

In September 1988, the FCC concluded that the public interest would be served best by the introduction of ATV in a "simulcast" mode.[1] That is, each broadcaster would be assigned a second channel for the exclusive purpose of broadcasting an ATV signal, while continuing to broadcast NTSC on the previously assigned channel. The Commission concluded further that ATV would have to be accommodated in the spectrum currently allocated to the VHF and UHF broadcast service.[2]

7.2.1.1 Station Spacing

For NTSC allotment purposes, the United States is divided into three zones. Zone I is the relatively high population density northeastern part of the country. Zone III, an area with unusual propagation conditions, includes all of Florida, southern Georgia, and a band skirting the Gulf of Mexico. Zone II is the balance of the country.

In any spectrum allotment plan, co-channel spacing is by far the principal determinant of the number of allotments that can be accommodated in any area. The FCC Rules specify the minimum co-channel spacing for the NTSC service as shown in Figure 7-1.

Minimum first adjacent-channel spacings for all zones are 95.7 kilometers (59.5 miles) for VHF stations and 87.7 kilometers (54.5 miles) for UHF stations.

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[1] Tentative Decision and Further Notice of Inquiry, MM Docket No. 87-268, adopted and released September 1, 1988, FCC 88-288, 3 FCC Rcd 6520 (1988).

[2] *Ibid.*

Zone	Channels 2 - 13 (km / miles)	Channels 14 - 69 (km / miles)
I	272.7 / 169.5	248.6 / 154.5
II	304.9 / 189.5	280.8 / 174.5
III	353.2 / 219.5	329.0 / 204.5

Figure 7-1. Minimum co-channel separation distance for the NTSC service.

Published ATV allotment studies by the FCC and others have assumed uniform spacing requirements throughout the United States without regard to zones. The expectation is that no separation differentiation is likely to be made on the basis of population density, but some allowance may be appropriate for the Gulf of Mexico and Southern California Coastal regions where propagation phenomena suggest different treatment than for the balance of the country.

7.2.1.2 Taboos

In addition to the foregoing restrictions on NTSC allotment spacings, so-called "taboo" restrictions are placed on allotments in the UHF portion of the television broadcast spectrum. The taboo restrictions are designed, principally, to avoid interference to UHF television reception that might occur due to receiver tuner characteristics.

To permit ATV broadcasting by every authorized television broadcaster, a second channel must be provided to each broadcaster from within the presently allocated broadcast spectrum. This requires that the ATV system adopted be able to operate at closer co-channel spacings than its NTSC counterpart. Such closer spacings apply to both the ATV/NTSC and ATV/ATV combinations. Since the greatest portion, if not all, of the ATV accommodation must come from the UHF band, the system must be relatively immune to taboo restrictions and able to operate in an adjacent-channel situation where stations are closely spaced.

7.2.1.3 Spectrum Allotment/Assignment

Studies made by the Commission staff and others have shown that minimum co-channel spacing on the order of 160 kilometers (100 miles) between ATV and NTSC stations is required if full, or nearly full, accommodation of authorized broadcasters is to be achieved. Furthermore, ATV stations should be capable of being operated at or near the sites of adjacent-channel NTSC or ATV stations without taboo restrictions and without unacceptable interference being caused or received. Allotment studies indicate that minimum ATV-to-ATV separation need not be as restrictive as ATV-to-NTSC separation. In any plan, whether NTSC or ATV, very few allotments are required to be at the minimum spacing. Therefore, the degree of interference experienced with stations spaced at minimum distance is rare. Nevertheless, the ATV service must be regarded as interference-limited rather than noise-limited. Contrary to the often held belief that the NTSC service area is defined by the Grade B contour, substantial interference from co-channel and adjacent-channel stations is encountered within the Grade B contour of most NTSC stations. That interference is found particularly in the case of VHF stations in Zone I.

The principal allotment/assignment criteria applied herein are: the achievement of full accommodation of all NTSC authorized facilities with a companion ATV assignment, and the provision of ATV service in all areas currently receiving NTSC service. The application of these twin criteria is believed to provide the best basis for comparison of the systems offered by proponents. The procedure is intended to be used for system comparison; it is not intended to yield the best allotment/assignment plan for the United States. After an ATV system is selected, the planning factors specific to that system, and the full capability of the computer program, should be used to produce an allotment/assignment table aimed at achieving the two criteria specified above, but tempered by optimization of ATV service and holding interference to NTSC service to the minimum achievable. At the start of the “transition period” (defined as that period during which both ATV and NTSC will be broadcast), and to a lesser degree as years pass, NTSC will be the primary service for television viewers.

A further consideration dictating the need for an ultimate allotment/assignment table different from that used herein for system comparisons, relates to the effective radiated power assumed for some ATV stations. For the system comparison objective herein, the effective radiated power for each ATV facility was set to produce the same distance to the noise-limited ATV coverage contour as the distance to the companion NTSC station’s Grade B contour. Since the antenna height of the ATV stations was assumed to be the same as that of the companion NTSC station, the resulting effective radiated power assumed in instances where VHF stations are operating with relatively low antennas, can be too great from the standpoint of available equipment. Particularly in the case of digital systems, the need to maintain linearity during transient peaks places a requirement on the ATV operator to employ a transmitter capable of achieving peak power levels substantially in excess of the average power used in service and interference studies. Consequently, the implementation of some ATV stations may include lower power levels or greater antenna heights than used in the spectrum studies.

Equating NTSC-into-NTSC interference and ATV-into-NTSC interference presents a somewhat difficult, but not impossible, task. The difficulty arises from the difference in appearance of the two types of interference. In the case of NTSC-into-NTSC interference, the presence of the strong carrier in the undesired signal produces “beats” with the carrier of the desired signal. Those beats are manifested by unwanted lines in the desired image. The lines are likely to drift through the picture at a rate dependent on the frequency difference between the desired and undesired visual carriers. In the ATV-into-NTSC case, beat patterns are not likely to be present but, particularly for digital systems, interference is more likely to be manifested by an increase of noise (“snow”) in the picture.

Despite the disparity in appearance of the two types of interference, they can be compared subjectively. Degrees of objectionability can be assigned by viewers to interference phenomena. By employing a numerical grading system, or even a descriptive grading system, the degree of ATV-into-NTSC interference can be equated to the same degree of NTSC-into-NTSC interference for a fixed NTSC desired-to-undesired ratio.

Allotment/assignment plans were first developed to compare the spectrum performance among the various systems. Plans included use of the entire VHF/UHF TV broadcast spectrum and for only the UHF portion of that spectrum. To achieve full accommodation for all 1,657 stations in the data base, a minimum co-channel spacing of 155 kilometers was used. The allotment plan was then adjusted for optimum assignments using co-channel and adjacent-channel laboratory results for each of the systems. The optimization consisted of attempting to provide ATV service in at least all locations where the companion NTSC station provided service, without violating an assumed ATV/NTSC adjacent-channel separation restriction of 10-80 kilometers. No further consideration of interference was given in the assignment of an ATV station from available allotments. Power levels for the ATV stations were selected to provide noise-limited coverage equal to the Grade B coverage of the companion NTSC stations. Transmitting locations and antenna heights were assumed to be identical to the companion NTSC stations.

7.2.1.4 Interference and Picture Quality

Being interference-limited, special consideration must be given to ATV system design to produce a system that minimizes interference to the NTSC service and, in turn, is relatively immune to interference from that service. In particular, this minimization of interference is effected by limiting the energy transmitted in those portions of the 6 MHz television channel wherein the NTSC signal is most sensitive to interference. In the case of interference received by the ATV system, a trade-off exists between image (and sound) quality and interference potential. Digital systems reserve some portion of transmission capacity for error correction and concealment. As more channel capacity is reserved for error correction and concealment, the less channel capacity will be available for improved image and sound quality.

7.2.2 Service Area

7.2.2.1 Definition

The service area of a NTSC television station is defined as the area within the station's Grade B contour reduced by the interference within that contour. For an ATV station, service area is defined as that area contained within the station's noise-limited contour reduced by the interference within that contour.

The service area of the new ATV signal expressed as a percentage of the existing NTSC service area, is as follows:

$$\frac{\text{ATV service area}}{\text{NTSC service area}} \text{ X } 100\%$$

Coverage area is not the same as service area. The coverage area of a NTSC television station is defined as the area within the station's Grade B contour without regard to interference from other television stations which may be present. For an ATV station, coverage area is defined as the area contained within the station's noise-limited contour without regard to interference which may be present.

7.2.2.2 Method of Determination

A model developed by PS/WP3, and implemented by a computer program funded by broadcasters, permits the rapid analysis of coverage and service provided by NTSC and ATV systems for individual stations and, globally, for the entire United States. The planning factor values used in the model are based on PS/WP3 analyses, including those of laboratory data from ATTC and ATEL. NTSC coverage and service area determinations consider the actual locations, power and height data for the existing inventory of authorized NTSC television facilities. ATV coverage and service area calculations assume locations and heights identical to those of the companion NTSC stations, and power sufficient to achieve distances to the noise-limited coverage contours equal to the distances to the NTSC companion stations' Grade B contours.

7.2.2.3 Target Value

Comparable to NTSC.

7.2.3 Accommodation Percentage

7.2.3.1 Definition

The percentage of existing NTSC stations that can be accommodated with an additional simulcast ATV channel (independent of the resulting service area).

7.2.3.2 Method of Determination

The number of existing NTSC stations that can be accommodated with an additional simulcast ATV channel is determined by a computer program. The result is dependent, particularly, on the minimum permissible co-channel spacing, but possibly affected also by other restrictions, such as required adjacent-channel spacing. System characteristics measured in the laboratory were employed as the determinant. Using the method of Section 7.2.2.2, the power/height limitation for the ATV station is determined. The allotment/assignment plan is developed for 100% accommodation with the goal of providing ATV service comparable to current NTSC service. The power/height data permit the calculation of coverage and service provided by the ATV facilities. This information, and the allotments derived from the computer program, permit relating either single station or global service to accommodation percentage.

7.2.3.3 Target Value

100% of currently authorized full service stations and pending applications for full service stations. It is desirable to accommodate all noncommercial vacant allotments.

7.3 ECONOMICS CRITERIA

7.3.1 Background

Initially, a key issue for broadcasters and cable operators would be the cost to "pass" programming. A key issue for consumers would be the cost of a receiver and a VCR after five years of production.

It is difficult to establish target values for cost issues. Furthermore, cost is a function of market conditions and production volume. In the case of consumer equipment, the cost of current top-of-the-line NTSC projection receivers and top-of-the-line VCRs may be noted for reference only, but not as target values.

7.3.2 Cost to Broadcasters

In implementing ATV, broadcasters will incur costs of new studio equipment such as ATV encoders and monitors, router/switchers and video recorders; new transmission equipment such as ATV broadcast transmitters, ATV antennas, transmission lines and studio-to-transmitter links; and possibly other new equipment.

Differences in the proponent ATV systems may result in cost differences in professional broadcast equipment and/or studio/station equipment configurations. These variations are analyzed and identified, as an element in the ATV selection process.

7.3.2.1 Definition

The equipment cost for a broadcast station to deliver a simulcast terrestrial ATV signal.

A “transitional” station was defined as one that provided the ability to “pass through” the signals of a network or syndicated program source with essentially the same production values in the program integration as today. The transitional station also was to have the ability to upgrade easily to more extensive ATV operations and to higher levels of performance as dictated by audience growth and station finances.

A “minimal” station was defined as one that provided the ability to “pass through” the signals of a network or syndicated program source with compromises made in its capabilities in order to reduce costs to a minimum. The minimal station would not bear the costs associated with providing for future upgrades and might require replacement if an upgrade were needed.

7.3.2.2 Method of Determination

Broadcast station equipment configurations are analyzed to determine cost variations due to differences in ATV proponent systems. Costs to broadcasters are based on a transitional television station — this being a generic station representative of one offering an early ATV service. A minimal ATV model was developed also to allow an estimate of what would constitute a “bare minimum” investment by a local broadcaster.

Broadcasters are expected to convert to ATV in phases, as follows:

Network pass-through
Local commercial insertion
Local program origination
Local program playback
Full ATV operation

The investment required to implement the first two phases above is taken to be an estimate of the cost to broadcasters for implementing ATV. Based on block diagrams of typical broadcast station configurations, the equipment needed to implement these two phases may include:

Satellite receiver
ATV routing and switching equipment
ATV videotape recorder
NTSC upconverter
ATV encoder
ATV receiver for off-air monitor
Studio-to-transmitter link (STL)
ATV transmitter and antenna

ATV encoder costs are estimated for an initial production run during the 1994-95 time frame. Encoder cost estimates are developed from the amount and speed of memory, count of gates, and other elements of electronic design, based on information supplied by each proponent.

Other equipment costs depend on the signal format and data rate (i.e., whether the signal is compressed or not) at various points in the broadcast plant. Block diagrams of the broadcast station plant are used in this analysis to estimate total station costs.

7.3.3 Cost to Alternative Media

7.3.3.1 Definition

The equipment cost for a cable system operator, or other alternative service provider, to deliver an ATV signal.

7.3.3.2 Method of Determination

Cable system equipment configurations are analyzed to determine cost variations due to differences in ATV proponent systems.

7.3.4 Cost to Consumers

7.3.4.1 Definition

The cost of manufacturing consumer ATV receivers.

7.3.4.2 Method of Determination

Based on analysis by SS/WP3. Develop assumptions for year and volume of production; type, size and resolution of baseline receivers (CRT and projection); and projections of IC capabilities and costs. System-specific receiver costs will be generated based on information provided by each proponent.

7.4 TECHNOLOGY CRITERIA

7.4.1 Background

The five selection criteria in this technology section relate to aspects other than spectrum utilization and economic considerations. Recognizing that the selection criteria are in general inter-related, the purpose in this section is to consider the aspects of these criteria that can be separated from the economic aspects and spectrum utilization aspects.

These technology criteria represent the measures of improved performance and additional capabilities that comprise much of the motivation for adopting a new television standard for the U.S. The audio/video quality criterion directly relates to consumer perceived quality of sound and images. The transmission robustness criterion measures the degree to which the system can continue to operate with anticipated impairments, while retaining acceptable sound and picture quality for the consumer. The scope of features and services criterion examines the capability of a system to support ancillary services and features that are currently available for NTSC transmissions, as well as anticipated improvements and new services. The extensibility criterion addresses the capability for a system to support future improvements such as increased picture quality, resolution or additional services, without requiring a complete revision of the underlying television standard. The interoperability criterion considers the degree to which an ATV system can be carried on a variety of transmission media, stored in and displayed on a variety of terminals and meets the needs of non-broadcast industries. These particular attributes also relate to present and future possibilities for applications that share technologies in the television, computer and communications industries.

The five technology criteria thus focus directly on the benefits to the consumer that will accrue from adopting an advanced television system. Some criteria may yield straightforward numerical results and comparisons, while others will lead to qualitative observations, and tradeoffs may need to be considered among all the criteria.

7.4.2 Audio/Video Quality

7.4.2.1 Definition

Inherent and received quality of the picture, as subjectively perceived by non-expert viewers, supplemented by objective characterization and performance data, including expert viewer results.

Inherent sound quality as subjectively perceived by expert listeners, and supplemented as necessary by objective characterization and performance data.

7.4.2.2 Method of Determination

The audio/video quality summary contains quantitative and narrative information based on the results of the appropriate test center. The information includes:

- Video Subjective
    - ATEL test results

Video Objective
ATTC test results

Audio Subjective
Westinghouse Science & Technology Center test results

Audio Objective
ATTC test results

Audio and video quality is primarily determined by the subjective tests. In addition, objective test results are included that support or contradict the subjective test results, that compare the results to proponent claims and that point out noteworthy data points.

The subjective tests are:

ATV Basic (Received) Video Quality
ATV Basic Audio Quality

In the video quality tests, the basic data consist of subjective test scores for the 23 video segments that have been developed to highlight, for non-expert observers, system performance on attributes such as static luminance resolution.

In the audio quality test, the basic data consist of subjective test scores for 10 audio segments selected to illustrate, for expert listeners, system performance over a wide range of critical programming.

The basic data, which express judgments of individual systems compared with corresponding judgments of the reference conditions, are presented in tabular and graphical form.

In addition, all objective test data was studied to ensure support of the subjective results, and to report anything that looks odd, interesting or is felt should be brought to the attention of the Advisory Committee for any reason.

7.4.2.3 Target Value

The CCIR has defined HDTV in terms of current television systems. That definition, applied to NTSC, leads to the following target value. The resolution should be about twice that of NTSC in both the vertical and horizontal directions, the temporal resolution should be not less than NTSC, the color rendition should be superior to NTSC, any artifacts should be less objectionable than are NTSC artifacts, the aspect ratio should be 16:9, and the subjective sound quality should be comparable to Compact Disc.

7.4.3 Transmission Robustness

7.4.3.1 Definition

The ability of a transmission system to maintain a useful received picture, sound, and data in the presence of co-channel, adjacent-channel, taboo channel, and discrete frequency interference; and such impairments as noise, multipath, airplane flutter, etc., for terrestrial broadcasting; and second and third order distortion, phase noise, etc., for cable transmission.[3]

7.4.3.2 Method of Determination

Transmission robustness contains quantitative and narrative information based on the results from the appropriate test centers. The information includes:

Video Objective Tests with Expert Observation and Commentary
ATTC and CableLabs test results

Video Subjective Tests
ATEL test results

The robustness is determined not only by TOV and POU, but also the character of the impairment and a description of failure and recovery appearance.

7.4.3.3 Target Value

Better than NTSC within the defined service area.

7.4.4 Scope of Services and Features

This selection criterion addresses the need of an ATV system to support an array of services, features and capabilities beyond those that are explicitly considered as part of the other selection criteria.

Some capabilities covered here are features of the overall system. These include details of the picture and sound performance near the edge of coverage, the ability to operate in different modes of robustness versus picture quality, and the ability to reallocate channel capacity on demand among video, audio and ancillary services.

Other capabilities are specific features of the picture coding, sound coding or ancillary data capacity, other than quality or robustness. These include the support of various multi-channel sound formats, services for viewers with special needs, and the ability to support inexpensive receivers with NTSC-quality video.

Other elements of this selection criterion cover the work done by the Implementation Subcommittee, such as speed of implementation or other implementation features that are not cost-related and are not considered as part of the other selection criteria.

[3] The results of the Susceptibility to Interference tests described in Section 19.5 of the Objective and Transmission Tests Procedures Plans will be taken into account as part of the coverage studies conducted by PS/WP3.

7.4.4.1 Definition

Services and features supported by a transmission system other than the program video and one program audio channel.

7.4.4.2 Method of Determination

Scope of services and features were evaluated based on information supplied by the proponents, supplemented by analysis done by working parties of the Advisory Committee.

An essential part of the evaluation takes into account whether the services and features have been implemented in the system that was submitted for testing at the Advanced Television Test Center. Services and features that are merely claimed but not yet implemented will be analyzed to evaluate how easy or difficult it will be to implement them. As part of the decision process, a determination will have to be made about how to evaluate these services and features that are claimed but not implemented.

7.4.4.3 Target Value

When compared with NTSC, increased capability and flexibility in the ability to provide audio, captioning, data services, etc.

7.4.5 Extensibility

7.4.5.1 Definition

The ability of a transmission system to support and incorporate extended functions and future technology advances.

7.4.5.2 Method of Determination

Based upon information from PS/WP4, declarations by the proponents and the judgment of industry experts.

7.4.5.3 Target Value

A new service must provide long life, just as NTSC has provided a long life, by supporting future enhancements and future technology advances.

7.4.6 Interoperability Considerations

Interoperability considerations include delivery over alternate media such as cable, satellite, VCR, and packet networks; transcoding with NTSC, film, and other video standards; integration with computers and interactive systems; and scalability and the use of headers/descriptors to accommodate a variety of applications.

7.4.6.1 Definition

The suitability of a transmission system for operation on a variety of media, in addition to terrestrial broadcasting.

7.4.6.2 Method of Determination

Based upon information from PS/WP4, declarations by the proponents and the judgment of industry experts, and results of tests for cable television operation.

7.4.6.3 Target Value

A new service should be “friendly” to alternate delivery media. Interoperability with Cable TV is mandatory. Interoperability with VCRs, satellite, computer, data communications, and telecommunications applications with simple interfacing hardware is also an objective.

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8. ANALYSIS OF SYSTEM DATA

Chapters 9 through 13 provide summaries and analyses of data acquired from four laboratories (Advanced Television Test Center, Cable Television Laboratories, Advanced Television Evaluation Laboratory, and Westinghouse Research) on the five simulcast systems tested. Additionally, they include conclusions reached by Advisory Committee working parties on matters extending beyond what can be measured in a laboratory or derived from laboratory data. After a brief description of the system, subsections relate to Spectrum Utilization, Economics, Technology, and System Improvements, primarily addressing the ten selection criteria discussed in Chapter 7. In this chapter, issues that pertain to the analyses of all the systems will be discussed.

8.1 SPECTRUM UTILIZATION

8.1.1 Calculation of ATV Service Area

The analysis of spectrum usage of the ATV systems employed an allotment approach developed by the FCC staff and a service and interference model developed by Specialist Group 11 of PS/WP3. Combining the two permitted the development of approximately optimum allotment/assignment plans and comparison of service expected to be provided by each ATV system, if implemented, with service provided by the NTSC system currently in use.[1]

The plan seeks, station-by-station, to match or exceed current interference-limited NTSC service area with future companion ATV service area. To the extent possible, the ATV service area for each station is optimized to provide for interference-free ATV service to any area that is served interference-free by the companion NTSC station. The analysis includes consideration of vacant noncommercial allotments as well as authorized stations and pending applications.[2] Station locations and antenna heights above average terrain are assumed to be the same for the NTSC and ATV services. Other input parameters to the program are the planning factors developed by Specialist Group 10 of PS/WP3 and factors specific to each ATV system as determined by the test programs at the ATTC and ATEL.

An initial NTSC program run provided the reference for each of the ATV systems tested. The program output includes Grade B coverage area and interference-limited service area for each of the 1,657 authorized and applied-for television facilities in the August 1, 1992 FCC data base. Interference-limited NTSC service areas were determined on the basis of a co-channel desired-to-undesired (D/U)

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[1] The data base for the reference NTSC analysis, and for the ATV analyses, is as of August 1, 1992. The need to maintain comparability for the five ATV systems studied requires that the same data base be retained throughout the analysis process. Although data base changes occur with time, those changes are moderate.

[2] In Puerto Rico, the large number of television stations assigned within the limited area of the island precludes the development of a plan providing 100% accommodation by the methodology employed herein. As a result, those stations are not included in the analysis. The comparative analysis attempted to protect all existing noncommercial vacant allotments; however, it did not attempt to assign them an ATV channel.

ratio of 28 dB and first adjacent D/U ratios of -6 dB for interference from the lower adjacent-channel and -12 dB for interference from the upper adjacent-channel. Taboo considerations are based on threshold of interference (TOV) data from ATTC. Subjective tests at ATEL of co-channel interference from NTSC to NTSC showed that a 28-dB co-channel ratio corresponded to a CCIR impairment rating of 3 for NTSC stations using precise offset.[3] Accordingly, co-channel interference from ATV to NTSC is based also on impairment grade 3. NTSC receiving antennas beyond the City Grade Contour are assumed to have a front-to-back (F/B) ratio of 6 dB. No directivity is assumed for receiving antennas within the City Grade Contour. NTSC service is based on median f(50,50)[4] signal strength. f(50,10) propagation data are used for both NTSC and ATV interfering signals.

The outer limit of NTSC service, in the absence of interference, is considered to be the Grade B level. As specified by the FCC, the median field strengths corresponding to Grade B are: 47 dBu for low VHF, 56 dBu for high VHF, and 64 dBu for UHF.

The outer limit of ATV service in the absence of interference is that determined by the carrier-to-noise ratio yielding a CCIR impairment grade of 4. For digital systems, the f(50,90) signal strength is used for noise and interference-limited service calculations. Figure 8-1 provides receiver planning factors applicable to all ATV systems.

8.1.2 Allotment and Assignment Constraints Used in Analysis

The PS/WP3 analysis was conducted under two allotment scenarios (using both VHF and UHF channels for ATV stations, and using only UHF channels) and two sets of interference constraints (considering only co-channel interference, and both co-channel and adjacent-channel interference). In addition, the impact of taboos was assessed by recalculating coverage and interference for each scenario assuming the taboo performance measured in the laboratory. PS/WP3 has determined that the analysis should be considered in the following priority order: 1) co-channel and adjacent-channel interference, 2) co-channel interference only, and 3) co-channel, adjacent-channel and taboo interferences.

While the analysis that includes taboo performance maximizes consideration of interference impacts, limitations in both test and analysis involving taboos cause the results to have more limited value. During test, measurements were taken at TOV, yielding overly stringent results. Further, maximum amplitude limitations of the laboratory test facility affected the completeness of taboo test results. Finally, the effect of taboo interference is exaggerated in the computer analysis since taboo performance was not used to optimize allotments/assignments.

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[3] The same subjective tests showed that a 40-dB co-channel ratio corresponded to a CCIR impairment rating of 3, and that 28 dB corresponded to a rating of approximately 2, for NTSC stations using the worst permissible offset. Neither the FCC's TV station data base nor the data base used in these calculations show which existing NTSC stations are actually employing precise offset. Consequently, the NTSC baseline interference-limited service area calculations may overstate the actual NTSC service areas by some unknown amount.

[4] f(x,y) is a notation representing field strength exceeded at x percent of locations y percent of the time.

	Low VHF	High VHF	UHF
Antenna Impedance (ohms)	75.0	75.0	75.0
Bandwidth (MHz)	6.0	6.0	6.0
Thermal Noise (dBm)	-106.2	-106.2	-106.2
Noise Figure (dB)	10.0	10.0	10.0
Frequency (MHz)	69	194	615
Antenna Factor (dBm/dBu)	-111.7	-120.7	-130.7
Line Loss (dB)	1.0	2.0	4.0
Antenna Gain (dB)	4.0	6.0	10.0
Antenna F/B Ratio (dB)*	10	12	14

* In addition to F/B ratio, a formula is employed for the forward lobe simulating an actual receiving antenna pattern.

Figure 8-1. Receiver planning factors applicable to all ATV systems.

The analysis that includes both co-channel and adjacent-channel interference maximizes interference considerations short of including taboos. Adjacent-channel performance reflects both system and tuner design considerations. Thus, to the extent that a proponent's tuner, as tested, was suboptimal, adjacent-channel performance of ATV may have been negatively impacted.

The co-channel interference only analysis removes all adjacent-channel constraints resulting in a different assignment table. Tuner design is not a direct consideration for this case.

In all instances it should be noted that no reassignment or power adjustment was attempted for the purpose of reducing new interference into NTSC, or for the purpose of maximizing ATV service area.

8.1.3 Threshold of Visibility (TOV) Determinations

ATV thresholds of visibility are determined by the classic staircase (up-down) method which may be most familiar as a hearing test. The result of this procedure is a sawtooth-like tracing having a range of perhaps 4 or 5 dB; the average between the peaks and troughs is taken as the threshold.

There were instances in the cable threshold of visibility tests for impairments on the digital systems where no range in which to increment/decrement existed, i.e. in a single decibel the impairment signal went from non-existent to strong. It frequently happened that the threshold choice was between quite strong impairment and none, in which case the strong impairment level was chosen as TOV. When a small range was encountered in ATTC or CableLabs testing, the experimenters confirmed the TOV by using a longer observation period of perhaps 2 or 3 minutes during which impairments might be noted.

8.2 ECONOMICS

8.2.1 Calculation of Cost to Broadcasters

Several assumptions were made about the state of the existing broadcast facility and about the capacity available for inclusion of new equipment. It was assumed, for instance, that the station's existing tower has sufficient capacity for installation of the new ATV antenna and transmission line; a new tower is not required. The station's equipment space was assumed to have room for additional gear without the need to add floor space, racks, power distribution, air conditioning, or other support services. Similarly, it was assumed that stereo audio facilities already exist in the station. Additionally, the analysis was based on the use of a compressed NTSC signal multiplexed into the same STL with the ATV signal, as opposed to construction of a totally new and separate microwave path to the transmitter.

A cost was developed for each item on a station block diagram for each of the proposed ATV systems. Where possible, the likely cost of an item was sought through surveys of manufacturers likely to produce that item. In the many cases where it was not possible to obtain expected costs of items from manufacturers or from comparable equipment in the marketplace, broadcast system designers estimated selling prices based on the relative complexity of the items.

Certain general assumptions were made about the design of the transitional station. These included a choice of uncompressed, HDTV-level interconnections for the interfaces between equipment in the system, a downconverter to NTSC for simulcast transmission, and an upconverter for programming originated in NTSC. Provision was made for ATV-quality station IDs plus graphics for announcements and commercial tags. The ability to record and play back programs and commercials was incorporated through the inclusion of a video tape recorder. Some signal routing was provided, although it may be limited in scope. Monitoring was assumed to be done with professional quality instruments.

The design of the minimal station assumed that programs that arrive in ATV form are downconverted elsewhere to NTSC and fed to the station separately for simulcast transmission. It was assumed also that much programming will originate in NTSC and will require upconversion. In addition, station IDs and graphics for announcements and commercial tags were assumed to be upconverted from NTSC. Thus, an upconverter was included in the system along with an encoder to provide compression of material that originates in NTSC. Because the encoder processes only signals that began as NTSC, it was assumed that it can be a simpler device than used in the transitional station to compress ATV-level signals. The videotape recorder, likely to be based on a consumer VCR, would operate with fully compressed signals. The ATV signal routing was assumed to be a patch panel. Monitoring was assumed to use computer displays rather than professional video monitors.

In the cost estimates, "Satellite Receiver, Demodulator, Decoder" includes an optical-to-electronic signal converter. "STL Subsystem" includes NTSC compressor (20 Mbits/sec), multiplexer, STL transmitter (QPSK), STL receiver (QPSK), demultiplexer, and ATV reformatter (error correction for STL plus addition of FEC for broadcast transmission). "ATV Transmission Subsystem" includes ATV transmitter ($300,000), panel antenna and transmission line ($300,000), ATV transmitter monitoring, and ATV off-air monitoring.

8.2.2 Calculation of Cost to Consumers

Cost estimates were based on a common format to compare the technical complexity and material costs of proponent system receivers. The following methods and assumptions were used as a basis for comparison:

Time Frame — Based on system selection in 1993 and subsequent field testing, 1998 was assumed as the time when mass production of HDTV receivers would achieve sufficient volume (1 million units cumulative).

Technology — Receiver cost was estimated consistent with predictions for 1998 improvements in key technologies such as displays, integrated circuits, and memories. For this cost study, second generation receiver designs were assumed which would utilize these improved technologies.

Volume — 1% market penetration, or approximately 1 million HDTV receivers would be built by 1998.

Tuners — The cost of the tuner was agreed to be $10 for standard phase noise requirements and $13 for an improved phase noise specification needed by some proponents.

Displays — It was generally recognized that the cost of the display would have a major impact on the cost of the receiver and that, therefore, the market study would be influenced by that cost more than by any other. As a result, considerable effort was expended to find accurate estimates. A cathode-ray tube (CRT) of widescreen 34” diagonal with near HDTV performance, costing $700, and a projector of 56” diagonal dimension using projection CRTs and HDTV optical components, costing $1050, were assumed.

Deflection, Power Supply and Video Output — For 34” interlaced scan systems with scan rates of about 32 kHz and about 20 MHz video amplifier bandwidth, a cost of $60 was assumed. For 34” progressive scan systems with scan rates of about 47 kHz and about 30 MHz video amplifier bandwidth, a cost of $73 was assumed. For 56” projectors, $176 was assumed for interlaced scan systems and $201 for progressive scan systems.

Memory — A cost premium of 40% over standard dynamic random access memory (DRAM) was assumed for high speed memory used in some systems.

Digital ICs — The proponents provided block diagrams, gate counts, and pin counts for a suggested chip set for their systems. The digital IC information provided by all proponents was entered into the FAIRCOST II program for equivalent cost estimates. This program was developed for the IC industry and provides reasonably accurate cost predictions for ICs.

Analog Circuits — There was some concern whether the cost of the analog circuits and display could be estimated properly. Proponents provided their own cost estimates which were scrutinized and accepted, or modified after discussion.

Other costs, such as audio amplifiers and speakers, circuitry for NTSC processing, and cabinets, were assumed the same for all proposed systems.

Cost estimates were developed only for materials. Using a simple multiplier of 2.5, crude estimates for HDTV receiver retail prices were obtained.

8.3 TECHNOLOGY

8.3.1 Audio and Video Statistical Procedures

The subjective judgments were rated on CCIR five-point scales. Subjects observed a reference trial and a test trial and then rendered a judgment rating of each. The difference in the scores between the reference and test signals was the statistic which was analyzed for significant differences using an experiment error rate of 5% (i.e. there is a 5% chance that the observed difference is just a random error rather than something real).

The audio quality subjective judgments were made using the CCIR five-point, four-interval Impairment Scale with the terms “Imperceptible”, “Perceptible, but not Annoying”, Slightly Annoying”, “Annoying” and “Very Annoying” in a discrete fashion. The method, called Triple Stimulus, Hidden Reference, employs the use of an announced reference and then the test signal and the reference again unannounced or “hidden” with regard to order. High variability and inconsistency among the judges seriously impaired the sensitivity of this test. A special audio task force reviewed the data and specific tapes and recommended against their use in this report.

Audio impairment subjective test results showed many irregularities. The special audio task force reviewed the data and tapes and recommended that the only conclusion (if true) that could be drawn from the tests was the following statement: “There was no evidence that the audio system failed before the accompanying video.”

The video quality subjective judgments were made using the CCIR Five-Point (five-interval) Continuous Quality Scale with the terms “Excellent”, “Good”, “Fair”, “Poor” and “Bad.” This method uses double presentations of reference and test signals in blind, pseudo-random orders. The responses were graded from 0 to 100, where 0-20 corresponds to “Bad”, 20-40 to “Poor”, 40-60 to “Fair”, 60-80 to “Good” and 80-100 to “Excellent”. The twenty-three video selections were compared using a t-test with an individual error rate of 5%. Emphasis is placed on describing the size of the differences between the 1125-line reference and test signal using averages and ranges, rather than on statistical significance. Estimates for stills and moving selections are reported separately where appropriate.

The significance of unusual observations or “outliers” was determined based on Tukey’s outlier-detection rule. The interquartile range is defined as the difference between the 75th percentile (3rd quartile) and the 25th percentile (1st quartile). A point is considered a possible outlier if it is outside the area described by {25% - 1.5 x [interquartile range]} or {75% + 1.5 x [interquartile range]}. A point is considered a definite outlier if it is outside {25% - 3 x [interquartile range]} or {75% + 3 x [interquartile range]}. Outliers so detected were reported separately and were not included in the calculation of the average or range.

8.3.2 Test Material Pictures

A number of different images, still and moving, have been used in the test program. A list of the images, with an indication of the application of the image, follows. In the list the prefix “S” means still picture and “M” means Motion Sequence. Pictures S1-S13 were scanned from film at very high resolution into a digital frame store. Sequences M1-M15 were captured by a live camera. Sequences M17-M20 were transferred from film using the same camera, in each format, used for M1-M15. S14, M16, and M16G were synthetic images electronically generated on a computer workstation.

ID	Still Pictures	Test Application
S1	Metal Table & Chairs	uminance resolution
S2	Vines	Luminance resolution, demo image
S3	Wavy Wall	Luminance rendition, demo image
S4	Columns	Luminance dynamic range
S5	Tulips	Chrominance resolution, noise impairment, demo image
S6	Sculptures	Chrominance resolution, demo image
S7	Fruits & Vegetables	Color gamut
S8	Toys	Chrominance dynamic range
S9	Girl with Toys	eripheral performance, interference, demo image
S10	Memorial Arch	Depth portrayal
S11	Woman with Roses	Noise impairment, interference
S12	Lorain Harbour	Noise impairment
S13	Flower on Plate	Multipath

ID	Electronically Generated	Test Application
S14	Cheshire Cat	Basic received quality

ID	Motion Sequences	Test Application
M1	Window	Basic received quality, luminance resolution, low acceleration
M2	Fax Machine	Basic received quality, dynamic luminance resolution, high acceleration
M3	Paint Store	Basic received quality, dynamic chrominance resolution, low acceleration
M4	Mannequins	Basic received quality, dynamic chrominance resolution, high acceleration
M5	Living Room	Basic received quality, motion rendition - camera movement
M6	Den	Basic received quality, motion rendition - single object in-scene movement, noise impairment, interference
M7	Park Ride	Basic received quality, motion rendition - multiple object in-scene movement
M8	Bubbles	Basic received quality
M9	Audience	Basic received quality, motion rendition - multiple object in-scene movement
M10	Woman & Room	Basic received quality, motion rendition - camera and in-scene movement combined
M11	Lamp	Noise and other impairment, demo image

M12	Times Square	Multipath and microreflections
M14	Co-Channel (Texas Dude)	Desired for co-channel, adjacent-channel, & taboo channel interference, Desired/Undesired for ATV-into-ATV, demo image
M15	Interferor	Undesired for ATV-into-NTSC and NTSC-into-ATV interference for Enhanced NTSC, Undesired for "benchmark" co-channel NTSC-into-ATV TOV for simulcast
ID	Electronically Generated	Test Application
M16	Rotating Pyramids	Basic received quality, point of unusability, multipath threshold of visibility
M16G	Rotating Pyramids Gated	Undesired for NTSC-into-NTSC, NTSC-into-ATV, and ATV-into-NTSC interference for simulcast
ID	Film Origination	Test Application
M17	Carousel	Basic received quality, film transfer, 35 mm/24 fps
M18	Bridge 24 Frames	Basic received quality, film transfer, 35 mm/24 fps
M19	Bridge 30 Frames	Basic received quality, film transfer, 35 mm/30 fps
M20	Helicopter	Basic received quality, film transfer, 70 mm/60 fps

8.3.3 Inverted Picture Quality Results

The processed images for two electronically generated graphic sequences were judged during subjective testing to be higher quality than the reference. For the first of those, a still, S14, the processed image was judged to be better than the reference for all systems. For the second, a motion sequence, M16, the processed image was judged to be better than the reference for the 787 progressive systems.

In S14, interline flicker appears in the 1125 interlace reference. The flicker is reduced in processed interlace images, since, in effect, those systems vertically filter the image. No flicker appears in the 787 progressive source and processed images. Additional vertical filtering during the creation of the image could have significantly reduced the source interline flicker and possibly eliminated the rating inversion.

In M16, interline flicker appears in scrolling text in both the 1125 interlace reference and the interlace processed images. No flicker appears in the 787 progressive source and processed images. Since the flicker is a motion-related artifact, additional vertical filtering during image creation would not eliminate the flicker.

8.3.4 787 Camera Source Noise

The 787 camera-generated material used in tests of two of the systems exhibited visible noise in areas of low luminance. This noise, which was coarse in appearance, was more visible than the noise in the corresponding 1125 reference material, and the 1050 test material which was derived from the 1125. In addition, frame-by-frame examination of the 787 material revealed horizontally coherent noise that appeared as short, dark streaks.

Before the cameras were used by PS/WP6 in shooting the test sequences, the 787 camera noise level was measured to be about 2 dB worse than the 1125 camera. A noise level difference greater than 2 dB was observed in the source material during subjective testing, possibly as much as 5 or 6 dB. Also, differences in black levels between the 787 material and 1125 material have been noted. While the differences in black levels were not documented during the shoot, PS/WP6 personnel recall that there was a difference. The black level difference, in conjunction with gamma correction, could account for the unexpected additional level of noise in the 787 camera material.

It is believed that the additional source noise adversely affected the basic received quality test results for all motion sequences except for M16. However, the additional source noise, while significant, does not fully account for picture quality performance differences obtained by the two systems tested with this material.

8.3.5 Resolution Measurements

The limiting resolutions of the ATV systems were measured using a variety of techniques. Static and dynamic moving zone plates were photographed and viewed directly from a CRT to measure resolution. In addition, radial resolution charts which contained printed resolution numbers were captured with the cameras and stored on tape. Radial patterns from these charts were captured also at several speeds of rotation. The test results exhibited inconsistencies among the various techniques. The presence of coding artifacts and/or moire in some instances is known to have affected the consistency of the measurements.

Digital coding artifacts were visible to varying degrees in the dynamic zone plates due to the presence of high spatial frequencies over a large area coupled with non-linear motion (not panning). Since coding artifacts do not necessarily result in apparent loss of resolution, their presence obscures the limiting resolution and can result in a non-monotonicity as a function of speed.

In the case of the radial resolution charts, moire was visible sometimes at spatial resolutions lower than the expected limiting resolutions of the systems.

Because of the inconsistencies, and the interpretation problems caused by coding artifacts, objective measurements of video resolution are not included in this report.

8.3.6 Random Noise Determination (C/N)

Since the outer limit of service of an ATV system, in the absence of interference from other generators of electromagnetic energy, is dependent on the system's robustness with respect to noise, noise power input where video or audio are affected is an important metric. At ATTC, a broadband noise source, with flat energy distribution over the 6-MHz television channel, was used. Employment of an average-reading power meter and an RF step attenuator provided the ability to measure the amount of noise power being injected into the system.

Random noise measurements on the ATV systems was done at the strong desired level to avoid effects of receiver noise factor or any other elements that may have impact on the results. As agreed by the proponents, the strong receiver input level was set at -28 dBm for the Narrow-MUSE analog system and -38 dBm for the four digital systems. For the analog ATV system, power level varies with modulation and, unlike NTSC, no constant sync pulse level is available. At the proponent's suggestion, white level was adopted as the reference. In Narrow-MUSE, positive modulation is used, so white level is higher than black level.

In general, digital system average power levels are independent of picture content. The DSC-HDTV power level, however, being dependent on the split between 2-level and 4-level VSB modulation, required a particular reference signal for calibration. The reference signal used was a gray field. For the remaining three digital systems, the average power was measured during whatever scene was being employed in the test. Desired power was held constant at the strong level and the noise power was increased to determine the TOV and the POU (point of unusability).

For the analog system, sufficient separation was found from TOV to POU to permit ranging, so subjective tests were performed by ATEL. For the four digital systems, the spread from TOV to POU was insufficient to permit ranging, so the TOV was used to determine the C/N for the limiting case.

8.3.7 Interoperability Considerations

Computers are expected to play an increasing role in video image generation and production and it is desirable to have an HDTV format which facilitates easy display and manipulation of decompressed HDTV video on the computer. Progressive scanning and square pixels are important factors for interoperability of an HDTV system with computers — nearly all bit-mapped computer graphics displays have these features. Progressive scanning and square pixels are most critical for real-time applications such as display, scan-conversion, frame capture, and video effects. They avoid artifacts that are common with interlaced display and facilitate processing 2-D transformations, especially rotations.

Conversion to and from systems with different frame rates is the most difficult type of conversion presently being done. Digital conversion between 59.94 fields per second and 50 fields per second requires a number of frame stores and very large processing capability. Methods that involve frame dropping lead to jerky motion, but other techniques produce acceptable images under most conditions. This difficult conversion may be easier from a progressive source than an interlaced source.

Latency, the time delay between a video frame going into the encoder and the corresponding frame coming out of the decoder in the back-to-back mode, can be important in interactive applications. Time delays include frame delays, required at the transmitter and receiver for coding and decoding, delay that may be needed to facilitate frame coding in an interlaced system, and rate buffers at the transmitter and at the receiver.

8.3.8 MPEG Description

The Moving Picture Experts Group (MPEG), a joint committee of the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC), is officially called ISO/IEC JTC1/SC29/WG11. The charter of the MPEG video and audio groups is to develop compression standards for full-motion video, associated audio and their multiplex for digital storage media. Transmission and encryption/conditional access techniques are not specified in the MPEG standards. The groups consist of diverse representation from among computer, telecommunications, television, and other industries worldwide. Their basic method consists of selecting the compression techniques that produce the best video and audio quality, based on mean squared error comparison of source and coded pictures and/or subjective expert evaluation of results from computer simulation.

The MPEG video and audio standards were nominally developed for 30 frames/second progressive scan, low resolution video (352H x 240V) at 1.5 Mbits/sec data rate, and stereo audio at a 256 kbits/sec data rate. Header/descriptors incorporated in the standards, however, allow modification of the nominal parameters, including changes in picture size, resolution and aspect ratio, pixel aspect ratio, frame rate, and compressed data rate. The MPEG standards (IS11172-1 [system], IS 11172-2 [video] and IS 11172-3 [audio]) were officially adopted by ISO in 1992. MPEG-1 video compression uses a bi-directional motion compensated Discrete Cosine Transform, and MPEG-1 audio compression uses adaptive Subband Coding. Compatibility between MPEG-1 encoders and decoders can depend on scanning format and data rate capabilities of the decoder. Integrated circuits for both video and audio operating at the nominal resolution and data rate are already available from several manufacturers.

Ongoing work in the MPEG committees is developing an MPEG-2 video compression standard with nominal parameters that include conventional (525/625 line) and HDTV resolutions and data rates, and a multi-channel audio standard. The MPEG-2 video standard will make specific provisions to efficiently compress interlaced scan formats, using both field and frame coding, but is expected to have as many elements as possible in common with the MPEG-1 standard. The multi-channel audio standard is expected to be fully backward compatible with the stereo MPEG audio standard. ISO standard development involves several interim steps: the MPEG-2 video committee currently has a Working Draft, and its current schedule is to freeze a Committee Draft of the core algorithm in March 1993, freeze a complete Committee Draft in November 1993, produce a Draft International Standard in March 1994 and to approve an International Standard within six months to one year later.

8.4 SYSTEM IMPROVEMENTS

Information on system improvements was derived from the report of the Technical Sub-Group of the Special Panel. The group met on November 18-20, 1992 to consider proposed ATV system improvements.

The Technical Sub-Group was constituted to decide how system improvements should be considered. The group agreed that each of the submitted system improvements would be placed in one of the following four categories:

The proposed improvement is approved with lab testing before field testing.

The proposed improvement is approved with lab testing recommended after system selection, but before field testing.

The proposed improvement is approved with performance verification at the start of field testing.

The proposed improvement is classified as a “future” improvement since it would not be available until after field testing.

The improvements that were approved by the Technical Sub-Group are presented in the associated system analysis chapter, grouped according to the following categories:

1. Already Implemented
2. Implemented in Time for Field Testing

Improvements that were classified as “future” improvements were neither approved nor disapproved and are not listed in this report.

9. NARROW-MUSE

9.1 SYSTEM OVERVIEW

Narrow-MUSE, proposed by NHK, the Japan Broadcasting Corporation, uses analog pulse-amplitude-modulation transmission for the visual signal, and digital transmission for sound and auxiliary data. By pre-processing and filtering, an 1125-line interlaced format is converted to a 750-line interlaced format, and then the converted signal is encoded into the Narrow-MUSE format using the Multiple Sub-Nyquist Sampling Encoding method. The field rate is 60.0 Hz. Aspect ratio is 16x9. The baseband spectrum of the stream of pulse-amplitude-modulated pulses produced by the video encoder is divided into two portions. The low video frequencies, to 0.75 MHz, which carry most of the video power and also the synchronization information, are modulated via VSB-AM on a carrier located 200 kHz above the lower band edge. This carrier placement means that this portion of the Narrow-MUSE modulated signal is attenuated by the Nyquist filter in an NTSC receiver tuned to the same channel, thus limiting interference into NTSC sets. The high video frequencies (from 0.75 MHz up), which represent the fine detail in the Narrow-MUSE picture, are modulated via SSB-AM, occupying a band extending from 1.42 MHz to approximately 6 MHz above the lower band edge. A gap in the spectrum from 1.1 MHz to 1.42 MHz is designed to minimize interference to and from co-channel NTSC. The Narrow-MUSE system has four channels of audio with 15 kHz bandwidth per channel. A near-instantaneous companding DPCM method is used for the audio. The audio is sampled at 32 kHz with 15 bit precision. Audio and auxiliary information are coded into ternary symbols for digital transmission.

9.2 SPECTRUM UTILIZATION

The Narrow-MUSE analysis was conducted under two allotment scenarios (using both VHF and UHF channels for ATV stations, and using only UHF channels) and two sets of interference constraints (considering only co-channel interference, and both co-channel and adjacent-channel interference). In addition, the impact of taboos was assessed by re-calculating coverage and interference for each case assuming the taboo performance measured in the laboratory.

Figure 9-1 shows planning factors, specific to the Narrow-MUSE system, as derived from test results. The numbers in the figure are desired-to-undesired ratios (D/U) in dB. The values for interference into NTSC are based on CCIR Impairment Grade 3 (slightly annoying) as determined from the ATEL subjective tests. Because the ATV service is intended to be an improvement over NTSC, interference into ATV is based on CCIR Impairment Grade 4 (perceptible but not annoying) if the range between the threshold of visibility (TOV) and the point of acquisition (POA) exceeds 5 dB. Otherwise, the TOV power level is used. Narrow-MUSE demonstrated a “graceful degradation” and thus D/U values are based on CCIR Impairment Grade 4. PS/WP3 set the maximum ERP at 37 dBk for Narrow-MUSE.

Co-Channel	D/U (dB)
ATV-into-NTSC	+16.8
NTSC-into-ATV	+21
ATV-into-ATV	+31

Carrier-to-Noise	+38

Adjacent-Channel	D/U (dB)
Lower ATV-into-NTSC	-31
Upper ATV-into-NTSC	-12.0
Lower NTSC-into-ATV	+28
Upper NTSC-into-ATV	-11.8
Lower ATV-into-ATV	-15.5
Upper ATV-into-ATV	+16.6

Figure 9-1. Planning factors specific to Narrow-MUSE.

9.2.1 ACCOMMODATION PERCENTAGE

Narrow-MUSE could provide 100% accommodation under both the VHF/UHF and UHF scenarios only if adjacent-channel and taboo constraints are not considered. Test results reveal that Narrow-MUSE cannot be collocated with a lower adjacent NTSC allotment, nor with another adjacent ATV allotment. Furthermore, the n+2 taboo for NTSC-into-ATV cannot support collocation and should be considered in developing an allotment/assignment table. Accommodation is achieved at the expense of reducing the ATV and NTSC service areas. No attempt was made to reduce interference to NTSC service by adjusting either ATV or NTSC power.

Under the VHF/UHF scenario, taking into account both co-channel and adjacent-channel constraints, 95.5% (1,582) of the 1,657 NTSC stations could be accommodated with a companion ATV station. Under the UHF scenario, 94.8% (1,571) could be accommodated. Furthermore, if the n+2 taboo constraint is considered and the impact of the remaining taboos are taken into account, the accommodation is reduced to 77.2% (1,279) in the VHF/UHF scenario and 73.7% (1,221) in the UHF scenario.

9.2.2 SERVICE AREA

Figure 9-2 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 both co-channel and adjacent-channel constraints. In this graph, the 1,657 current NTSC stations are placed in order of decreasing ATV to NTSC service area ratio. Examination of the graph reveals that 0.9% (14) of the 1,582 accommodated ATV stations under this scenario would have an ATV service area at least 20% larger than their companion NTSC service area and 17.8% (281) would have an ATV service area at least 80% of their companion NTSC service area. The total ATV interference-limited service area for the 1,582 stations is 19.2 million square kilometers.

Figure 9-3 shows the interference statistics for the VHF/UHF scenario. During the transition period, 8.6% of ATV stations would receive no interference. This would rise to 16.4% after the transition period ends. Also during the transition period, 61.6% of the ATV stations would receive interference in more than 35% of their noise-limited coverage area. This would fall to 49.5% after the transition period ends. The total interference area created within the ATV noise-limited coverage area during the transition period is 13.71 million square kilometers. This would decrease to 11.30 million square kilometers after the transition period ends. Of the existing NTSC stations, 74.4% would not receive any new interference because of the ATV service, while 0.5% would receive new interference in more than 35% of their Grade B area. The total new interference into NTSC created under this plan is 0.80 million square kilometers.

When the adjacent-channel constraints of Figure 9-1 are not included in the VHF/UHF scenario, the allotment/assignment table is different. In that case, 3.3% (55) of the ATV stations would have an ATV service area at least 20% larger than their companion NTSC service area and 41% (680) would have an ATV service area at least 80% of their companion NTSC service area. During the transition period, 19.1% of ATV stations would receive no interference. This would rise to 23.5% after the transition period ends. Also during the transition period, 27.9% of the ATV stations would receive interference in more than 35% of their noise-limited coverage area. This would fall to 27.1% after the transition period ends. Of the existing NTSC stations, 81.1% would not receive any new interference because of the ATV service, while 0.7% would receive new interference in more than 35% of their Grade B area.

Figure 9-4 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 UHF scenario, taking into account both co-channel and adjacent-channel constraints. In this graph, as before, the 1,657 current NTSC stations are placed in order of decreasing ATV to NTSC service area ratio. Examination of the graph reveals that 0.8% (12) of the 1,571 accommodated ATV stations under this scenario would have an ATV service area at least 20% larger than their companion NTSC service area and 16.0% (251) would have an ATV service area at least 80% of their companion NTSC service area. The total ATV interference-limited service area for the 1,571 stations is 18.8 million square kilometers.

Figure 9-5 shows the interference statistics for the UHF scenario. During the transition period, 7.8% of ATV stations would receive no interference. This would rise to 14.2% after the transition period ends. Also during the transition period, 64.0% of the ATV stations would receive interference in more than 35% of their noise-limited coverage area. This would fall to 52.7% after the transition period ends. The total interference area created within the ATV noise-limited coverage area during the transition period is 13.80 million square kilometers. This would decrease to 11.54 million square kilometers after the transition period ends. Of the existing NTSC stations, 77.7% would not receive any new interference because of the ATV service, while 0.2% would receive new interference in more than 35% of their Grade B coverage area. The total new interference created under this plan is 0.77 million square kilometers.

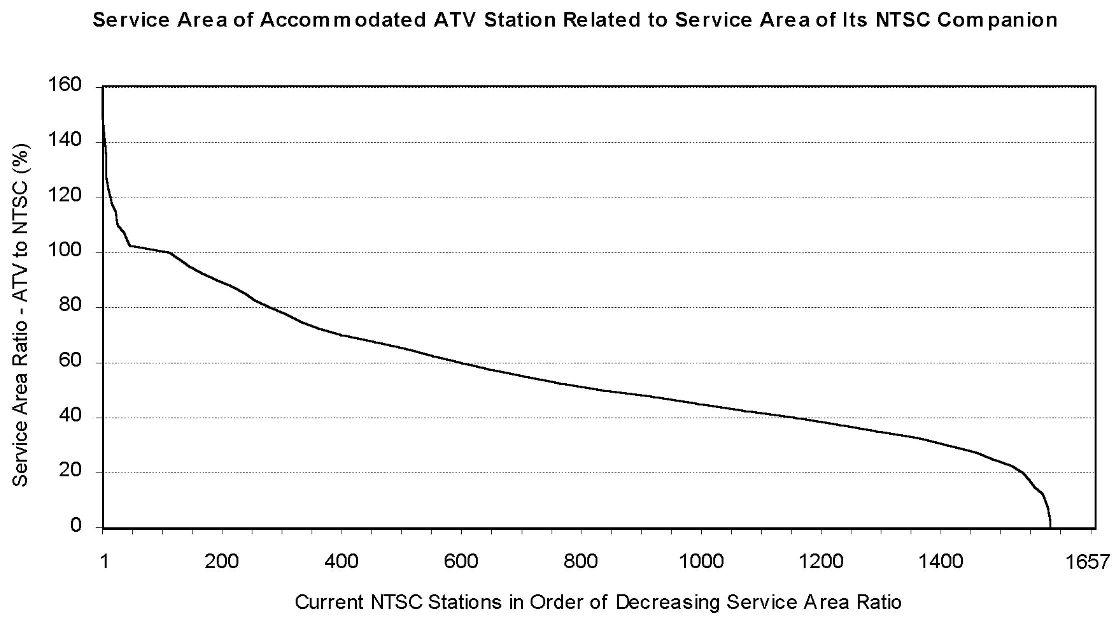

Figure 9-2. Narrow-MUSE VHF/UHF Scenario — Interference-limited service area of each ATV station relative to the interference-limited service area of its companion NTSC station (co-channel and adjacent-channel constraints).

Interference Area Compared to Coverage Area	ATV Stations with Interference		NTSC Stations with Added Interference Due to ATV
	During Transition	After Transition	
No Interference	8.6 %	16.4 %	74.4 %
0 - 5 %	2.9 %	4.2 %	10.9 %
5 - 10 %	3.4 %	4.0 %	6.6 %
10 - 15 %	3.1 %	4.0 %	3.6 %
15 - 20 %	4.0 %	3.9 %	1.9 %
20 - 25 %	4.1 %	4.9 %	1.1 %
25 - 30 %	5.6 %	6.2 %	0.8 %
30 - 35 %	6.7 %	6.9 %	0.2 %
> 35 %	61.6 %	49.5 %	0.5 %

Figure 9-3. Narrow-MUSE VHF/UHF Scenario — Interference characteristics (co-channel and adjacent-channel constraints).

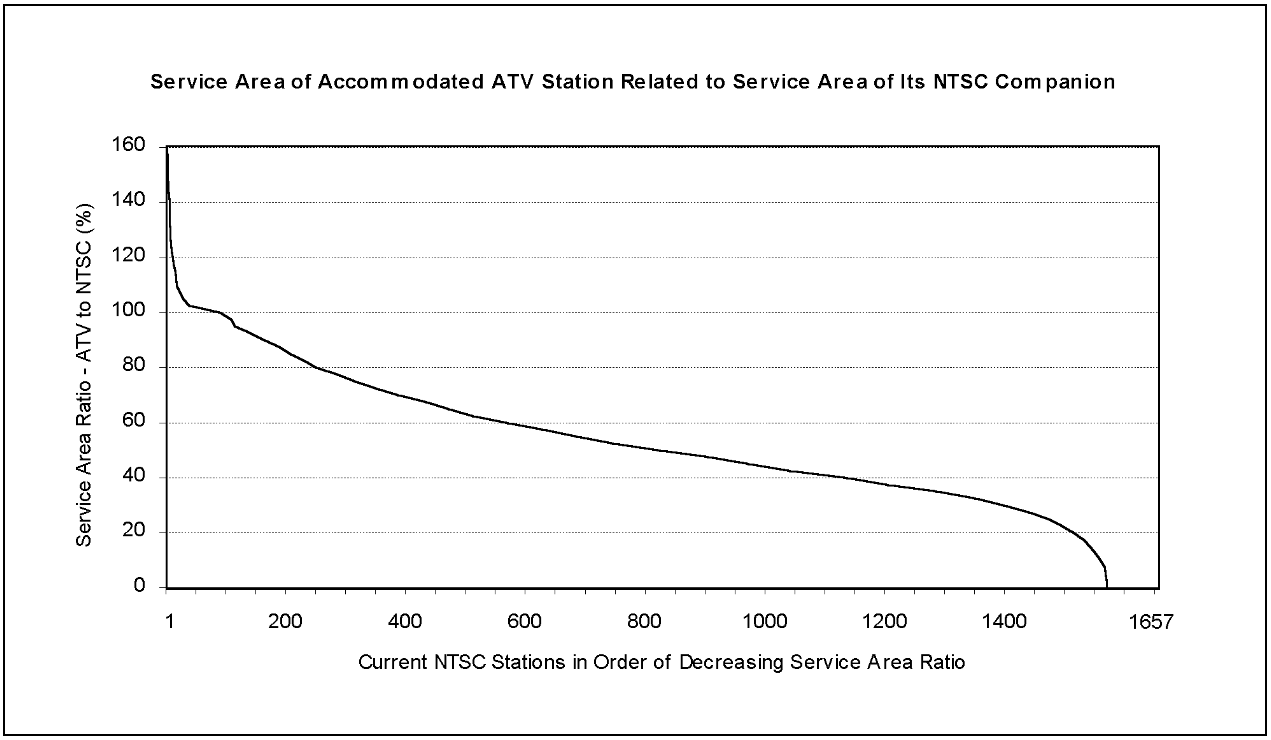

Figure 9-4. Narrow-MUSE UHF Scenario — Interference-limited service area of each ATV station relative to the interference-limited service area of its companion NTSC station (co-channel and adjacent-channel constraints).

Interference Area Compared to Coverage Area	ATV Stations with Interference		NTSC Stations with Added Interference Due to ATV
	During Transition	After Transition	
No Interference	7.8 %	14.2 %	77.7 %
0 - 5 %	2.8 %	3.3 %	7.9 %
5 - 10 %	2.7 %	3.8 %	5.4 %
10 - 15 %	2.8 %	4.2 %	3.8 %
15 - 20 %	4.0 %	4.8 %	2.2 %
20 - 25 %	4.9 %	5.1 %	1.4 %
25 - 30 %	5.3 %	6.0 %	0.9 %
30 - 35 %	5.7 %	5.9 %	0.4 %
> 35 %	64.0 %	52.7 %	0.2 %

Figure 9-5. Narrow-MUSE UHF Scenario — Interference characteristics (co-channel and adjacent-channel constraints).

When the adjacent-channel constraints of Figure 9-1 are not included in the UHF scenario, the allotment/assignment table is different. In that case, 3.4% (56) of the ATV stations would have an ATV service area at least 20% larger than their companion NTSC service area and 41% (673) would have an ATV service area at least 80% of their companion NTSC service area. During the transition period, 19.3% of ATV stations would receive no interference. This would rise to 29.7% after the transition period ends. Also during the transition period, 27.5% of the ATV stations would receive interference in more than 35% of their noise-limited coverage area. This would fall to 21.6% after the transition period ends. Of the existing NTSC stations, 71.2% would not receive any new interference because of the ATV service, while 0.2% would receive new interference in more than 35% of their Grade B area.

The frequency distribution of ATV station effective radiated power levels needed to achieve ATV noise-limited coverage comparable to NTSC Grade B coverage was calculated. The maximum effective radiated power level was limited to 37 dBk (5,000 kW). The results are shown in Figure 9-6.

Effective Radiated Power Level		Number of TV Stations			
		VHF/UHF Scenario			UHF Scenario
(dBk)	(kW)	Low VHF	High VHF	UHF	UHF
Less than 5	Less than 3.2			2	2
5 - 10	3.2 - 10.0	2		5	5
10 - 15	10.0 - 31.6	2	1	35	35
15 - 20	31.6 - 100	1	7	29	30
20 - 25	100 - 316		3	49	48
25 - 30	316 - 1,000			108	108
30 - 35	1,000 - 3,160		1	324	330
35 - 40	3,160 - 10,000			1,013	1,013
> 40	> 10,000				
TOTAL		5	12	1,565	1,571

Figure 9-6. Narrow-MUSE power level distribution.

9.3 ECONOMICS

9.3.1 Cost to Broadcasters

The estimated equipment cost for a Narrow-MUSE transitional station is shown in Figure 9-7. The total cost of the transitional station was estimated to be $1,710,700. The total cost of a minimal station was estimated to be $1,114,300. A general description of the methods used to develop the cost data is contained in Section 8.2.1.

9.3.2 Cost to Alternative Media

Information on this topic was not provided.

Subsystem	Cost (thousands)
Satellite Receiver, Demodulator, Decoder	$ 13.5
Character Generator, Still Store, Two 28" Monitors	200.0
Routing Switcher (10 x 10), Master Control	125.0
2 ATV VTRs and Monitors	170.0
NTSC Upconverter, including Line Doubler	19.0
ATV-to-NTSC Downconverter	15.0
34" Monitor, Seven 17" Monitors, Eight Decoders	110.0
ATV Encoder	200.0
STL Subsystem	92.5
ATV Modulator, NTSC Exciter	25.0
ATV Transmission Subsystem	740.7
TOTAL COST	$1,710.7

Figure 9-7. Equipment cost for a Narrow-MUSE transitional station.

9.3.3 Cost to Consumers

The estimated material cost data for a Narrow-MUSE receiver are shown in Figure 9-8. A general description of the methods used to develop the cost data is contained in Section 8.2.2.

Using a 2.5 multiplier, the resulting estimated retail price for a Narrow-MUSE receiver is $2,620 for a 34" direct view receiver and $3,910 for a 56" projector receiver.

Subsystem	34" Widescreen Direct View Receiver	56" Widescreen CRT Type Projector
Signal Processing Components	$ 168	$ 168
Audio Amplifiers, Speakers	30	30
Scan System, Power Supply, Video Amps	60	176
Display	700	1,050
Cabinet	90	140
TOTAL MATERIAL COST	$1,048	$1,564

Figure 9-8. Material cost data for a Narrow-MUSE receiver.

9.4 TECHNOLOGY

9.4.1 Audio/Video Quality

In video subjective tests of Narrow-MUSE, the system performed differently across segments of test material. For 8 of the 9 stills, Narrow-MUSE was judged, on average, to be about 0.5 grade lower in quality than the 1125-line studio reference. The remaining still, electronically generated, was judged to be better in quality than the reference.[1] For the 14 motion sequences, Narrow-MUSE was judged to be about 1 grade lower in quality than the reference. These quality judgments appear mainly to reflect the static and dynamic resolution limits of Narrow-MUSE as confirmed by the objective measurements. The judgments, however, may also reflect, to some extent, other system characteristics and implementation deficiencies, which resulted in visible artifacts in the Narrow-MUSE images.

No problems were noted for Narrow-MUSE in tests of temporal transient response and response to scene cuts. When subjected to noise at source, however, the system introduced a loss in resolution that was progressive with the level of noise introduced. Further, some problems, which may be significant in light of current distribution practice, were noted when material was subjected to two concatenated Narrow-MUSE encode/decode processes.

There was no evidence that the audio system failed before the accompanying video.

9.4.1.1 Video Quality

Subjective judgments of image quality by non-experts are summarized in Figure 9-9. Scores are the differences between judgments of the reference and judgments of Narrow-MUSE for 9 stills and 14 motion sequences.[2] For 8 of the 9 stills, Narrow-MUSE was judged, on average, to be 0.5 grade (i.e., about 10 points on the 100 point scale) lower in quality than the 1125-line studio reference; for the remaining still (S14), the system was judged to be 1.2 grades higher in quality than the reference (this may reflect reduced visibility of interlacing artifacts in the Narrow-Muse rendering of this picture). For motion sequences, Narrow-MUSE was judged, on average, to be 1 quality grade (i.e., about 19 points) lower in quality than the reference.

Narrow-MUSE performed differently for different segments of test material. For stills, differences ranged from -0.3 to -0.8 grade (not including S14); for moving sequences, differences ranged from -0.6 to -1.5. The variability among viewers differed somewhat across materials, but was within acceptable limits. Analysis of differences in judgment between the reference system and Narrow-MUSE as a function of image content indicates that viewers' judgments were influenced primarily by limitations of the Narrow-MUSE system in static and dynamic luminance/chrominance resolution.

The conclusion that subjective results primarily reflect resolution limits is supported by objective measurements of static and dynamic resolution. The system showed a decrease in dynamic luminance resolution that is progressive over the range of velocities studied. The conclusion is further supported by

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[1] See Section 8.3.3.

[2] Note: There were errors in rendering 8 of the stills for testing Narrow-Muse which affected the clarity and color tint of the pictures. This is fully documented by a letter to NHK from ATTC found on page III-43 of the Narrow-MUSE report. While experts agree that these errors do not invalidate the results shown in Figure 9-9, caution should be exercised if future tests are implemented involving comparisons of the Narrow-MUSE images with the images from the other tested systems.

expert commentaries, which note a loss in resolution for static material and a greater loss in resolution for dynamic material.[3]

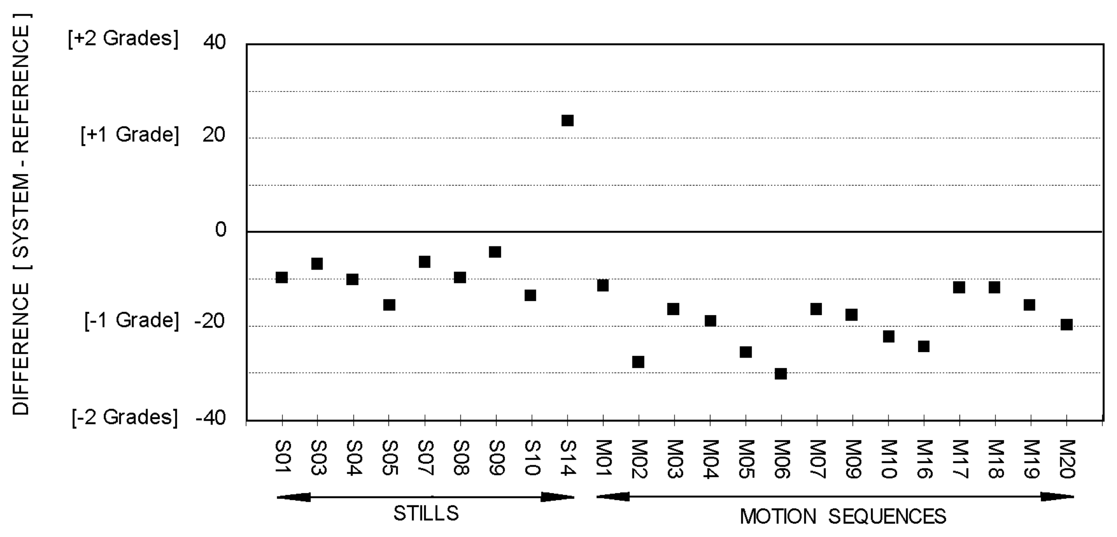

Figure 9-9. Average differences between quality judgments for the 1125-line studio quality reference and for Narrow-MUSE.

While the data suggest that Narrow-MUSE was judged to be lower in quality than the reference system primarily because of its resolution limits, it is likely that quality judgments for Narrow-MUSE were also influenced by the following system artifacts: reduced fidelity in hue and saturation, ringing, and the introduction of "halos," particularly in dynamic material. Further, it is reasonable to assume that judgments of the system were influenced by visible artifacts caused by implementation deficiencies.

Expert observers sometimes noted that a "leading ghost" was visible, even in "unimpaired" pictures. Leading ghosts were not visible in the tapes used for subjective quality tests.

When subjected to noisy source material, Narrow-MUSE introduced luminance and color noise as well as a reduction in resolution that was progressive with the level of noise introduced. No motion artifacts, however, were observed.

During measurements of transmitted signal spectrum, it was noted that, when a particular video test pattern was transmitted, the Narrow-MUSE receiver could not reliably acquire synchronization lock.

When subjected to scene cuts, Narrow-MUSE introduced no artifacts that were visible in normal viewing. Field-by-field inspection, however, showed that information prior to a cut was retained for 1

[3] See Section 8.3.5.

field and that 4-5 fields were required after a cut to achieve full static resolution for the new scene. Examinations of luminance transient response yielded similar results.

Some system artifacts became pronounced when material was subjected to two encode/decode passes through the system. During the first pass, Narrow-MUSE introduced a reduction in resolution, a slight loss of fidelity in hue and saturation, and some ringing, moire, and ghosting. These artifacts were most pronounced in dynamic material and were increasingly evident following the second pass.

9.4.1.2 Audio Quality

There was no evidence that the audio system failed before the accompanying video.[4]

Objective tests were performed for dynamic range, total harmonic distortion (THD), THD+noise (THD+N), intermodulation distortion (IMD), dynamic intermodulation distortion (DIM), frequency response, and overload vs. frequency. The dynamic range for the Narrow-MUSE system was found to be 86 dB. The THD was generally under 0.1%, rising to 0.8% for the high level 20 Hz test in channel 1. Channel 2 showed 16% THD under the same condition. For high level signals, THD+N was 0.05% in the mid band, rising to nearly 1% at 20 Hz and 10 kHz. Channel 2 showed aberrant behavior for low frequencies, similar to that shown in the THD test. IMD was under 0.03% in channel 1, and under 0.1% in channel 2. Frequency response was very flat from 20 Hz to nearly 15 kHz. The system overload point was uniform from 50 Hz to 5 kHz, dropped 8 dB at 20 Hz, and 3 dB at 8 kHz. No overload data are available at 15 kHz since the system response did not extend that far.

In the test of co-channel ATV-into-NTSC, Narrow-MUSE caused no interference into BTSC audio, and degraded NTSC VBI data only at the highest level of the ATV undesired signal. With Narrow-MUSE as an upper adjacent-channel, the amount of interference in the three NTSC receivers varied from no interference in one receiver, gradual impairment with increasing interference in the second receiver, to constant interference in the third receiver.

9.4.2 Transmission Robustness

When exposed to impairments such as random channel noise, multipath or co-channel interference, Narrow-MUSE exhibited gradual or graceful degradation characteristics, similar to NTSC. It performed similarly relative to NTSC for impulsive noise. With the exception of two of the six adjacent-channel interference tests, Narrow-MUSE equalled or exceeded the interference susceptibility (more robust) of NTSC (see Figure 9-1). Narrow-MUSE has better performance for co-channel interference into NTSC than NTSC-into-NTSC. Most of the impairment artifacts were similar to what is generally observed with NTSC.

Narrow-MUSE showed weaknesses: it had a slow channel acquisition time, the adaptive equalizer had a long convergence time, and it occasionally introduced a residual leading ghost when no impairment

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[4] See Section 8.3.1.

was added. It was slightly more susceptible than NTSC to discrete frequency interference into the adjacent-channels.

9.4.2.1 Noise Performance

The performance of Narrow-MUSE when subjected to random channel noise (based on a 6 MHz noise bandwidth) is shown in Figure 9-10. The system exhibits a graceful degradation: impairment rating varies from "imperceptible" to "very annoying" over a range of 31 dB. A mean subjective rating of 4.0 (perceptible, but not annoying) is obtained at a carrier-to-noise ratio (C/N) of 38 dB, and a rating of 3.0 (slightly annoying) is obtained with a C/N of 31.8 dB.[5] Random noise appeared as snow, as in NTSC. Channel noise did not cause motion artifacts.

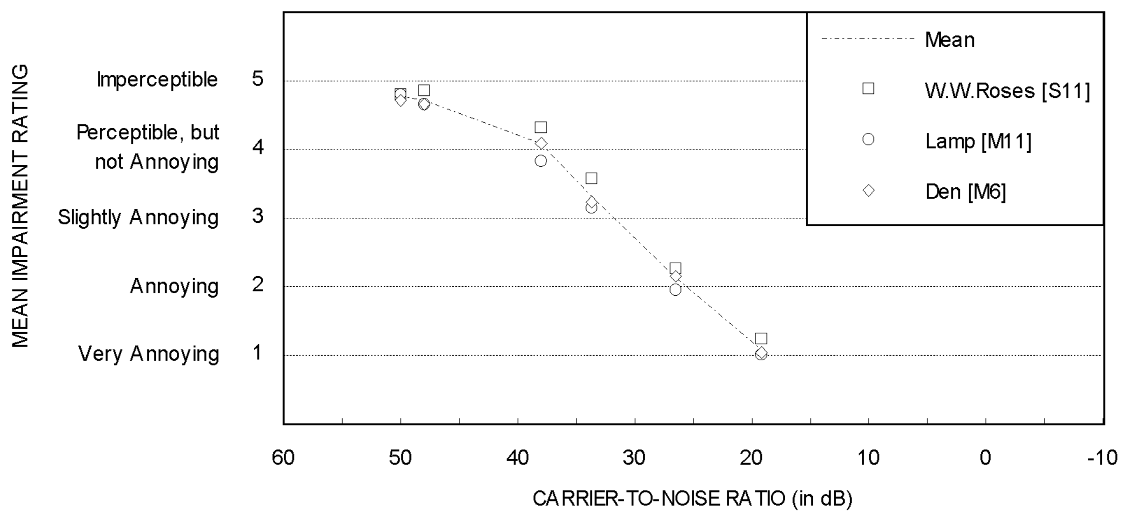

Figure 9-10. The performance of Narrow-MUSE when subjected to random noise.

9.4.2.2 Static Multipath

Ghosts on Narrow-MUSE have a similar appearance as ghosts on NTSC. The adaptive equalizer had a convergence time of the order of 20 seconds. A residual leading ghost was present during this test, even when no impairment was added, due to the particular implementation of the equalizer. The TOV for ghosts of +0.08 µsec and +0.32 µsec were at a D/U around 30 dB (3.3%). The TOV for a ghost of -0.08 µsec could not be measured due to the presence of the residual ghost. The TOV for the +2.56

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[5] Caution must be exercised in comparing C/N between analog and digital systems, as definition of carrier levels is not consistent. Measurement of power level is consistent, however, among digital systems. (See Section 8.3.6.)

µsec ghost could not be found because of the presence of the leading ghost and periodicity in the test picture. Ghost levels for the points of unusability were significantly higher than for the points of acquisition, reflecting a strong hysteresis.

9.4.2.3 Flutter

The TOV for airplane flutter of 2 Hz and 5 Hz were at D/U levels of 40.6 dB (0.93%) and 43.6 dB (0.66%) respectively. These results are substantially lower than for static multipath due presumably to the long convergence time of the equalizer.

9.4.2.4 Impulse Noise

Impulse noise performance appears to be equivalent to NTSC.

9.4.2.5 Discrete Frequency Interference

D/U ratios at the TOV for discrete frequency interference were 24 ± 2 dB in the first upper and lower adjacent-channels, and ranged from 55 dB to 38 dB in-band.

9.4.2.6 Cable Transmission

The subjective tests show that cable transmission per se has no adverse effect on Narrow-MUSE performance; however, the poor adjacent-channel interference performance of the tested receiver is a major concern for cable system adjacent-channel operation. The system performed much better than NTSC with composite triple beat interference. Phase noise and residual FM performance was poor compared to NTSC.

9.4.2.7 Co-Channel Interference into ATV

The Narrow-MUSE spectrum has a notch at frequencies around the NTSC visual carrier, which provides for a better co-channel performance than NTSC-into-NTSC.

The system exhibits a graceful degradation with co-channel interference: impairment ratings vary from “imperceptible” to “very annoying” over a range of 16 dB for NTSC-into-ATV interference (Figure 9-11) and over a range of 17 dB for ATV-into-ATV interference (Figure 9-12). Expert observers described co-channel interference into Narrow-MUSE as a lattice or herringbone pattern. System-specific tests have shown that channel frequency offset has no effect on the co-channel performance of Narrow-MUSE.

9.4.2.8 Co-Channel Interference into NTSC

For co-channel interference into NTSC, impairment ratings vary from “imperceptible” to “very annoying” over a range of 15 dB. See Figure 9-13.

9.4.2.9 Adjacent-Channel Interference

When compared with NTSC interference into NTSC, Narrow-MUSE exhibited poor performance in lower adjacent-channel interference from NTSC and in upper adjacent-channel interference from ATV. Of the six adjacent-channel interference tests, the four tests of interference into ATV exhibit impairment ratings that vary from “imperceptible” to “very annoying” over a range of 7 to 25 dB. The two tests of interference into NTSC exhibit a range of 12 and 13 dB.

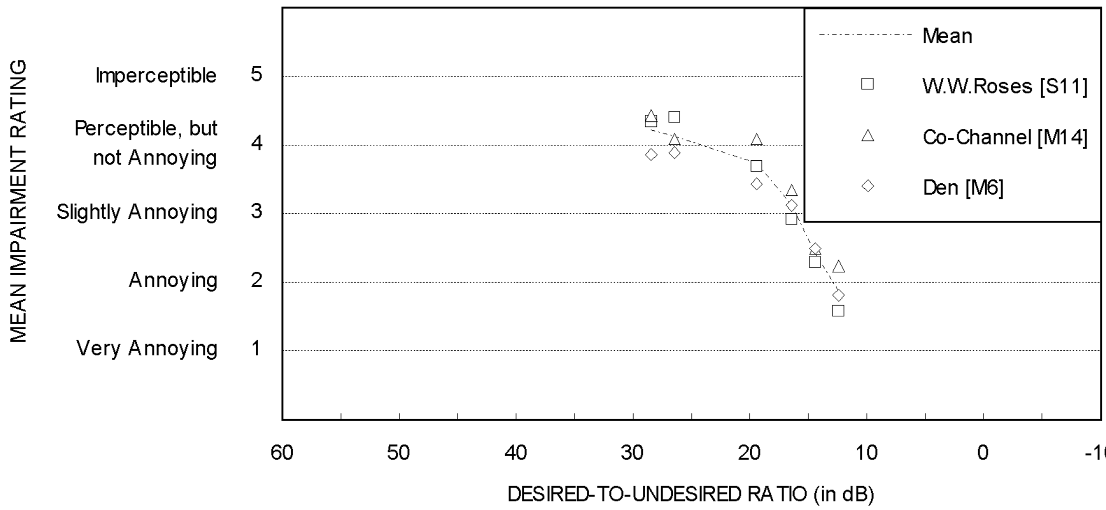

Figure 9-11. The performance of Narrow-MUSE when subjected to NTSC co-channel interference for weak signal condition (-58 dBm).

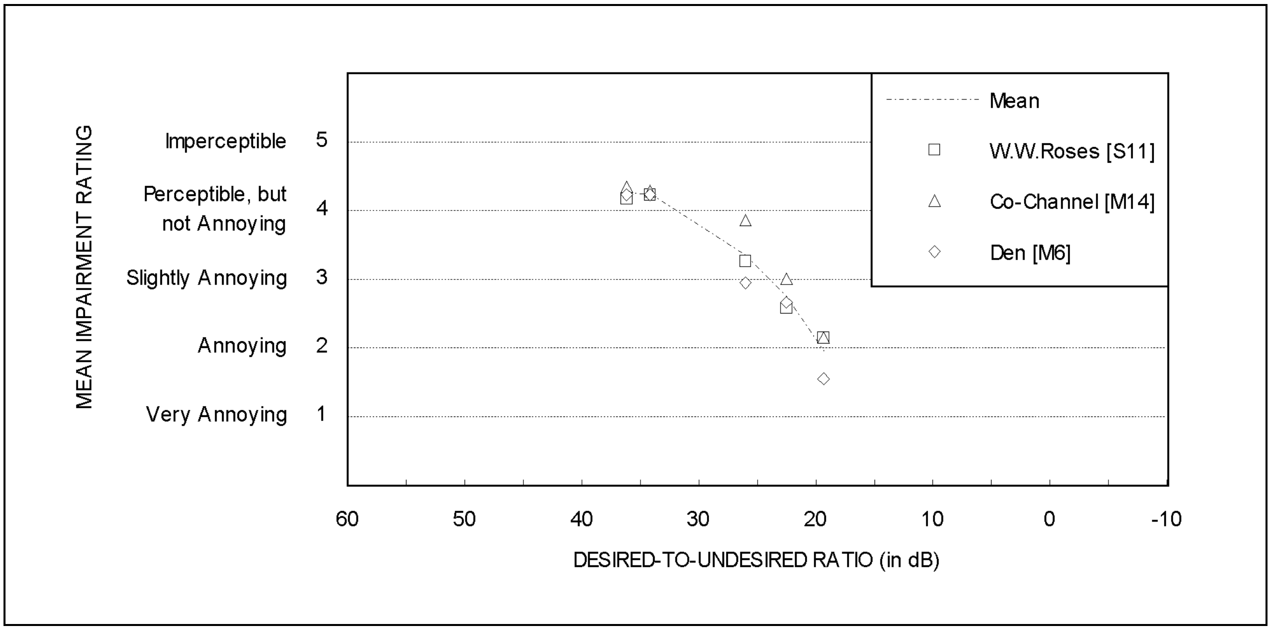

Figure 9-12. The performance of Narrow-MUSE when subjected to ATV co-channel interference for weak signal condition (-58 dBm).

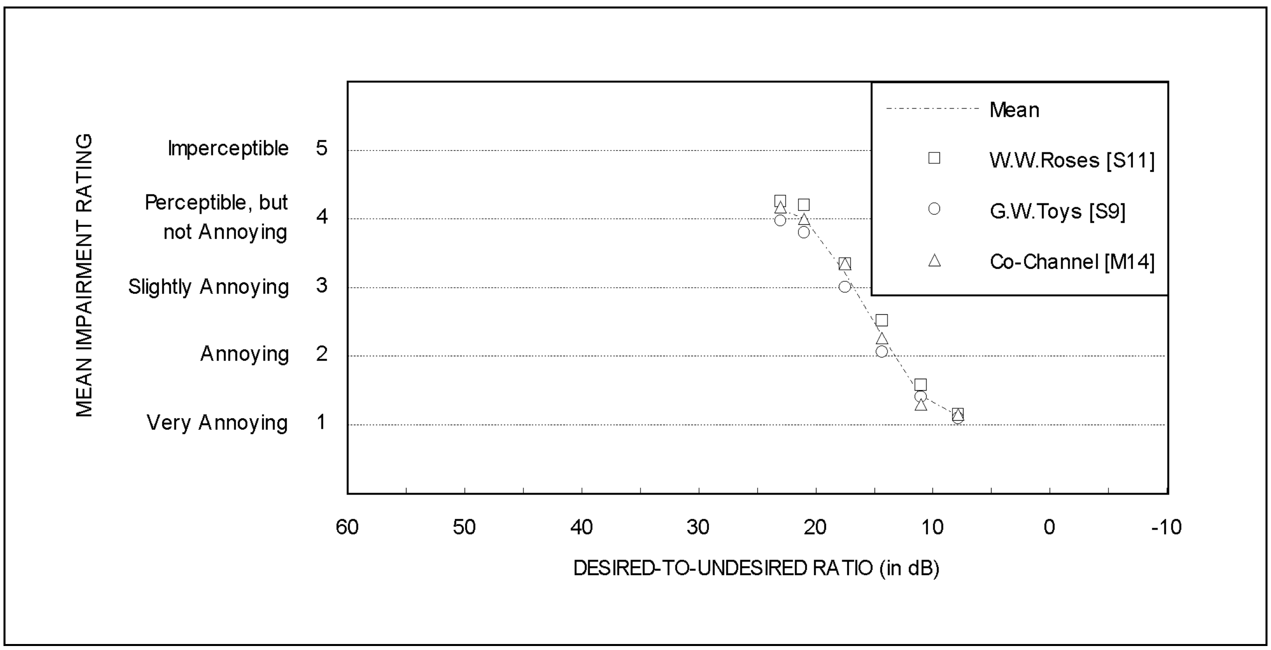

Figure 9-13. Impairment to NTSC when subjected to Narrow-MUSE co-channel interference for weak signal condition (-55 dBm).

9.4.2.10 Taboo Interference

Of the seven taboos tested (n±2, n+4, n-7, n-8, n+14, and n+15), the Narrow-MUSE system is sensitive only to n±2. Under strong desired signal conditions for n±2, the ATV signal must be stronger than the undesired NTSC signal for no detectable interference. A similar situation exists under moderate desired signal conditions for n+2. In the n-2 situation for the moderate desired ATV signal case, the undesired NTSC signal may be no more than 3 dB greater than the ATV signal for no detectable interference. When the ATV signal is weak, the undesired NTSC signal two channels above or below the ATV channel may be no more than 11 to 12 dB greater than the ATV signal for no detectable interference.

The taboo performance of Narrow-MUSE, based only on TOV data, is given in Figure 9-14. Note that the more negative the D/U ratio, the better the performance. The figure provides data reflecting primarily taboo rejection characteristics of the particular tuner supplied for testing.

9.4.2.11 Channel Acquisition

Narrow-MUSE had a channel acquisition time which varied between 5 and 20 seconds, depending on channel conditions.

9.4.3 Scope of Services and Features

9.4.3.1 Data

Narrow-MUSE provides 128 kbits/sec of ancillary data. The interface for the data channel is RS-422. All data services are transmitted using the ancillary data channel.

	ATV-into-NTSC		NTSC-into-ATV		ATV-into-ATV	
CHANNEL	Strong	Weak	Strong	Weak	Strong	Weak
n+2	-8	-32	+2	-10	-1	-15
n-2	<-10*	-32	+1	-12	-14	-25
n+4	<-10*	-27	-19	-31	-18	-33
n+7	**	**	**	**	**	**
n-7	<-10*	<-40*	<-23*	<-43*	<-23*	<-43*
n+8	**	**	**	**	**	**
n-8	<-10*	<-40*	<-23*	<-43*	<-23*	<-43*
n+14	<-10*	<-40*	<-23*	<-43*	<-23*	<-43*
n+15	<-10*	<-28*	<-23*	<-43*	<-23*	<-43*

* Determination of TOV level was beyond the limits of ATTC's RF test bed range. Consequently, the system performance was better than the indicated result.

** Test not performed.

Figure 9-14. Taboo threshold of visibility for Narrow-MUSE (D/U in dB).

9.4.3.2 Encryption

The system submitted for testing did not include encryption. The proponent suggests a combination of line rotation and line permutation for signal security for which decoder chips are already developed.

9.4.3.3 Addressing

The addressing information is transmitted through the ancillary data channel.

9.4.3.4 VCR Capability

The proponent claims that a digitized Narrow-MUSE signal with an 80-Mbits/sec data rate or a DPCM-encoded Narrow-MUSE signal with a 40-Mbits/sec data rate can be digitally recorded on a 1/2 inch cassette VCR.

The proponent claims that the quality of a rapid search picture will be comparable to that of a 4-head VHS machine. Only sync blocks whose ID signals are detected correctly are used for fast forward and reverse. Sync blocks whose ID signals are not detected correctly are replaced with interpolated information. These functions can be achieved based on the four-field sequence of the Narrow-MUSE algorithm. Editing functions can be implemented by adjusting the subsampling phases between the materials to be edited using the subsampling phase information which is transmitted as a part of the control signal. Special effects are not done with the Narrow-MUSE signal.

9.4.4 Extensibility

9.4.4.1 To No Visible Artifacts

MUSE-T, a higher member of the MUSE family claimed to provide a picture with no visible artifacts, has a bandwidth of 16.2 MHz and employs only intrafield subsampling. A digitized MUSE-T can be further compressed using DPCM. The main part of a Narrow-MUSE receiver can be shared for MUSE-T decoding when MUSE-T is transmitted through alternate media such as DBS.

9.4.4.2 To Studio Quality Data Rate

It is possible to extend Narrow-MUSE to 240M by transmitting the difference between the locally decoded Narrow-MUSE and 240M signals through an additional channel as augmentation information. The bandwidth of the studio-quality signal is 60 MHz (30 MHz for luminance signal and 15 MHz for each color-difference signal).

9.4.4.3 To Higher Resolution

The proponent suggests that it is possible to extend Narrow-MUSE to VHDTV and UHDTV by transmitting the difference between the locally decoded Narrow-MUSE and VHDTV/UHDTV through an additional channel as an augmentation signal.

9.4.4.4 Provision for Future Compression Enhancement

The proponent claims that the dynamic resolution can be improved by increasing the number of motion vectors. The additional motion vectors can be transmitted through the data channel at the expense of data for other purposes.

9.4.5 Interoperability Considerations

9.4.5.1 With Cable Television

Information on the performance of Narrow-MUSE over cable can be found in Section 9.4.2.6.

9.4.5.2 With Digital Technology

While the transmitted signal is analog, all of the signal processing in the encoder, modulator, demodulator, and decoder is performed in the digital domain. A digital interface port is provided in the receiver for the digitized transmitted signal.

9.4.5.3 Headers/Descriptors

The proponent states that headers/descriptors could be assigned into the ancillary data channel of Narrow-MUSE.

9.4.5.4 With NTSC

There are two conversion methods from Narrow-MUSE to NTSC — from the 750-line transmission format and from the 1125-line display format. The conversion from the transmission format requires only vertical interpolation because Narrow-MUSE employs an analog transmission technique. The conversion from 1125/60 also would require horizontal interpolation. In both conversions, field-rate conversion from 60.00 Hz to 59.94 Hz is required. The proponent claims that a motion-adaptive field-rate converter is available and is used for the daily simulcast operation in Japan. A frame skip must take place every 33 seconds, because of the 1001/1000 frame conversion. The hardware attempts to perform this cut on a motionless picture or on a scene change. The proponent also claims that a converter from MUSE-E to home display is sold on the market, and that the same technique can be applied to Narrow-MUSE.

9.4.5.5 With Film

This system does not have a film mode within its encoding algorithm. Since the field rate of this system is 60 Hz, the temporal conversion from film to HDTV is accurate. Use of 24 fps film still requires 3:2 pull-down. A motion-compensated continuous-film-transfer telecine is already available for this system.

9.4.5.6 With Computers

Progressive scanning and square pixels, not included in the Narrow-MUSE system tested, are important factors for interoperability of an HDTV system with computers. The shape of the displayed Narrow-MUSE pixel format of 1440 (H) x 1035 (V) is 1:0.78. The proponent claims that the field rate of 60.00

Hz is a better selection than 59.94 Hz for interoperability with computers that have integer field rates such as 72 Hz.

9.4.5.7 With Satellites

This system can be transmitted through a satellite using FM with an RF channel bandwidth of approximately 15 MHz. FM transmission of MUSE-E through a satellite is a proven technology. The proponent claims that Narrow-MUSE also can be transmitted through a satellite using digital transmission. The Narrow-MUSE signal can be encoded by DPCM to a data rate of approximately 40 Mbits/sec which includes error correction of 8%. Satellite links typically use more error correction than this, e.g., 14% to 50%. The RF channel bandwidth with QPSK is approximately 24 MHz. Digital transmission of MUSE-E in conjunction with DPCM is also a proven technology.

9.4.5.8 With Packet Networks

Packetizing is not practical because this system employs analog transmission.

9.4.5.9 With Interactive Systems

According to the proponent, the total delay for Narrow-MUSE through an encoder and a decoder is 6 fields (approximately 100 msec), 3 fields for each. Acquisition time is reported in Section 9.4.2.11.

9.4.5.10 Format Conversion

9.4.5.10.1 With 1125/60

No vertical or temporal format conversion is required because this system uses 1125/60 format. The decoded Narrow-MUSE signal can be converted to the Common Image Format (1920 x 1080) through a vertical and horizontal sample rate conversion. These are 24:23 vertically and 4:3 horizontally (based on the displayed format).

9.4.5.10.2 With 1250/50

This difficult conversion is easier than for systems using 59.94 Hz field/frame rates because its field rate is exactly 60.00 Hz. The vertical interpolation ratio from 1125 to 1250 is 9:10.

9.4.5.10.3 With MPEG[6]

Narrow-MUSE does not have interoperability with MPEG.

9.4.5.10.4 With Still Image

The Narrow-MUSE transmission format does not have compatibility with JPEG, Photo CD, or CD-I. An 1125/60 still image disk system based on the JPEG algorithm has been developed and

[6] See Section 8.3.8 for a discussion of MPEG, the MPEG-1 standard, and the MPEG-2 development effort.

demonstrated. The system uses multiple disks, with video, audio, and control data recorded on separate disks.

9.4.5.11 Scalability

This system uses a multiple sub-sampling technique with a four-field sequence. Therefore, the spatial resolution of the reconstructed picture can be controlled by selecting fields to be used for the interpolation. When all four fields are used, a full-quality picture is obtained. When one of every four fields is used, a picture with reduced resolution can be obtained by interpolation. Also, a picture with reduced size can be obtained by using only a selected field. The proponent claims that the MUSE family is based on the concept of scalability. The MUSE family consists of MUSE-T, MUSE-E (full-band MUSE), Narrow-MUSE, and NTSC MUSE-4, all based on the same coding algorithm. All these systems have been demonstrated.

For display on a computer, pictures reduced by $1/2^n$ can be made with only intrafield information. Other ratios require more processing. Since this system uses a multiple sub-sampling technique with a four-field sequence, the temporal resolution of the reconstructed picture can be controlled by selecting fields to be used for the interpolation. When all four fields are used, full temporal resolution, 1/60 sec, is obtained. To reduce the amount of data, the field repetition rate can be reduced for pictures with less temporal resolution. The multiple sub-sampling technique makes possible two types of receivers differing in complexity. A simple receiver can be built that handles only intrafield interpolation, while the full-capability receiver handles both intrafield and interfield interpolation.

The low-frequency component below 2 MHz of the Narrow-MUSE signal does not contain the aliasing component caused by frame offset sub-sampling. Therefore, a picture whose quality is equivalent to NTSC can be reproduced by using only this low-frequency component. Picture-in-picture, picture-out-of-picture, and multiple programs can be accommodated using only the intrafield information from the Narrow-MUSE signal. A frame store in the receiver can be used for this purpose.

9.5 SYSTEM IMPROVEMENTS

9.5.1 Already Implemented

9.5.1.1 Modified PLL/AGC Circuit

The PLL/AGC circuit in the Narrow-MUSE receiver has been modified to improve lower adjacent-channel NTSC-into-ATV interference and upper adjacent-channel ATV-into-ATV interference. The input signal to the PLL and AGC circuits, which was originally connected to the output of the IF filter, has been connected to the output of the band-pass filter that is cascaded with the IF filter and used for sync separation. In addition, the width of the sampling pulse in the AGC circuit has been modified to maximize the aperture effect.

9.5.1.2 Corrected ROM's for Digital Roll-Off Filter

The wrong set of ROM's, which was installed in the tested receiver accidentally, has been replaced with the correct set of ROM's. The purpose of this modification was to improve upper adjacent-channel ATV-into-ATV interference.

9.5.1.3 Modified Ghost Canceling Algorithm and Added Channel Memories

The ghost canceling algorithm has been modified to reduce the residual ghost and the convergence time. Parameters, such as the threshold values that decide whether the ghost canceling operation is activated and evaluate the status of convergence, have been modified. Also the integration loop for the received training signal has been modified to improve the SN ratio. These modifications are software changes.

Channel memories have been added to reduce convergence time. The values of the tap coefficients are stored after convergence.

9.5.1.4 Modified Clock Timing and Control Pulse Timing

The purpose of these modifications was to eliminate artifacts that were observed on the screen but had nothing to do with the compression algorithm. These artifacts consisted of white sparkles and a black and white area at the left side of the screen.

9.5.1.5 Adjusted RF/IF Amplifiers and Frequency Converter Circuit

To improve taboo performance, the RF/IF amplifiers and the frequency converter have been adjusted to improve linearity.

9.5.1.6 Fixed ALC Circuit

To reduce channel acquisition time, the reset value of the up-down counter in the ALC circuit, which was accidentally set to its maximum value, has been set to the center value.

9.5.1.7 ATSC T3/186 Functionality

Audio/data channels, with 1.184 Mbits/sec packetized transmission capability, were installed in the Narrow-MUSE hardware delivered to ATTC. The 1.184 Mbits/sec data are forward error protected. The proponent believes the data capacity is large enough to support the various services described in ATSC T3/186.

The proponent does not have a specific proposal for the five-channel audio at this moment and is waiting for the results of the CCIR or ISO-MPEG work. The proponent also is ready to accept a five-channel audio system standardized by other appropriate standardization bodies. Therefore, the five-channel audio capability will not be incorporated in the Narrow-MUSE hardware before field testing.

9.5.2 Implemented in Time for Field Testing

No improvements were proposed for this category.

10. DIGICIPHER

10.1 SYSTEM OVERVIEW

DigiCipher, proposed by the American Television Alliance (General Instrument Corporation and the Massachusetts Institute of Technology) is a digital simulcast system that requires a single 6 MHz television transmission channel. The DigiCipher video source is an analog RGB signal with 1050 lines, 2:1 interlaced, a 59.94 Hz field rate, and an aspect ratio of 16:9. The video sampling frequency is 53.65 MHz. The image in a single frame consists of 960 lines of 1408 pixels. Chrominance information is subsampled horizontally by a factor of 4, and vertically by a factor of 2 by discarding every second field. The system uses motion compensated predictive coding with a Discrete Cosine Transform (DCT) and Huffman coding. The video encoder uses four independent coders, each working on one-fourth of the image (full height and one-fourth width). The system features adaptive field/frame coding and progressive PCM refresh with the one-fourth width panels moving continuously to the left. Two transmission modes are supported: 32 QAM, the primary transmission mode, and 16 QAM, both with a symbol rate of 4.88 M-symbols per second. The 32 QAM primary mode has a video data rate of 17.47 Mbits/sec and a total transmission rate of 24.39 Mbits/sec. Concatenated trellis coding, Reed-Solomon block coding, and adaptive equalization are used to protect against channel errors. The DigiCipher system provides 4 digital audio channels using Dolby Laboratories AC-2 compression system. The audio is sampled at 48 kHz with 16-bit precision. The compressed audio rate is 252 kbits/sec per pair of channels. The system also provides 126 kbits/sec of data capacity and 126 kbits/sec for control such as subscriber addressing.

10.2 SPECTRUM UTILIZATION

The DigiCipher analysis was conducted under two allotment scenarios (using both VHF and UHF channels for ATV stations, and using only UHF channels) and two sets of interference constraints (considering only co-channel interference, and both co-channel and adjacent-channel interference). In addition, the impact of taboos was assessed by re-calculating coverage and interference for each case assuming the taboo performance measured in the laboratory.

Figure 10-1 shows planning factors, specific to the DigiCipher system, as derived from test results. The numbers in the figure are desired-to-undesired ratios (D/U) in dB. The values for interference into NTSC are based on CCIR Impairment Grade 3 (slightly annoying) as determined from the ATEL subjective tests. Because the ATV service is intended to be an improvement over NTSC, interference into ATV is based on CCIR Impairment Grade 4 (perceptible but not annoying) if the range between the threshold of visibility (TOV) and the point of acquisition (POA) exceeds 5 dB. Otherwise, the TOV power level is used. DigiCipher demonstrated a “cliff effect” and thus D/U values are based on TOV data. Also, the data show that DigiCipher can support collocation on both the upper and lower adjacent-channels.

Co-Channel	D/U (dB)
ATV-into-NTSC	+35
NTSC-into-ATV	+7.6
ATV-into-ATV	+16.4

Carrier-to-Noise	+16.0

Adjacent-Channel	D/U (dB)
Lower ATV-into-NTSC	-13.5
Upper ATV-into-NTSC	-21
Lower NTSC-into-ATV	-30
Upper NTSC-into-ATV	-24
Lower ATV-into-ATV	-23
Upper ATV-into-ATV	-23

Figure 10-1. Planning factors specific to DigiCipher.

10.2.1 Accommodation Percentage

DigiCipher could provide a 100% accommodation of all NTSC assignments for co-channel only, and co-channel and adjacent-channel constraints, under both the VHF/UHF and UHF scenarios. The accommodation is achieved at the expense of reducing the ATV and NTSC service areas. No attempt was made to reduce interference to NTSC service by adjusting either ATV or NTSC power.

10.2.2 Service Area

Figure 10-2 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 both co-channel and adjacent-channel constraints. In this graph, the 1,657 current NTSC stations are placed in order of decreasing ATV to NTSC service area ratio. Examination of the graph reveals that 8.1% (135) of the ATV stations under this scenario would have an ATV service area at least 20% larger than their companion NTSC service area and 94% (1,559) 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 38.4 million square kilometers.

Figure 10-3 shows the interference statistics for the VHF/UHF scenario. During the transition period, 42.4% of ATV stations would receive no interference. This would rise to 60.2% after the transition period ends. Also during the transition period, 4.2% of the ATV stations would receive interference in more than 35% of their noise-limited coverage area. This would fall to 1.8% after the transition period ends. The total interference area created within the ATV noise-limited coverage area during the transition period is 3.80 million square kilometers. This would decrease to 1.96 million square kilometers after the transition period ends. Of the existing NTSC stations, 60.1% would not receive any new interference because of the ATV service, while 2.1% would receive new interference in more than 35% of their Grade B area. The total new interference into NTSC created under this plan is 1.41 million square kilometers.

When taboos are included in the interference calculations for the VHF/UHF scenario, the number of ATV stations with no interference during the transition period is 34.0%; the number of ATV stations with interference in more than 35% of their noise-limited coverage area is 4.8%. The number of NTSC stations receiving no new interference is 54.4%; the number of NTSC stations with interference in more than 35% of their Grade B area is 2.3%.

When the adjacent-channel constraints of Figure 10-1 are not included in the VHF/UHF scenario, the allotment/assignment table is different. In that case, 15.6% (259) of the ATV stations would have an ATV service area at least 20% larger than their companion NTSC service area and 98% (1,629) would have an ATV service area at least 80% of their companion NTSC service area. During the transition period, 71.9% of ATV stations would receive no interference. This would rise to 85.5% after the transition period ends. Also during the transition period, 1.1% of the ATV stations would receive interference in more than 35% of their noise-limited coverage area. This would fall to 0.5% after the transition period ends. Of the existing NTSC stations, 64.2% would not receive any new interference because of the ATV service, while 2.0% would receive new interference in more than 35% of their Grade B area.

Figure 10-4 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 UHF scenario, taking into account both co-channel and adjacent-channel constraints. In this graph, as before, the 1,657 current NTSC stations are placed in order of decreasing ATV to NTSC service area ratio. Examination of the graph reveals that 8.5% (141) of the ATV stations under this scenario would have an ATV service area at least 20% larger than their companion NTSC service area and 92% (1,528) 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 38.5 million square kilometers.

Figure 10-5 shows the interference statistics for the UHF scenario. During the transition period, 45.7% of ATV stations would receive no interference. This would rise to 60.3% after the transition period ends. Also during the transition period, 4.6% of the ATV stations would receive interference in more than 35% of their noise-limited coverage area. This would fall to 3.0% after the transition period ends. The total interference area created within the ATV noise-limited coverage area during the transition period is 3.71 million square kilometers. This would decrease to 2.13 million square kilometers after the transition period ends. Of the existing NTSC stations, 62.9% would not receive any new interference because of the ATV service, while 7.6% would receive new interference in more than 35% of their Grade B coverage area. The total new interference created under this plan is 2.12 million square kilometers.

When taboos are included in the interference calculations for the UHF scenario, the number of ATV stations with no interference during the transition period is 36.7%; the number of ATV stations with interference in more than 35% of their noise-limited coverage area is 6.1%. The number of NTSC stations receiving no new interference is 58.5%; the number of NTSC stations with interference in more than 35% of their Grade B area is 7.6%.

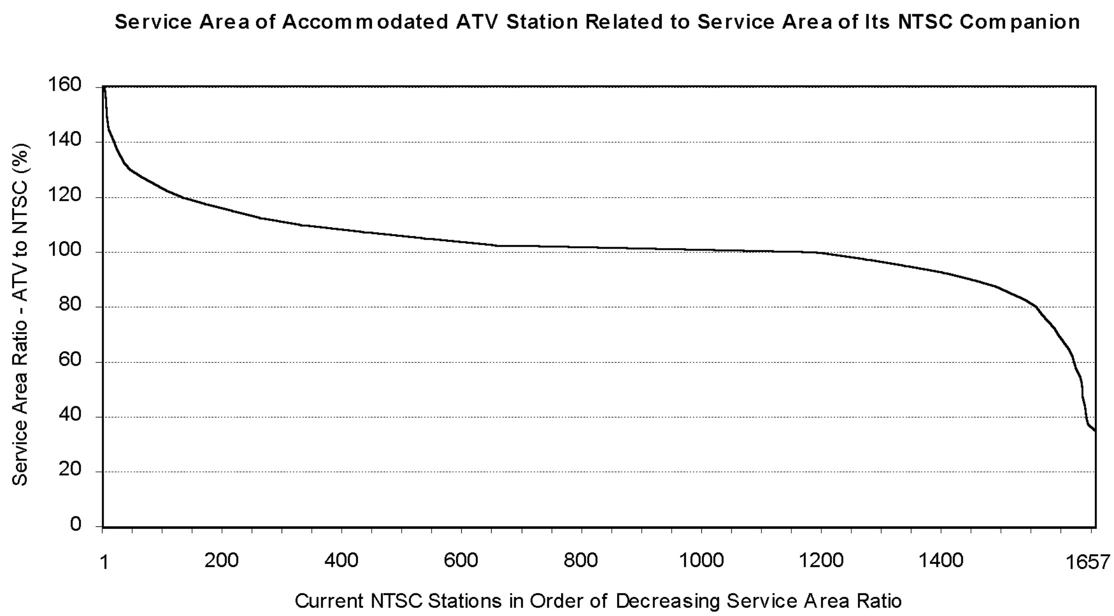

Figure 10-2. DigiCipher VHF/UHF Scenario — Interference-limited service area of each ATV station relative to the interference-limited service area of its companion NTSC station (co-channel and adjacent-channel constraints).

Interference Area Compared to Coverage Area	ATV Stations with Interference		NTSC Stations with Added Interference Due to ATV
	During Transition	After Transition	
No Interference	42.4 %	60.2 %	60.1 %
0 - 5 %	17.0 %	17.7 %	15.9 %
5 - 10 %	12.1 %	9.0 %	8.5 %
10 - 15 %	10.0 %	5.8 %	5.5 %
15 - 20 %	6.5 %	2.7 %	4.0 %
20 - 25 %	3.7 %	1.4 %	1.8 %
25 - 30 %	2.2 %	0.5 %	1.4 %
30 - 35 %	1.9 %	0.8 %	0.7 %
> 35 %	4.2 %	1.8 %	2.1 %

Figure 10-3. DigiCipher VHF/UHF Scenario — Interference characteristics (co-channel and adjacent-channel constraints).

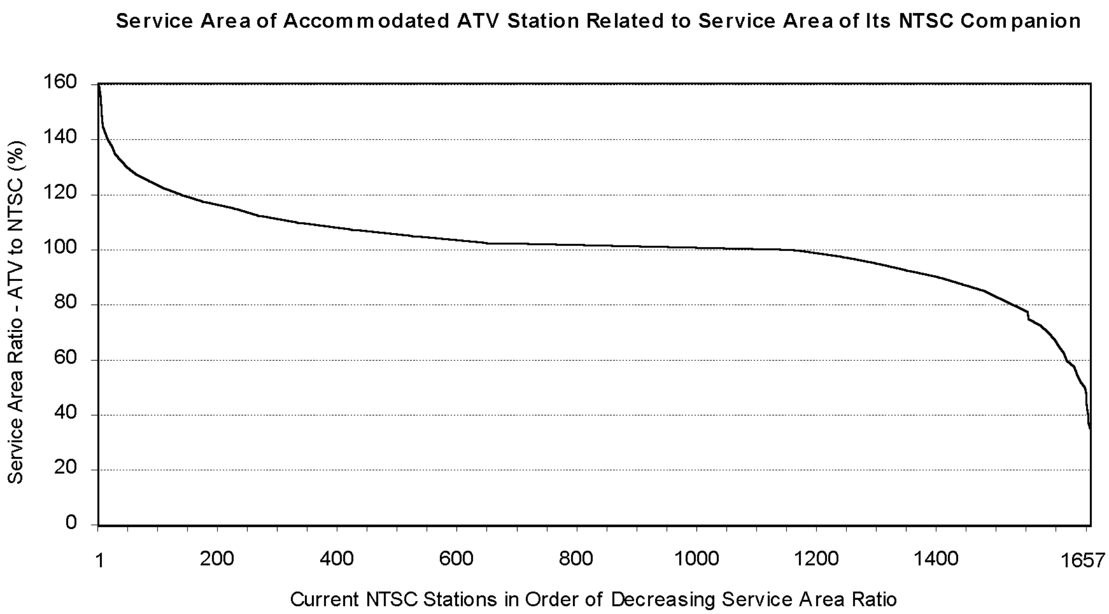

Figure 10-4. DigiCipher UHF Scenario — Interference-limited service area of each ATV station relative to the interference-limited service area of its companion NTSC station (co-channel and adjacent-channel constraints).

Interference Area Compared to Coverage Area	ATV Stations with Interference		NTSC Stations with Added Interference Due to ATV
	During Transition	After Transition	
No Interference	45.7 %	60.3 %	62.9 %
0 - 5 %	13.5 %	14.5 %	8.4 %
5 - 10 %	10.0 %	8.0 %	6.3 %
10 - 15 %	7.8 %	6.3 %	3.9 %
15 - 20 %	6.8 %	3.7 %	3.3 %
20 - 25 %	5.2 %	1.5 %	3.0 %
25 - 30 %	3.1 %	1.4 %	2.5 %
30 - 35 %	3.2 %	1.4 %	2.0 %
> 35 %	4.6 %	3.0 %	7.6 %

Figure 10-5. DigiCipher UHF Scenario — Interference characteristics (co-channel and adjacent-channel constraints).

When the adjacent-channel constraints of Figure 10-1 are not included in the UHF scenario, the allotment/assignment table is different. In that case, 12.7% (210) of the ATV stations would have an ATV service area at least 20% larger than their companion NTSC service area and 96% (1,587) would have an ATV service area at least 80% of their companion NTSC service area. During the transition period, 59.2% of ATV stations would receive no interference. This would rise to 75.3% after the transition period ends. Also during the transition period, 2.2% of the ATV stations would receive interference in more than 35% of their noise-limited coverage area. This would fall to 1.9% after the transition period ends. Of the existing NTSC stations, 64.8% would not receive any new interference because of the ATV service, while 7.1% would receive new interference in more than 35% of their Grade B area.

The frequency distribution of ATV station average effective radiated power levels needed to achieve ATV noise-limited coverage comparable to NTSC Grade B coverage was calculated. The maximum average effective radiated power level was 38.23 dBk (6,650 kW). The results are shown in Figure 10-6.

Average Effective Radiated Power Level		Number of TV Stations			
		VHF/UHF Scenario			UHF Scenario
(dBk)	(kW)	Low VHF	High VHF	UHF	UHF
Less than 5	Less than 3.2	12	24	100	100
5 - 10	3.2 - 10.0	3	8	47	48
10 - 15	10.0 - 31.6	2	11	129	138
15 - 20	31.6 - 100		4	251	258
20 - 25	100 - 316			288	302
25 - 30	316 - 1,000			240	254
30 - 35	1,000 - 3,160			317	327
35 - 40	3,160 - 10,000			221	230
> 40	> 10,000				
TOTAL		17	47	1,593	1,657

Figure 10-6. DigiCipher power level distribution.

Certain analyses also were performed for the 16 QAM Alternate Mode. In general, the ATV service area is slightly greater and interference is less for both ATV and NTSC. The results are shown in the PS/WP3 final report.

10.3 ECONOMICS

10.3.1 Cost to Broadcasters

The estimated equipment cost for a DigiCipher transitional station is shown in Figure 10-7. The total cost of the transitional station was estimated to be $1,700,500. The total cost of a minimal station was estimated to be $1,104,100. A general description of the methods used to develop the cost data is contained in Section 8.2.1.

Subsystem	Cost (thousands)
Satellite Receiver, Demodulator, Decoder	$ 13.5
Character Generator, Still Store, Two 28” Monitors	200.0
Routing Switcher (10 x 10), Master Control	125.0
2 ATV VTRs and Monitors	170.0
NTSC Upconverter, including Line Doubler	19.0
ATV-to-NTSC Downconverter	15.0
34” Monitor, Seven 17” Monitors, Eight Decoders	110.0
ATV Encoder	200.0
STL Subsystem	92.5
ATV Modulator, ATV Exciter	30.0
ATV Transmission Subsystem	725.5
TOTAL COST	$1,700.5

Figure 10-7. Equipment cost for a DigiCipher transitional station.

10.3.2 Cost to Alternative Media

Information on this topic was not provided.

10.3.3 Cost to Consumers

The estimated material cost data for a DigiCipher receiver are shown in Figure 10-8. A general description of the methods used to develop the cost data is contained in Section 8.2.2.

Using a 2.5 multiplier, the resulting estimated retail price for a DigiCipher receiver is $2,445 for a 34” direct view receiver and $3,735 for a 56” projector receiver.

Subsystem	34” Widescreen Direct View Receiver	56” Widescreen CRT Type Projector
Signal Processing Components	$ 98	$ 98
Audio Amplifiers, Speakers	30	30
Scan System, Power Supply, Video Amps	60	176
Display	700	1,050
Cabinet	90	140
TOTAL MATERIAL COST	$ 978	$1,494

Figure 10-8. Material cost data for a DigiCipher receiver.

10.4 TECHNOLOGY

10.4.1 Audio/Video Quality

In video subjective tests of DigiCipher, the system performed consistently across segments of test material with no difference between still and moving materials. For 8 of the 9 stills and 14 motion sequences, DigiCipher was judged, on average, to be about 0.3 grade lower in quality than the 1125-line studio reference. The remaining still, electronically generated, was judged to be better in quality than the reference.[1]

No significant problems were noted when the system was subjected to noisy source material, scene cuts, two encode/decode operations, or a sudden stop in motion. Slight deficiencies were noted when the system was tested for video coder or motion-compensation overload. Some weaknesses in resolution and dynamic range were noted in the blue channel.

Certain tests also were performed for the 16 QAM Alternate Mode. The 16 QAM mode exhibited a greater reduction in quality than the 32 QAM mode for most segments of test material, an observation confirmed by expert commentary.

There was no evidence that the audio system failed before the accompanying video.

10.4.1.1 Video Quality

Subjective judgments of image quality by non-experts are summarized in Figure 10-9. Scores are the differences between judgments of the reference and judgments of DigiCipher for 9 stills and 14 motion sequences. For 8 of the 9 stills, DigiCipher was judged, on average, to be 0.3 grade (i.e., about 6 points on the 100-point scale) lower in quality than the 1125-line studio reference; for the remaining still (S14), the system was judged to be 0.6 grade higher in quality than the reference (this may reflect reduced visibility of interlacing artifacts in the DigiCipher rendering of this picture). For motion sequences, DigiCipher also was judged, on average, to be 0.3 grade (i.e., about 6 points) lower in quality than the reference.

DigiCipher performed consistently across all segments of test material. Differences ranged from -0.1 to -0.6 grade (not counting S14). The variability among viewers was consistent across materials and within accepted limits. Expert commentary, supported by reports from the non-expert viewers, attributed the small differences between DigiCipher and the reference primarily to quantization noise (visible in flat areas, as well as at edges and in areas of high detail) and to reduced resolution (especially in colored areas). It is expected, however, that “busy-ness” in areas of high detail (i.e., time-varying noise correlated with image content) and artifacts of periodic PCM updating also may have contributed, but to a lesser extent.

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[1] See Section 8.3.3.

Consistent performance for stills and motion sequences is supported by objective tests of static and dynamic resolution. For luminance resolution, tests show retention of static-level resolution at all but the highest rate of movement. For chrominance resolution, the results were similar; however, lower horizontal and diagonal resolution were noted for the blue channel.[2]

When subjected to noisy source material, DigiCipher introduced an increase in visible noise at the output and, for critical sequences, a slight increase in “busy-ness”.

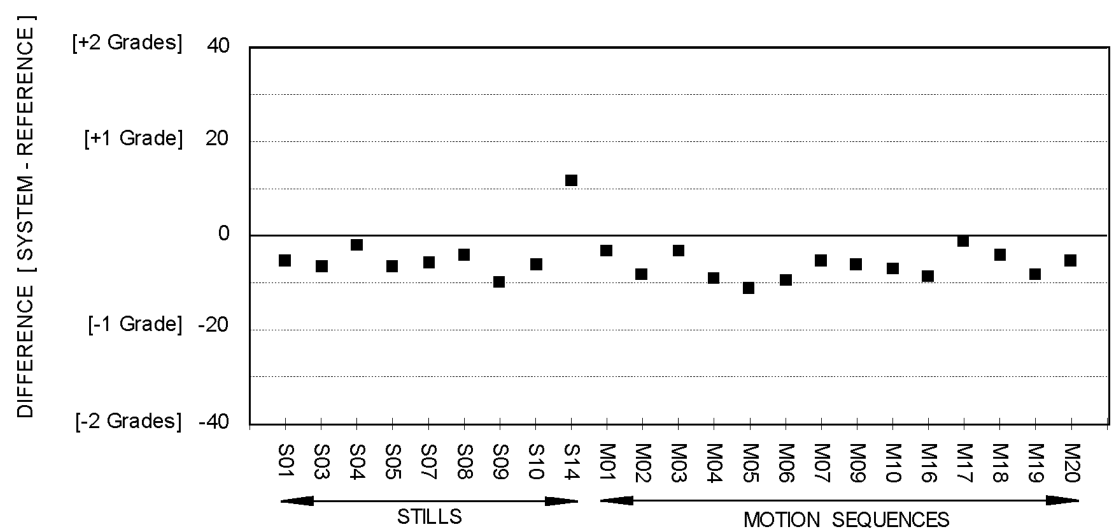

Figure 10-9. Average differences between quality judgments for the 1125-line studio quality reference and for DigiCipher.

When subjected to scene cuts and viewed in real time, DigiCipher introduced no artifacts that were visible in flat fields or in motion sequences, but did introduce artifacts that were visible in highly detailed stills. Examination of freeze frames showed “build up” in resolution following cuts to highly detailed stills with resolution restored almost fully by the second frame and restored fully by the third frame (1/10 second).

Slight system artifacts became visible when material was subjected to two encode/decode passes through the system. During the first pass, DigiCipher introduced a barely perceptible loss in resolution and increase in quantization noise. During the second pass, these artifacts increased slightly and a barely perceptible loss in color was introduced.

[2] See Section 8.3.5.

The DigiCipher system exhibited good chrominance dynamic range in the red and green channels, but performance was not as good in the blue channel.

When tested for video-coder overload, DigiCipher exhibited no significant failures, but did introduce some quantization noise as well as some “blockiness” and “mottling.” When tested for motion-compensation overload with velocities of up to 0.44 picture height per second (the limit of the test software), the system introduced slight quantization noise and occasional “blockiness”; further, the character of the quantization noise changed with velocity of movement, first becoming patterned (i.e., coherent), and then stationary. No artifacts were noted in response to a sudden stop in movement.

The difference in unimpaired video quality between 16 QAM and 32 QAM was evident to both expert and non-expert observers; the performance difference in motion sequences was clearly evident. In video subjective tests of image quality by non-experts, 16 QAM DigiCipher was judged, on average, to be about 0.7 grade lower in quality for stills and 0.9 grade lower in quality for motion sequences than the reference.[3] For the challenging video sequences documented in this report, the experts were almost always able to recognize whether the viewed image was from reference, 32 QAM, or 16 QAM material. The quality of the 32 QAM images was, in general, close to, but distinguishable from, the reference material. Except for the least challenging video sequences, quantization noise was always apparent for 16 QAM coding. Expert commentary noted increased “busy-ness” and more frequent “blockiness” in response to noise in the video source, slower (i.e., 5 frames) recovery of resolution following a scene cut to a highly detailed still, and more visible artifacts in tests of video-coder and motion-compensation overload.

10.4.1.2 Audio Quality

There was no evidence that the audio system failed before the accompanying video.[4]

Objective tests were preformed for dynamic range, total harmonic distortion (THD), THD+noise (THD+N), intermodulation distortion (IMD), dynamic intermodulation distortion (DIM), frequency response, and overload vs. frequency. The dynamic range for the DigiCipher system was found to be 81 dB. With one exception, THD remained below 0.1% for both channels over a tested frequency range of 20 Hz to 8 kHz. The exception was at 4 kHz on channel 2, with input of 0.1232 volts rms, where the THD rose to 0.121%. For high level signals, THD+N was 0.1% or less for frequencies above 300 Hz, and less than 0.2% for lower frequencies to 20 Hz. IMD was less than 0.02% in both channels. Frequency response was extremely flat over the entire range from 20 Hz to 20 kHz for both channels. Frequency response remained within 0.1 dB to approximately 10 kHZ and was approximately 0.3 at 20 kHz.

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[3] For the electronically generated still (S14), 16 QAM DigiCipher was judged better than the reference. The average difference reported here does not include this value.

[4] See Section 8.3.1.

Under weak signal conditions, at levels of ATV-into-NTSC adjacent-channel interference which would cause “slightly annoying” video degradation, BTSC audio distortion begins to become significant. In the test of co-channel ATV-into-NTSC, DigiCipher caused no significant degradation of NTSC VBI data.

10.4.2 Transmission Robustness

Generally, DigiCipher performed as predicted by the proponent. Its performance equalled or exceeded that of NTSC in almost all impairment conditions. Typically, the system exhibited apparent immunity to a variety of transmission impairments over a wide range of impairment levels. Beyond that range, the system exhibited a sharp degradation characteristic. All transmission impairments into DigiCipher had similar manifestations in the observed video and were quite different from their effects on NTSC. Transmission impairments and interference, when strong enough, produced display errors which caused randomly spaced rectangular patches of images to freeze, or to display erroneous information, for a short time. Recovery from loss of signal was through a right to left wipe pattern in each of four vertical panels.

DigiCipher interference into NTSC had the characteristic of white noise and produced a graceful degradation. Cable transmission caused no adverse effect on DigiCipher performance.

10.4.2.1 Noise Performance

When DigiCipher was subjected to random channel noise (based on a 6 MHz noise bandwidth), the carrier-to-noise ratio[5] (C/N) at the TOV was measured and is shown in Figure 10-1. The system had a sharp degradation — the range between TOV and the point of unusability (POU) was 0.5 dB. The carrier-to-noise ratio at the TOV was measured for the 16 QAM Alternate Mode also and found to be 12 dB.

10.4.2.2 Static Multipath

The system performed well at levels that would be highly objectionable in NTSC. The TOV for echoes of -0.08 µsec, +0.08 µsec, +0.32 µsec, and +2.56 µsec occurred at D/U ratios of 6.7 dB (i.e., echo amplitude of 46%), 9.5 dB (33%), 8.9 dB (35%), and 3.6 dB (66%) respectively.

10.4.2.3 Flutter

The TOV for airplane flutter of 2 Hz and 5 Hz were at D/U levels of 14.5 dB (18.8%) and 10.4 dB (30%) respectively.

[5] Caution must be exercised in comparing C/N between analog and digital systems, as definition of carrier levels is not consistent. Measurement of power level is consistent, however, among digital systems. (See section 8.3.6.)

10.4.2.4 Impulse Noise

Impulse noise performance was judged to be better than NTSC by approximately 10 dB for TOV. The range between TOV and POU was about 4 dB.

In the gated noise test at a fixed 10 Hz repetition rate, TOV was reached when the pulse width was increased to 5 µsec. When the pulse width was decreased to 4 µsec, TOV was reached when the pulse repetition rate was increased to 1.7 kHz.

10.4.2.5 Discrete Frequency Interference

The D/U ratio at the TOV for discrete frequency interference was -27 (±0.5) dB in the first adjacent channels, and between +7.5 dB and +11.6 dB in-band.

10.4.2.6 Cable Transmission

The subjective tests showed that cable transmission *per se* had no adverse effect on DigiCipher performance.

Among the cable-specific tests conducted, the system performed better than NTSC when subjected to hum (TOV > 15%); composite triple beat, or CTB, (TOV @ -31 dBc); and composite second order, or CSO, (TOV @ -16 dBc). Its performance was poorer than NTSC when subjected to phase noise (TOV @ -82 dBc), residual FM (TOV @ 5.7 kHz), and local oscillator instability (+40 kHz, - 60 kHz).

The threshold values for the ancillary data channel (as measured on the second audio channel pair at 251 kbits/sec) were consistent with the values found in other tests for Gaussian noise, CTB, hum modulation, and phase noise.

10.4.2.7 Co-Channel Interference into ATV

DigiCipher was much more robust than NTSC to co-channel interference from either NTSC or ATV. Results are summarized in Figure 10-1. The system performance exhibited a sharp degradation when co-channel interference was increased beyond TOV. The range from TOV to POU was less than 2 dB for NTSC-into-ATV co-channel interference, and approximately 0.5 dB for ATV-into-ATV co-channel interference.

10.4.2.8 Co-Channel Interference into NTSC

For co-channel interference into NTSC, impairment ratings varied gradually from “imperceptible” to “very annoying” over a range of 24 dB at weak desired signal level. (See Figure 10-10). The D/U for a mean impairment rating of 3 was about 35 dB. The interference appeared as random noise, except for a narrow horizontal band where the noise pattern appeared to be fixed.

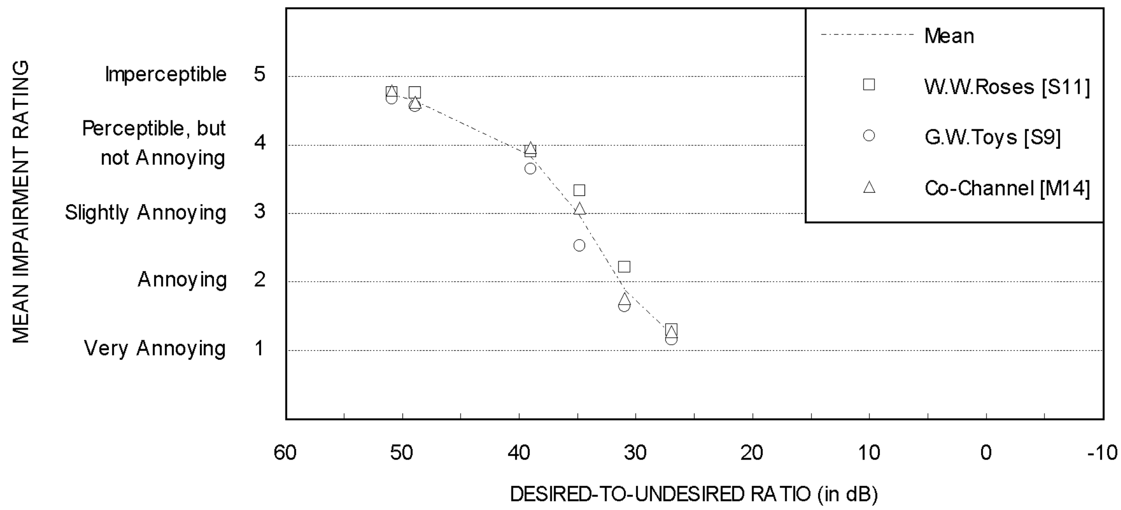

Figure 10-10. Impairment to NTSC when subjected to DigiCipher co-channel interference for weak signal condition (-55 dBm).

10.4.2.9 Adjacent-Channel Interference

The D/U ratio at the TOV for adjacent-channel interference into DigiCipher is given in Figure 10-1. The D/U ratio for a mean rating of 3 (slightly annoying) for adjacent-channel interference into NTSC is given also in Figure 10-1. Note that the more negative the D/U ratio, the better the performance. In practice, it is expected that the DigiCipher signal would be transmitted with an average power 10-15 dB lower than NTSC peak power. Under this assumption, the data indicate that DigiCipher supports collocation.

The system exhibited a sharp degradation when subjected to adjacent-channel interference from NTSC and ATV. The range from TOV to POU was about 1 dB.

ATV-into-NTSC impairment ratings varied from “imperceptible” to “very annoying” over a range of 13 dB for the upper adjacent-channel and 28 dB for the lower adjacent-channel. Ratings varied from 4 (perceptible but not annoying) to 2 (annoying) over a range of 5 dB for the upper adjacent-channel and 11 dB for the lower adjacent-channel.

10.4.2.10 Taboo Interference

The taboo performance of DigiCipher, based on TOV, is given in Figure 10-11. Note that the more negative the D/U ratio, the better the performance.

In practice, it is expected that the DigiCipher signal would be transmitted with an average power 10-15 dB lower than NTSC peak power. Under this assumption, the data show that DigiCipher could support collocation on the basis of taboo channel interference requirements.

CHANNEL	ATV-into-NTSC Strong	ATV-into-NTSC Weak	NTSC-into-ATV Strong	NTSC-into-ATV Weak	ATV-into-ATV Strong	ATV-into-ATV Weak
n+2	< -1*	-30	-29	-34	-29	-36
n-2	< +4*	-25	-34	-45	-30	-38
n+4	< -4*	-27	<-33*	-58	<-33*	-57
n+7	< +2*	-39	<-33*	<-58*	<-33*	-59
n-7	< +2*	-35	<-33*	-58	**	-57
n+8	< +2*	<-38*	<-33*	<-58*	<-33*	<-63*
n-8	< -2*	-34	<-33*	-58	**	-58
n+14	< -2*	-27	<-33*	<-58*	<-33*	<-63*
n+15	-2	-17	<-33*	<-58*	<-33*	<-63*

* Determination of TOV level was beyond the limits of ATTC's RF test bed range. Consequently, the system performance was better than the indicated result.

** Test not performed.

Figure 10-11. Taboo threshold of visibility for DigiCipher (D/U in dB).

10.4.2.11 Channel Acquisition

Under a variety of impairment conditions above TOV, the DigiCipher system fully acquired the signal and displayed a recognizable picture within one second.

10.4.2.12 Failure and Recovery Appearance

Transmission impairments, when strong enough, produced visible effects which were independent of the type of impairment. Each visible effect lasted for a maximum of 1/3 second. Transmission errors appeared as incorrect and/or frozen patches. Patch size ranged from small blocks, through clusters of blocks, to as large as a “panel” which was 1/4 screen wide by a full screen height. Error recovery showed a right-to-left wiping of the error, during which the patch was updated with correct video. For multiple errors, the refresh appeared as four equally spaced vertical wipes.

During a loss of signal, or when the signal was overwhelmed with impairments, the whole screen image froze, sometimes with errors displayed. Recovery from a loss of signal was through a right-to-left wipe in four distinct vertical panels. The wipe transition was about 1/3 second or less.

10.4.2.13 Peak-to-Average Power Ratio

The peak-to-average power ratio for the 32 QAM mode was less than 4.8 dB 99% of the time, and less than 6 dB 99.9% of the time. For 16 QAM, these ratios were 4.6 dB and 5.7 dB respectively.

10.4.2.14 Multiple Impairments

The performance of DigiCipher when simultaneously subjected to multiple impairments, is shown in Figure 10-12 for two cases:

(1) The POA[6] for NTSC co-channel interference versus random noise, and

(2) The TOV for composite triple beat versus random noise.

Asymptotes are shown reflecting the measured single impairment performance. The operating region lies above and to the right of the respective curves.

10.4.3 Scope of Services and Features

10.4.3.1 Data

A 126 kbits/sec channel is provided for ancillary data. A separate 126 kbits/sec channel is assigned for conditional access use. Four data channels at 9600 bits/sec were implemented in the tested system to illustrate asynchronous data transmission.

10.4.3.2 Encryption

Encryption was not implemented in the tested system. However, the proponent claims to have developed a security system.

[6] For the DigiCipher system, the POA and TOV differ by less than 1 dB.

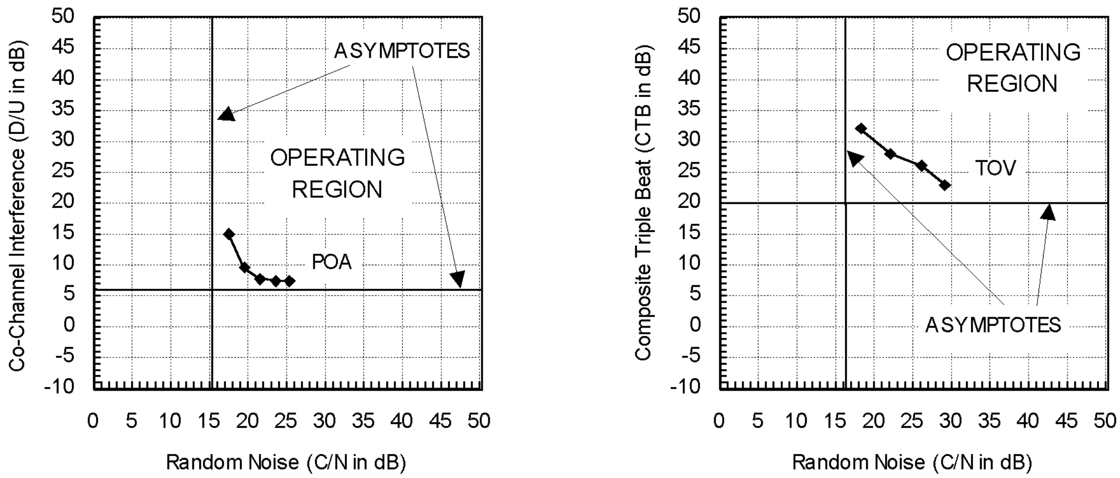

Figure 10-12. Multiple impairments into DigiCipher. (Left) POA for NTSC co-channel interference and random noise. (Right) TOV for composite triple beat and random noise.

10.4.3.3 Addressing

A 126 kbits/sec channel is assigned for conditional access use (subscriber addressing).

10.4.3.4 VCR Capability

A consumer-grade VCR has been publicly exhibited by GI and Toshiba. It records a digital signal at the 18.2 Mbits/sec data rate of DigiCipher. It uses two-hour metallized-tape cassettes similar in format to 8-mm NTSC cassettes. The proponent reports running simulations showing that a full set of trick mode features can be supported. In the trick mode simulations, the DigiCipher VCR uses PCM refresh data from each field and attempts to use DPCM data also. Switching between compressed video images should be done at frame sync, preferably with the new scene at black, or at a scene change when the image is being processed in the PCM mode. Switching within a frame may be done at the macroblock level with some restrictions. Otherwise, editing during frames requires decompression and recompression with a small loss in quality due to concatenation. However, it is anticipated that most editing will be done prior to compression.

10.4.4 Extensibility

10.4.4.1 To No Visible Artifacts

The proponent reports simulating compression at 30 Mbits/sec with favorable results, and believes that the algorithm can be extended to 40-45 Mbits/sec which would constitute a distribution level of quality suitable for network feeds to local affiliates. The proponent is investigating an approach that would allow the transmission-level signal to be included in the distribution-level signal as a kernel. This would permit pass-through of the transmission-level signal at the local affiliate level by stripping away the distribution-level augmentation.

10.4.4.2 To Studio Quality Data Rate

The proponent speculates that studio quality intraframe compression can be achieved at a bit rate in the 100-200 Mbits/sec range. This format has not been developed yet.

10.4.4.3 To Higher Resolution

The proponent believes that DigiCipher technology is extensible and suggests a resolution increase by a factor of about four.

10.4.4.4 Provision for Future Compression Enhancement

The proponent suggests that, as decreasing digital processing costs enable increasing complexity at the encoder, improvements can be made without changing receivers or the transmitted bit rate. These improvements are in forward analysis, perceptual analysis, motion compensation, coefficient quantization, and special effects editing.

10.4.5 Interoperability Considerations

10.4.5.1 With Cable Television

Information on the performance of DigiCipher over with cable can be found in Section 10.4.2.6.

10.4.5.2 With Digital Technology

Because this system is all-digital, the advantages of all-digital systems apply.

10.4.5.3 Headers/Descriptors

The proponent discussed the use of the ancillary data space for transmitting the program name, remaining times, and program rating. In the system tested, there is a 7-byte header at the beginning of each data frame; three bytes are available. There is a one-byte header at the beginning of each video frame; one bit is available. There is a fully defined two-byte header at the beginning of each macroblock.

10.4.5.4 With NTSC

The proponent selected the field rate of 59.94 Hz for compatibility with NTSC. The number of active video lines was selected to be double the number of active NTSC lines. Down-conversion involves interpolation between HDTV pixels in a line and between HDTV lines.

10.4.5.5 With Film

The tested system accepts 24 fps film, converted using 3:2 pull-down to 59.94 Hz video, 2:1 interlaced. The DigiCipher encoder recognizes the redundancy in each five-field sequence as having originated in

24 fps film and converts the 59.94 fields/sec video back to 23.98 frames/sec. The image is processed and transmitted as 23.98 frames/sec progressive. It is converted back to 59.94 fields/sec interlace in the decoder using 3:2 pull-down. Future receivers could alternatively use 3:1 frame repeat to display progressive at 72 Hz. Film at 30 fps, delivered to the encoder as 59.94 fields/sec video, can be processed and transmitted as 29.97 frames/sec progressive. The benefit is more efficient coding, and thus higher quality.

10.4.5.6 With Computers

Progressive scanning and square pixels, not included in the DigiCipher system tested, are important factors for interoperability of an HDTV system with computers. The system has pixels that are 21% wider than high. The tested system was built to select between field processing and frame processing for each superblock, depending on its motion, in order to provide optimum motion handling. However, computer interoperability would be enhanced if the encoder were forced to do frame processing on all superblocks. With this feature, coding and transmission would be in progressive form. The proponent has proposed adding this feature as an option at the encoder.

10.4.5.7 With Satellites

Satellite transmission of the DigiCipher HDTV signal has been demonstrated using QPSK in a 24-MHz bandwidth achieving a raw data rate of 39 Mbits/sec. Instead of the trellis coding used in the terrestrial system, convolutional coding with a Viterbi decoder was used. The coding was rate -1/2; the data rate after Viterbi decoding was 19.51 Mbits/sec. Reed-Solomon coding was used also with the information rate being 18.2 Mbits/sec, identical to the terrestrial signal. A 5.5 dB C/N threshold was achieved, an improvement over the 8+ dB threshold typically achieved in NTSC satellite transmission. The proponent recommends using rate -3/4 coding to yield a 50% increase in the information rate. This would support a higher-level compressed HDTV signal, or an NTSC signal sharing the channel with the HDTV signal. In a 36-MHz transponder, two transmission-quality HDTV signals, or alternatively one distribution-quality 40-45 Mbits/sec signal, can be transmitted.

10.4.5.8 With Packet Networks

In the system tested, the data is packaged into fixed-length data lines, 1160 bits long. Data space was reserved in each data line which could have been used as a header. For lost data lines, the decoder will use error concealment which is already implemented to handle transmission errors.

10.4.5.9 With Interactive Systems

According to the proponent, the latency of DigiCipher is 83 msec. Acquisition time is reported in Section 10.4.2.11.

10.4.5.10 Format Conversion

10.4.5.10.1 With 1125/60

Up-converting to the Common Image Format (1920 x 1080) requires 8:9 vertical interpolation and 11:15 horizontal interpolation. SMPTE 240M uses 1035 active lines and would require 14:15 vertical interpolation. Colorimetry used by DigiCipher is the same as SMPTE 240M.

10.4.5.10.2 With 1250/50

This difficult conversion is not simplified by the fact that both the source system and the target system are interlaced 2:1.

10.4.5.10.3 With MPEG[7]

The DigiCipher decoder would require modification to decode MPEG-1. The proponent claims that there would be a modest increase in complexity because DigiCipher shares many commonalties with MPEG-1. MPEG-1 decoders will not decode DigiCipher.

10.4.5.10.4 With Still Image

The proponent has identified still-frame as a useful capability, and believes that forward compatibility with JPEG, Photo CD and CD-I is feasible. The proponent claims that receivers can be built to decode JPEG, Photo CD, and CD-I if the marketplace supports such products. The frame-coding option offered by the proponent enhances compatibility with still images.

10.4.5.11 Scalability

Though the receive and display clocks are currently linked, the proponent proposes to operate them independently in the future. The receiver could then receive non-real-time video at slower rates. According to the proponent, picture-in-picture and picture-out-of-picture are possible with DigiCipher as receiver design options.

DigiCipher processes the image in four parallel panels. Each panel processor is comparable to a DigiCipher NTSC processor and thus is able to process a DigiCipher NTSC signal. There is also a compatible bus that can support both NTSC and HDTV signals. The proponent claims that the compatibility extends to VCRs and satellite and cable receivers.

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[7] See Section 8.3.8 for a discussion of MPEG, the MPEG-1 standard, and the MPEG-2 development effort.

10.5 SYSTEM IMPROVEMENTS

10.5.1 Already Implemented

10.5.1.1 Error Concealment

The purpose of this improvement was to reduce the visibility of uncorrected transmission errors and to reduce the visibility of the refresh at the end of error concealment. During error concealment, tainted macroblock update data is not used; prior frame data is carried over instead. Interpanel communication has been added. With the improvement, normal panel right-to-left motion is maintained by importing data from the adjacent panel. The change impacts only the decoder.

10.5.1.2 Encoder IF SAW Filter

To reduce ATV lower adjacent-channel interference into NTSC, the encoder IF SAW filter has been replaced. The new filter reduces the out-of-band response along the lower skirt.

10.5.1.3 Tuner IF Filters

To improve adjacent-channel rejection and close-in taboo performance, the receiver 1200 MHz and 43.5 MHz IF filters have been modified to tighten the passband.

10.5.1.4 Peak-to-Average Ratio

An adjustable clipping amplifier has been added in the encoder just ahead of the IF SAW filter. The SAW filter suppresses out-of-band spurious signals which might be generated by the clipping operation. Since the signal stays within a few dB of its average the vast majority of time, the improvement allows a reduction in peak-to-average ratio with an offsetting fractional reduction in C/N threshold performance and some possible reduction in interference performance when the ATV signal is the interferor. For field testing, clipping will be set at the ATTC measured maximum peak value, 7 dB.

10.5.2 Implemented in Time for Field Testing

10.5.2.1 Packetized Transmission

In order to support ATSC T3/186 flexibility requirements, packetizing will be implemented at the transport layer. The packet length will be 155 bytes, identical to the current data line structure. The change involves organizing packets by data type, rather than the current data multiplexing within a line, and inclusion of a header at the beginning of each packet. The modification affects both encoder and decoder.

10.5.2.2 Multichannel Sound

The purpose of this improvement is to implement ATSC T3/186 audio features, including composite-coded multichannel surround sound. The system will incorporate two Dolby Laboratories AC-3 encoders on the transmit side and one AC-3 decoder in the receiver. The AC-3 system is flexible with numerous modes of operation, including 5.1 channel composite-coded surround sound, or two independently coded AC-2A channels.

11. DIGITAL SPECTRUM COMPATIBLE HDTV

11.1 SYSTEM OVERVIEW

DSC-HDTV, proposed by Zenith and AT&T, is a digital simulcast system that requires a single 6 MHz television transmission channel.[1] The video source is an analog RGB signal with alternate 787/788 lines, progressively scanned, a 59.94 Hz frame rate, and an aspect ratio of 16:9. The display format is 720 lines by 1280 pixels per line. The video sampling frequency is 75.3 MHz. Chrominance signals are decimated by a factor of two both horizontally and vertically. Nine-bit precision is employed for all luminance and chrominance samples. The video compression includes perceptual coding, vector quantization, and adaptive fractional leak. Motion is estimated by hierarchical block matching with 1/2 pixel accuracy. A displaced frame difference (DFD) is computed and transformed with a Discrete Cosine Transform (DCT). Block sizes for motion compensation, varying from 32H x 16V to 8 x 8, are adapted spatially to places in the image providing the most benefit. Time division multiplexing between 4-level and 2-level VSB transmission is employed to provide improved error performance and extended coverage. The amount of time at each level depends on the complexity of the image being processed, with more complex images requiring more 4-level data. To provide a measure of "graceful degradation," certain critical data are always transmitted in the more rugged 2-level mode. In addition to the Standard Mode, the DSC-HDTV system also offers a Robust Mode, which increases the ratio of 2-level to 4-level data that is transmitted. The variable length codes are packed into slices (64H x 48V) with a header providing identification of the first slice boundary in each segment to allow restart of the variable length decoding. Transmission is by vestigial sideband modulation with a pilot carrier 0.31 MHz above the lower edge of the 6 MHz channel. Video data rate ranges from 8.45 to 16.92 Mbits/sec and the total transmission rate ranges from 11.14 to 21.0 Mbits/sec. The system employs a post-comb-filter in the receiver which automatically switches in to minimize the effects of NTSC co-channel interference. The DSC-HDTV system provides four digital audio channels using Dolby Laboratories AC-2 compression system. The audio is sampled at 47 kHz, the horizontal scan rate, with 16 bit precision. The compressed audio rate is 252 kbits/sec per pair of channels. One pair is transmitted as 2-level data and the other as 4-level data. The system also provides 413 kbits/sec of data capacity in two separate ancillary data channels.

11.2 SPECTRUM UTILIZATION

The DSC-HDTV analysis was conducted under two allotment scenarios (using both VHF and UHF channels for ATV stations, and using only UHF channels) and two sets of interference constraints

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[1] An incorrectly programmed integrated circuit chip in the DSC-HDTV system encoder was discovered during testing. The Advisory Committee decided to rerun certain tests after the proponent adjusted the system to conform with its certified specifications. Subsequently, SS/WP2 agreed that the data from the retest, not from the corresponding original test, should be used by the Advisory Committee for analysis and evaluation of the proponent's system.

(considering only co-channel interference, and both co-channel and adjacent-channel interference). In addition, the impact of taboos was assessed by re-calculating coverage and interference for each case assuming the taboo performance measured in the laboratory.

Figure 11-1 shows planning factors, specific to the DSC-HDTV system, as derived from test results. The numbers in the figure are desired-to-undesired ratios (D/U) in dB. The values for interference into NTSC are based on CCIR Impairment Grade 3 (slightly annoying) as determined from the ATEL subjective tests. Because the ATV service is intended to be an improvement over NTSC, interference into ATV is based on CCIR Impairment Grade 4 (perceptible but not annoying) if the range between the threshold of visibility (TOV) and the point of acquisition (POA) exceeds 5 dB. Otherwise, the TOV power level is used. DSC-HDTV demonstrated a “cliff effect” except for the case of co-channel NTSC-into-ATV; D/U values are based on TOV data.[2] Also, the data show that DSC-HDTV can support collocation on both the upper and lower adjacent-channels.

Co-Channel	**D/U (dB)**
ATV-into-NTSC	+35
NTSC-into-ATV	+3.5
ATV-into-ATV	+18.2

Carrier-to-Noise	+16.0

Adjacent-Channel	**D/U (dB)**
Lower ATV-into-NTSC	-17.2
Upper ATV-into-NTSC	-7.5
Lower NTSC-into-ATV	-43
Upper NTSC-into-ATV	-42
Lower ATV-into-ATV	-35
Upper ATV-into-ATV	-36

Figure 11-1. Planning factors specific to DSC-HDTV.

11.2.1 Accommodation Percentage

DSC-HDTV could provide a 100% accommodation of all NTSC assignments for co-channel only, and co-channel and adjacent-channel constraints, under both the VHF/UHF and UHF scenarios. The accommodation is achieved at the expense of reducing the ATV and NTSC service areas. No attempt was made to reduce interference to NTSC service by adjusting either ATV or NTSC power.

11.2.2 Service Area

Figure 11-2 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 both co-channel and adjacent-channel constraints. In this graph, the 1,657 current NTSC stations are placed in order of decreasing ATV to NTSC service area

[2] The range between TOV and POU for Co-Channel NTSC-into-ATV was 7 dB. The weak level ATEL impairment tape showed unexpectedly large amounts of impairments starting at TOV. This result was anomalous. Because it was not possible to derive an agreeable CCIR Impairment Grade 4 rating, the weak level TOV was used for spectrum utilization analyses.

ratio. Examination of the graph reveals that 13.2% (218) 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% (1,624) 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 40.5 million square kilometers.

Figure 11-3 shows the interference statistics for the VHF/UHF scenario. During the transition period, 59.9% of ATV stations would receive no interference. This would rise to 71.7% after the transition period ends. Also during the transition period, 1.3% of the ATV stations would receive interference in more than 35% of their noise-limited coverage area. This would fall to 1.1% after the transition period ends. The total interference area created within the ATV noise-limited coverage area during the transition period is 1.73 million square kilometers. This would decrease to 1.12 million square kilometers after the transition period ends. Of the existing NTSC stations, 58.2% would not receive any new interference because of the ATV service, while 2.4% would receive new interference in more than 35% of their Grade B area. The total new interference into NTSC created under this plan is 1.51 million square kilometers.

When taboos are included in the interference calculations for the VHF/UHF scenario, the number of ATV stations with no interference during the transition period is 56.5%; the number of ATV stations with interference in more than 35% of their noise-limited coverage area is 1.4%. The number of NTSC stations receiving no new interference is 53.3%; the number of NTSC stations with interference in more than 35% of their Grade B area is 2.4%.

When the adjacent-channel constraints of Figure 11-1 are not included in the VHF/UHF scenario, the allotment/assignment table is different. In that case, 16.1% (267) of the ATV stations would have an ATV service area at least 20% larger than their companion NTSC service area and 98% (1,630) would have an ATV service area at least 80% of their companion NTSC service area. During the transition period, 72.3% of ATV stations would receive no interference. This would rise to 80.4% after the transition period ends. Also during the transition period, 1.0% of the ATV stations would receive interference in more than 35% of their noise-limited coverage area. This would fall to 0.8% after the transition period ends. Of the existing NTSC stations, 64.5% would not receive any new interference because of the ATV service, while 2.0% would receive new interference in more than 35% of their Grade B area.

Figure 11-4 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 UHF scenario, taking into account both co-channel and adjacent-channel constraints. In this graph, as before, the 1,657 current NTSC stations are placed in order ofdecreasing ATV to NTSC service area ratio. Examination of the graph reveals that 11.9% (198) of the ATV stations under this scenario would have an ATV service area at least 20% larger than their companion NTSC service area and 95% (1,577) 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 39.8 million square kilometers.

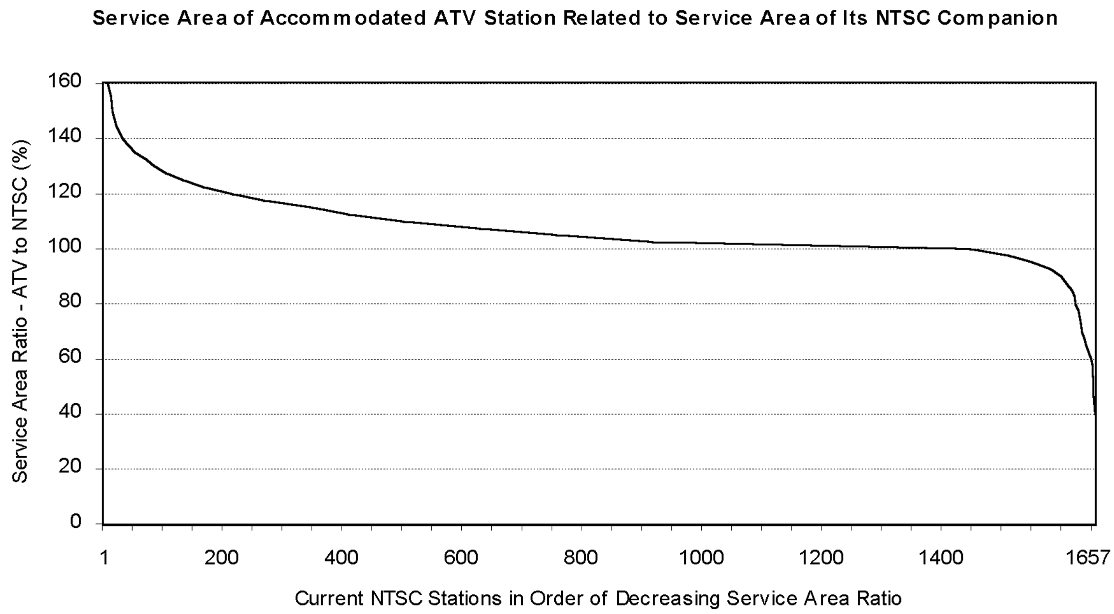

Figure 11-2. DSC-HDTV VHF/UHF Scenario — Interference-limited service area of each ATV station relative to the interference-limited service area of its companion NTSC station (co-channel and adjacent-channel constraints).

Interference Area Compared to Coverage Area	ATV Stations with Interference		NTSC Stations with Added Interference Due to ATV
	During Transition	After Transition	
No Interference	59.9 %	71.7 %	58.2 %
0 - 5 %	20.8 %	16.5 %	16.3 %
5 - 10 %	9.2 %	5.9 %	8.9 %
10 - 15 %	4.6 %	2.5 %	5.4 %
15 - 20 %	1.6 %	0.8 %	4.6 %
20 - 25 %	1.3 %	0.6 %	1.7 %
25 - 30 %	0.7 %	0.4 %	1.6 %
30 - 35 %	0.6 %	0.5 %	0.8 %
> 35 %	1.3 %	1.1 %	2.4 %

Figure 11-3. DSC-HDTV VHF/UHF Scenario — Interference characteristics (co-channel and adjacent-channel constraints).

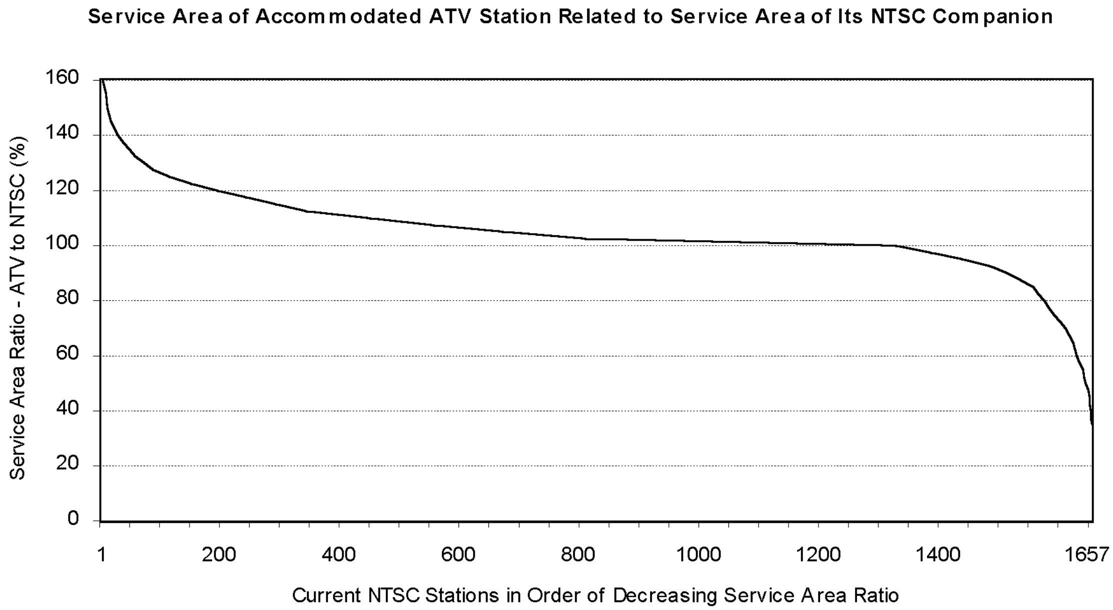

Figure 11-4. DSC-HDTV UHF Scenario — Interference-limited service area of each ATV station relative to the interference-limited service area of its companion NTSC station (co-channel and adjacent-channel constraints).

Interference Area Compared to Coverage Area	ATV Stations with Interference		NTSC Stations with Added Interference Due to ATV
	During Transition	After Transition	
No Interference	54.3 %	64.8 %	61.1 %
0 - 5 %	15.2 %	14.5 %	9.4 %
5 - 10 %	11.3 %	7.4 %	5.9 %
10 - 15 %	6.8 %	4.1 %	3.9 %
15 - 20 %	4.0 %	2.4 %	3.8 %
20 - 25 %	2.7 %	1.9 %	3.3 %
25 - 30 %	1.5 %	1.0 %	2.4 %
30 - 35 %	1.1 %	1.0 %	2.2 %
> 35 %	3.0 %	2.9 %	8.0 %

Figure 11-5. DSC-HDTV UHF Scenario — Interference characteristics (co-channel and adjacent-channel constraints).

Figure 11-5 shows the interference statistics for the UHF scenario. During the transition period, 54.3% of ATV stations would receive no interference. This would rise to 64.8% after the transition period ends. Also during the transition period, 3.0% of the ATV stations would receive interference in more than 35% of their noise-limited coverage area. This would fall to 2.9% after the transition period ends. The total interference area created within the ATV noise-limited coverage area during the transition period is 2.46 million square kilometers. This would decrease to 1.78 million square kilometers after the transition period ends. Of the existing NTSC stations, 61.1% would not receive any new interference because of the ATV service, while 8.0% would receive new interference in more than 35% of their Grade B coverage area. The total new interference created under this plan is 2.26 million square kilometers.

When taboos are included in the interference calculations for the UHF scenario, the number of ATV stations with no interference during the transition period is 52.1%; the number of ATV stations with interference in more than 35% of their noise-limited coverage area is 3.1%. The number of NTSC stations receiving no new interference is 57.2%; the number of NTSC stations with interference in more than 35% of their Grade B area is 8.0%.

When the adjacent-channel constraints of Figure 11-1 are not included in the UHF scenario, the allotment/assignment table is different. In that case, 14.0% (232) of the ATV stations would have an ATV service area at least 20% larger than their companion NTSC service area and 96% (1,584) would have an ATV service area at least 80% of their companion NTSC service area. During the transition period, 59.8% of ATV stations would receive no interference. This would rise to 70.7% after the transition period ends. Also during the transition period, 2.8% of the ATV stations would receive interference in more than 35% of their noise-limited coverage area. This would remain at 2.8% after the transition period ends. Of the existing NTSC stations, 64.9% would not receive any new interference because of the ATV service, while 7.0% would receive new interference in more than 35% of their Grade B area.

The frequency distribution of ATV station average effective radiated power levels needed to achieve ATV noise-limited coverage comparable to NTSC Grade B coverage was calculated. The maximum average effective radiated power level was 38.25 dBk (6,680 kW). The results are shown in Figure 11-6.

Spectrum utilization analyses were not performed for the DSC-HDTV Robust Mode. The proponent claims that this mode offers improved transmission robustness (see Section 11.4.2.1).

11.3 ECONOMICS

11.3.1 Cost to Broadcasters

The estimated equipment cost for a DSC-HDTV transitional station is shown in Figure 11-7. The total cost of the transitional station was estimated to be $1,759,500. The total cost of a minimal station was estimated to be $1,139,100. A general description of the methods used to develop the cost data is contained in Section 8.2.1.

Average Effective Radiated Power Level		Number of TV Stations			
		VHF/UHF Scenario			UHF Scenario
(dBk)	(kW)	Low VHF	High VHF	UHF	UHF
Less than 5	Less than 3.2	12	24	100	100
5 - 10	3.2 - 10.0	3	8	47	48
10 - 15	10.0 - 31.6	2	11	127	136
15 - 20	31.6 - 100		4	253	260
20 - 25	100 - 316			287	301
25 - 30	316 - 1,000			241	255
30 - 35	1,000 - 3,160			316	326
35 - 40	3,160 - 10,000			222	231
> 40	> 10,000				
TOTAL		17	47	1,593	1,657

Figure 11-6. DSC-HDTV power level distribution.

Subsystem	Cost (thousands)
Satellite Receiver, Demodulator, Decoder	$ 13.5
Character Generator, Still Store, Two 28” Monitors	200.0
Routing Switcher (10 x 10), Master Control	125.0
2 ATV VTRs and Monitors	170.0
NTSC Upconverter, including Line Tripler	24.0
ATV-to-NTSC Downconverter	20.0
34” Monitor, Seven 17” Monitors, Eight Decoders	119.0
ATV Encoder	240.0
STL Subsystem	92.5
ATV Modulator, ATV Exciter	30.0
ATV Transmission Subsystem	725.5
TOTAL COST	$1,759.5

Figure 11-7. Equipment cost for a DSC-HDTV transitional station.

11.3.2 Cost to Alternative Media

Information on this topic was not provided.

11.3.3 Cost to Consumers

The estimated material cost data for a DSC-HDTV receiver are shown in Figure 11-8. A general description of the methods used to develop the cost data is contained in Section 8.2.2.

Using a 2.5 multiplier, the resulting estimated retail price for a DSC-HDTV receiver is $2,523 for a 34” direct view receiver and $3,843 for a 56” projector receiver.

Subsystem	34" Widescreen Direct View Receiver	56" Widescreen CRT Type Projector
Signal Processing Components	$ 116	$ 116
Audio Amplifiers, Speakers	30	30
Scan System, Power Supply, Video Amps	73	201
Display	700	1,050
Cabinet	90	140
TOTAL MATERIAL COST	$1,009	$1,537

Figure 11-8. Material cost data for a DSC-HDTV receiver.

11.4 TECHNOLOGY

11.4.1 Audio/Video Quality

In video subjective tests of DSC-HDTV, the system performed differently across segments of test material. For 8 of the 9 stills, DSC-HDTV was judged, on average, to be about 0.5 grade lower in quality than the 1125-line studio reference. For 13 of the 14 motion sequences, DSC-HDTV was judged to be about 1.2 grades lower in quality than the reference. The remaining still and the remaining motion sequence, both electronically generated, were judged to be better in quality than the reference.[3]

Problems were noted when the system was subjected to noisy source material, scene cuts, and two encode/decode operations. No significant problems were reported when the system was subjected to a sudden stop in motion or tested for video-coder or motion-compensation overload.

Certain tests also were carried out for the Robust Mode. When judged by non-experts, the Robust Mode exhibited a greater reduction in quality than the Standard Mode for a number of segments of test material. Expert observers always could tell the difference between Standard Mode and Robust Mode.

There was no evidence that the audio system failed before the accompanying video.

11.4.1.1 Video Quality

Subjective judgments of image quality by non-experts are summarized in Figure 11-9. Scores are the differences between judgments of the reference and judgments of DSC-HDTV for 9 stills and 14 motion sequences. For 8 of the 9 stills, DSC-HDTV was judged, on average, to be 0.5 grade (i.e., about 9 points on the 100-point scale) lower in quality than the 1125-line studio reference; for the remaining still (S14), the system was judged to be 0.7 grade higher in quality than the reference (this may reflect the absence of interlacing artifacts in the 787/788 source and in the DSC-HDTV rendering of this picture). For 13 of the 14 motion sequences, DSC-HDTV was judged, on average, to be 1.2

[3] See Section 8.3.3.

grades (i.e., about 24 points) lower in quality than the reference[4]; for the remaining sequence (M16), the system was judged to be 0.7 grade higher in quality than the reference (this probably reflects the absence of interlacing artifacts in the 787/788 source and in the DSC-HDTV rendering of this picture).

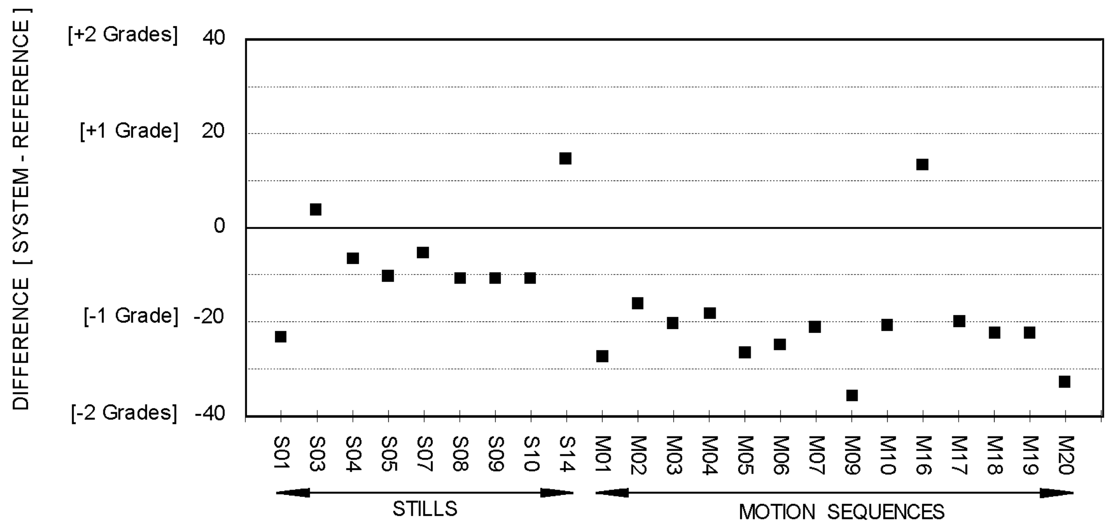

Figure 11-9. Average differences between quality judgments for the 1125-line studio quality reference and for DSC-HDTV.

DSC-HDTV performed differently for different segments of test material. For stills, differences ranged from +0.2 to -1.2 grades (not including S14); for moving sequences, differences ranged from -0.8 to -1.8 (not including M16). The variability among viewers differed somewhat across materials, but was within acceptable limits. Expert commentary, supported by reports from non-expert viewers, attributed differences between DSC-HDTV and the reference for stills to constant "busy-ness" in detailed areas and to reduced chrominance resolution. Expert commentary, again supported by reports from non-expert viewers, attributed differences between DSC-HDTV and the reference for motion sequences to occasional "blockiness" in the flat areas of sequences that elsewhere contained significant amounts of moving detail, to visible noise that "pulsed" at a low temporal frequency, to reduced resolution, and to exaggeration of source noise, which became coarser and "blocky" after processing.

Objective tests of static and dynamic resolution showed slight losses in horizontal, vertical, and diagonal luminance resolution at high rates of movement.[5]

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[4] The 787/788 progressively scanned camera material used in testing DSC-HDTV exhibited horizontally coherent noise and increased random noise as compared with the cameras used for 1125-line reference images. See Section 8.3.4.

When subjected to noisy source material, the system introduced an increase in noise at the output (which tended to be more coarse than at the source as well as blocky). In addition, the system introduced blur, "blockiness," and shimmer. At the highest level of source noise tested, pictures from the system were judged unusable by expert observers.

When subjected to scene cuts and viewed in real time, the system introduced "blockiness" that was particularly visible following a cut from a complex image to a still. Examination of freeze frames showed that it took about 6 frames (1/10 second) for the "blockiness" to subside. The artifacts were most visible following a cut to a still, but also were visible following a cut to a motion sequence.

Artifacts appeared when material was subjected to two encode/decode passes through the system. During the first pass, the system introduced high levels of noise. During the second pass, the noise was increased, sharpness was reduced, and "blockiness" was introduced.

The DSC-HDTV system exhibited good chrominance dynamic range in red, green, and blue channels.

When tested for video-coder overload, DSC-HDTV exhibited no significant failures. When tested for motion-compensation overload with velocities of up to 1.0 picture height per second, the system exhibited no artifacts. No artifacts were noted in response to a sudden stop in movement.

In examining video quality for an extended service area, where only the 2-level component would be receivable, expert observers concluded that image quality for typical material would be tolerable only for short periods.

Subjective judgments of the image quality of Robust Mode DSC-HDTV also were made by non-experts. The system again performed differently across segments of test material; on average, stills were judged to be about 0.8 grade lower in quality than the reference, while motion sequences were judged to be about 1.4 grades lower in quality than the reference[6]. In general, picture quality differences between Standard and Robust Modes were more evident for stills than for motion sequences. For most stills, the difference in unimpaired video quality between Robust Mode and Standard Mode was evident to non-expert observers. Furthermore, for all materials, expert observers could distinguish easily among source, Standard Mode, and Robust Mode (expert commentary judged the Robust Mode not to produce HDTV-quality images). Expert commentary attributes the lower performance of the Robust Mode DSC-HDTV system to a significant loss in resolution. For the Robust Mode, experts also noted increased susceptibility to source noise for some pictures, increased "blockiness" following a scene cut, and increased visibility of "blockiness" in tests of video-coder overload.

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[5] See Section 8.3.5.

[6] For the electronically generated still (S14) and motion sequence (M16), Robust Mode DSC-HDTV was judged equivalent to the reference. The average differences reported here do not include these values.

11.4.1.2 Audio Quality

There was no evidence that the audio system failed before the accompanying video.[7]

Objective tests were performed for dynamic range, total harmonic distortion (THD), THD+noise (THD+N), intermodulation distortion (IMD), dynamic intermodulation distortion (DIM), frequency response, and overload vs. frequency. The dynamic range for the DSC-HDTV system was found to be 88 dB. THD was typically less than 0.1%. For high level signals, THD+N was 0.1% or less for frequencies above 500 Hz, and less than 0.2% for lower frequencies to 20 Hz. IMD was approximately 0.02% for both channels. Frequency response was extremely flat from 20 Hz to 20 kHz.

For co-channel interference of ATV-into-NTSC, at both moderate and weak signal level, when the video impairment was “slightly annoying” the BTSC audio began to degrade. For upper adjacent-channel interference of ATV-into-NTSC, one receiver always showed interference, one never did, and the third showed that audio began to degrade when the video quality was “slightly annoying.” In the test of ATV co-channel interference into NTSC, DSC-HDTV caused no significant degradation of NTSC VBI data.

11.4.2 Transmission Robustness

In most regards, DSC-HDTV performed as predicted by the proponent. Its performance equalled or exceeded that of NTSC in almost all impairment conditions. Typically, the system exhibited immunity to a variety of transmission impairments over a wide range of impairment levels. Transmission impairments and interference, when strong enough, produced large shimmering areas of noisy video, visible blocks of various sizes, and patches of erroneous data. In most instances, the intensity and hue of damaged portions of the image were similar to the correct video around them; only very rarely were there blocks of strongly contrasting color or luminance. In the extended service area where just the 2-level component would be receivable, expert observers concluded that the 2-level data would have utility only for short, temporary, and infrequent signal fading. There was no evidence that the audio system failed before the accompanying video.[8]

DSC-HDTV interference into NTSC had the characteristic of white noise and produced a graceful degradation. Cable transmission caused no adverse effect on DSC-HDTV performance.

11.4.2.1 Noise Performance

When DSC-HDTV was subjected to random channel noise (based on a 6 MHz noise bandwidth), the carrier-to-noise ratio[9] (C/N) at the TOV was measured and is shown in Figure 11-1. This was also the

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[7] See Section 8.3.1.

[8] A special audio task force detected no audio impairments within the range of available data where impairments to video varied from “imperceptible” to “very annoying.”

[9] Caution must be exercised in comparing C/N between analog and digital systems, as definition of carrier levels is not consistent. Measurement of power level is consistent, however, among digital systems. (See section 8.3.6.)

noise threshold of the 4-level data. The system had a sharp degradation — the range between TOV and the point of unusability (POU) was 1.25 dB. The 2-level noise threshold was measured to be at a C/N of 11 dB. The Robust Mode noise thresholds, both 4-level and 2-level, were measured to be 0.5 dB lower than for the Standard Mode.

For video material used in testing, most images other than stills required significant amounts of 4-level data. In the extended service area where just the 2-level component would be receivable, expert observers concluded that the 2-level data would have utility only for short, temporary, and infrequent signal fading.

11.4.2.2 Static Multipath

The system performed well at levels that would be highly objectionable in NTSC. The TOV for echoes of +0.08 µsec, +0.32 µsec and +2.56 µsec occurred at D/U ratios of 3.3 dB (i.e., echo amplitude of 68%), 4.6 dB (59%), and 5.5 dB (53%), respectively. For an echo of -0.08 µsec, no impairment was observed up to the D/U limit of 0 dB.

11.4.2.3 Flutter

The TOV for airplane flutter of 2 Hz and 5 Hz were at D/U levels of 12.6 dB (23%) and 17.0 dB (14%) respectively.

11.4.2.4 Impulse Noise

Impulse noise performance was judged to be better than NTSC by approximately 27 dB for TOV. The range between TOV and POU was about 6 dB.

In the gated noise test at a fixed 10 Hz repetition rate, TOV was reached when the pulse width was increased to 21 µsec. Pulse width at POU was greater by approximately a factor of 10. When the pulse width was decreased to 18 µsec, TOV was reached when the pulse repetition rate was increased to 280 Hz.

11.4.2.5 Discrete Frequency Interference

The D/U ratio at the TOV for discrete frequency interference was -45 (±3) dB in the first adjacent channels, and between -7.3 dB and +14.0 dB in-band.

11.4.2.6 Cable Transmission

The subjective tests showed that cable transmission *per se* had no adverse effect on DSC-HDTV performance.

Among the cable-specific tests conducted the system performed better than NTSC when subjected to hum (TOV @ 11%); composite triple beat, or CTB, (TOV @ -11 dBc); composite second order, or CSO, (TOV @ -20 dBc); and local oscillator instability (>+100 kHz, <-100 kHz). Its performance was poorer than NTSC when subjected to phase noise (TOV @ -82 dBc) and residual FM (TOV @ ±1.2 kHz).

The threshold values for the ancillary data channel were consistent with the values found in other tests for Gaussian noise, CTB, hum modulation, and phase noise for 4-level data. For 2-level data CTB performance was 1 dB worse than 4-level. For Gaussian noise, hum, and phase noise, 2-level data performance was at least 6 dB better than 4-level.

11.4.2.7 Co-Channel Interference into ATV

DSC-HDTV was much more robust than NTSC to co-channel interference from either NTSC or ATV.

ATV-into-ATV results are summarized in Figure 11-1. The system performance exhibited a sharp degradation when ATV co-channel interference was increased beyond TOV. The range from TOV to POU was about 2 dB.

NTSC-into-ATV results are shown in Figure 11-10. Impairment ratings varied from “imperceptible” to “very annoying” over a range of about 6 dB for the two motion sequences. For the still, however, the rating remained uniformly close to “imperceptible” over the test range.

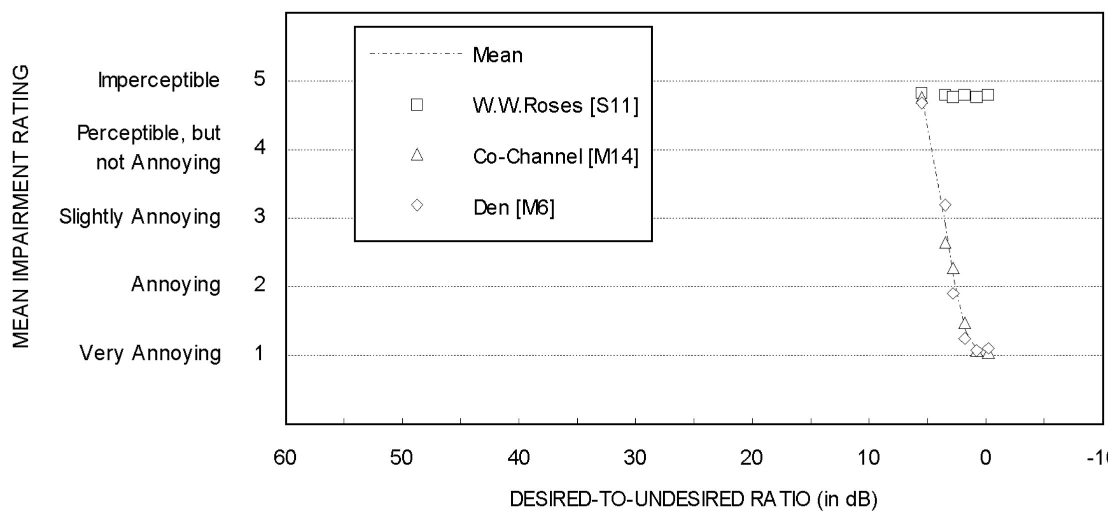

Figure 11-10. The performance of DSC-HDTV when subjected to NTSC co-channel interference for weak signal condition (-68 dBm).

11.4.2.8 Co-Channel Interference into NTSC

For co-channel interference into NTSC, impairment ratings varied gradually from “imperceptible” to “very annoying” over a range of 22 dB at weak desired signal level. (See Figure 11-11). The D/U for a mean impairment rating of 3 was about 35 dB. The interference appeared as random noise in the NTSC picture, plus a narrow vertical bar.

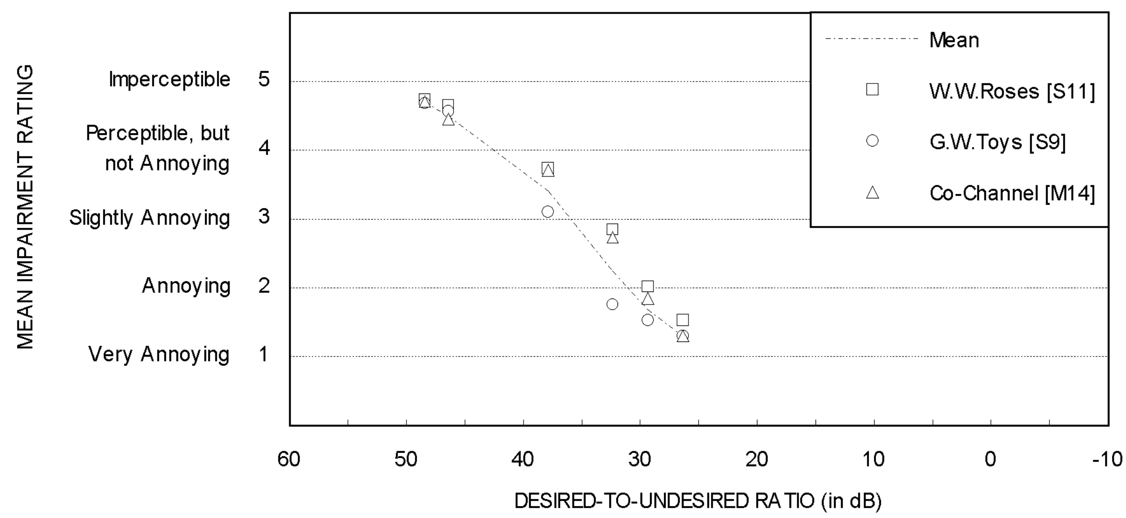

Figure 11-11. Impairment to NTSC when subjected to DSC-HDTV co-channel interference for weak signal condition (-55 dBm).

11.4.2.9 Adjacent-Channel Interference

The D/U ratio at the TOV for adjacent-channel interference into ATV is given in Figure 11-1. The D/U ratio for a mean impairment rating of 3 for adjacent-channel interference into NTSC is given also in Figure 11-1. Note that the more negative the D/U ratio, the better the performance. In practice, it is expected that the DSC-HDTV signal would be transmitted with an average power at least 10 dB lower than NTSC peak power. Under this assumption, the data indicate that DSC-HDTV supports collocation.

The system exhibited a sharp degradation when subjected to adjacent-channel interference from NTSC and ATV. The range from TOV to POU was between 1 and 3 dB.

ATV-into-NTSC mean impairment ratings varied from “imperceptible” to “very annoying” over a range of 14 dB for upper adjacent-channel and 18 dB for lower adjacent-channel. Mean impairment ratings varied from “perceptible, but not annoying” to “annoying” over a range of 6 dB for the upper adjacent-channel and 5 dB for the lower adjacent-channel.

11.4.2.10 Taboo Interference

The taboo performance of DSC-HDTV, based on TOV, is given in Figure 11-12. Note that the more negative the D/U ratio, the better the performance.

In practice, it is expected that the DSC-HDTV signal would be transmitted with an average power at least 10 dB lower than NTSC peak power. Under this assumption, the data show that DSC-HDTV could support collocation on the basis of taboo channel interference requirements.

	ATV-into-NTSC		NTSC-into-ATV		ATV-into-ATV	
CHANNEL	Strong	Weak	Strong	Weak	Strong	Weak
n+2	< -1*	-28	<-33*	<-58*	<-32*	-56
n-2	< -3*	-24	<-33*	<-58*	<-32*	-59
n+4	< -4*	-25	<-33*	<-58*	<-32*	-55
n+7	< -3*	-34	<-33*	<-58*	<-33*	<-63*
n-7	< -3*	-35	<-33*	<-58*	<-33*	<-63*
n+8	< -3*	-36	<-33*	<-58*	<-33*	<-62*
n-8	< -5*	-34	<-33*	<-58*	<-33*	<-63*
n+14	< -1*	-26	<-33*	<-58*	<-33*	<-63*
n+15	< -2*	-17	<-33*	<-58*	<-33*	<-63*

* Determination of TOV level was beyond the limits of ATTC's RF test bed range. Consequently, the system performance was better than the indicated result.

Figure 11-12. Taboo threshold of visibility for DSC-HDTV (D/U in dB).

11.4.2.11 Channel Acquisition

Under a variety of heavy impairment conditions, the DSC-HDTV system fully acquired the signal and displayed a recognizable picture within 3 seconds. Under a variety of moderate impairment conditions, a recognizable picture was displayed within 1 second.

11.4.2.12 Failure and Recovery Appearance

In general, all transmission impairments had similar manifestations in the observed video. When transmission path impairments or interfering signals were strong enough to be visible in the desired picture, they caused large "shimmering" areas of noisy video, visible blocks of various sizes, and patches of erroneous data. In most instances, the intensity and hue of the damaged portions of the image were similar to the correct video around them; only very rarely were there blocks of strongly contrasting color or luminance. Depending on the level of the impairment and complexity of the desired image, the effects of the impairment persisted for about 2-5 seconds after the impairment was removed. Higher levels of impairment created more frequent and larger affected regions. Complex images were more prone to visible effects of a given impairment level than were simpler images.

During a loss of signal, or when the signal was overwhelmed with impairments, the image "dissolved" into blocky artifacts or barely recognizable video and then froze. Upon reacquisition, the blocks "dissolved" into a good image in a period of 2-5 seconds.

11.4.2.13 Peak-to-Average Power Ratio

The peak-to-average power ratio was less than 6.3 dB 99% of the time, and less than 7.6 dB 99.9% of the time.

11.4.2.14 Multiple Impairments

The performance of DSC-HDTV, when simultaneously subjected to multiple impairments, is shown in Figure 11-13 for two cases:

(1) The TOV and POA for NTSC co-channel interference versus random noise, and

(2) The TOV for composite triple beat versus random noise.

Asymptotes are shown reflecting the measured single impairment performance. The operating region lies above and to the right of the respective curves.

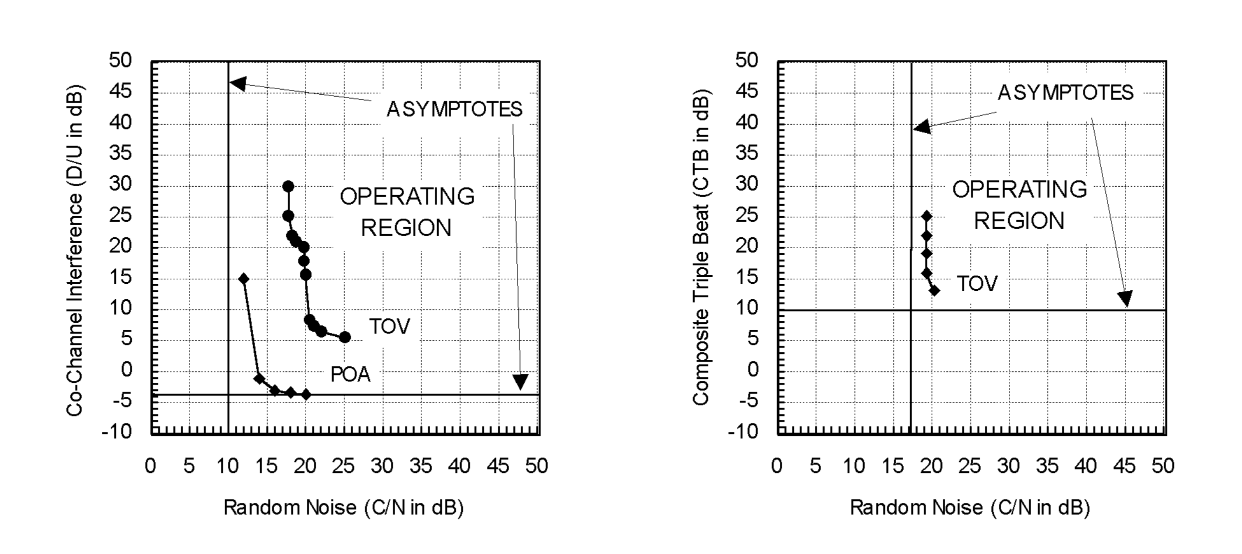

Figure 11-13. Multiple impairments into DSC-HDTV. (Left) POA and TOV for NTSC co-channel interference versus random noise. (Right) TOV for composite triple beat versus random noise.

11.4.3 Scope of Services and Features

11.4.3.1 Data

Two separate channels were provided for ancillary data in the system tested. The total capacity of 413 kbits/sec was divided into one channel of 30 kbits/sec sent as 2-level data and another of 383 kbits/sec sent as 4-level data.

11.4.3.2 Encryption

The system tested did not have encryption implemented. The proponent expects to develop encryption with industry participation.

11.4.3.3 Addressing

The addressing information is transmitted through the ancillary data channel.

11.4.3.4 VCR Capability

The proponent claims that the current S-VHS mechanism is sufficient for the 21.5 Mbits/sec DSC-HDTV data, and that such ½ inch cassette equipment exists in prototype form. According to the proponent, the system knows what fraction of the original image is contained in the displaced frame difference (DFD). A usable picture is obtained without motion compensation by amplifying the DFD by a factor proportional to the inverse of the leak factor. This can be used for VCR forward or reverse scan modes when only a small portion of each compressed frame is acquired. In addition, the segment headers are needed to identify the slice numbers from the acquired data. The picture would appear “blocky” with some slices lost, but suitable for rapid searching. Still frame is simple if the VCR had been playing. If random access to a particular frame on the tape is required, the decoding of several frames leading up to it is needed to achieve full quality. Splicing is optimal if each splice starts with a scene change. Otherwise, the decoder can be signaled to initiate a leak factor inversion for fast startup at the beginning of each splice or insert. Cropping is possible by manipulation or replacement of compressed slices. Image processing for special effects is best performed in the pixel domain after decoding. Square pixels and progressive scanning simplify the implementation of special effects.

11.4.4 Extensibility

11.4.4.1 To No Visible Artifacts

The proponent suggests a rate of 41 Mbits/sec for no visible artifacts regardless of detail and motion, and claims that this can be accomplished with a small change to the compressed video interface.

11.4.4.2 To Studio Quality Data Rate

Claims are made that the compression techniques used for the broadcast of DSC-HDTV are easily simplified to produce a 200 Mbits/sec signal for use in the studio. This signal uses only intraframe processing, and thus is suitable for all editing and special effects processing. The claim is made that the quality is suitable for multiple decoding/encoding as required. This bit rate is suitable for serial data interfaces and also for video tape recording on D-1 VTRs.

11.4.4.3 To Higher Resolution

If it is desirable in the future to maintain higher pixel numbers in the production studio, the higher-resolution signal could be compressed into the 200 Mbits/sec studio signal plus a high-frequency residual signal. The standard DSC-HDTV system would code the studio signal frames, and a simple augmentation encoder would code the residual signal. The final output of editing or special effects could still be recorded using the 200 Mbits/sec portion of the compressed signal.

11.4.4.4 Provision for Future Compression Enhancement

The proponent suggests that the compression algorithm permits improvements in the selection of vector quantization patterns from the codebook, motion estimation, perceptual error threshold computation, buffer control, leak adaptation, and transmission prioritization. These improvements can be made without changing receivers or the transmitted data rate.

11.4.5 Interoperability Considerations

11.4.5.1 With Cable Television

Information on the performance of DSC-HDTV over cable can be found in Section 11.4.2.6.

11.4.5.2 With Digital Technology

Since this system is all-digital, the advantages of all-digital systems apply.

11.4.5.3 Headers/Descriptors

The tested system did not have explicit headers and descriptors. However, ancillary data space was provided for a number of purposes including headers/descriptors.

11.4.5.4 With NTSC

As the DSC-HDTV line-rate is directly related to NTSC, transcoding to NTSC is straightforward. Conversion to and from NTSC has been demonstrated using real-time hardware. Up-conversion from NTSC requires line tripling, horizontal line-rate conversion and interpolation.

11.4.5.5 With Film

The encoder buffer control automatically detects the presence of 24 fps or 30 fps scene material from film sources. When a film source is detected, an alternate buffer control algorithm will be used which takes advantage of repeated frames in the source and minimizes variations in distortion between repeated frames. If film is detected, all video segments will undergo 2-level transmission for maximum coverage area and minimum video data rate. The alternate buffer control for film mode was not completed in time for testing.

11.4.5.6 With Computers

Progressive scanning and square pixels, both of which are used in this system, are important factors for interoperability of an HDTV system with computers. The frame rate used in DSC-HDTV is 59.94 Hz.

11.4.5.7 With Satellites

The maximum total data rate for DSC-HDTV is 21.5 Mbits/sec. As satellite data communication channels use a constant bit rate, the variable bit rate used by DSC-HDTV for terrestrial transmission makes it necessary for the bit stream to be reformatted for satellite transmission. The reformatted bit stream must contain the data needed to permit reconstruction of the variable-rate bit stream for separate

2-level and 4-level terrestrial modulation. The proponent has suggested transmitting two programs per channel using TDM or SCPC in a 36-Mhz transponder, and has considered both two programs/channel and one program/channel DBS scenarios.

11.4.5.8 With Packet Networks

The DSC-HDTV symbols are organized in a form of packet structure using fixed-length data segments. Segment headers include pointers to slices (64H x 48V), so that packet loss results in loss of, at most, a few slices prior to error concealment. The segments make up data frames of duration 1/59.94 sec. In order to carry DSC-HDTV on an ATM network, the data in data frames would be encapsulated in the ATM cell structure. While the number of bits in a data frame varies because of the 2-level transmission, circuit-switched networks use constant bit rate. The proponent suggests repeating 2-level segments for added robustness to fill out the data stream for a constant-bit-rate channel. For a packet network, packets can be used as needed to carry the actual varying bit rate. When cell loss is detected, the decoder will perform error concealment by replacing missing segments with default data or with pixel data from a previous frame.

11.4.5.9 With Interactive Systems

The proponent claims that the delay through the encoder and decoder for the DSC-HDTV system is about 14 frames (224 msec). The proponent claims that an enhancement to the current system allows the latency to be determined by the encoder for interactive applications that require lower latency. Acquisition time is reported in Section 11.4.2.11.

11.4.5.10 Format Conversion

11.4.5.10.1 With 1125/60

Up-converting to the Common Image Format (1920 x 1080) requires 2:3 interpolation horizontally and vertically. SMPTE 240M uses 1035 active lines and would require 16:23 vertical interpolation. Colorimetry is the same as SMPTE 240M.

11.4.5.10.2 With 1250/50

This difficult conversion is somewhat easier with a progressive system such as DSC-HDTV than with an interlaced system.

11.4.5.10.3 With MPEG[10]

Although the DSC-HDTV decoder shares many commonalties with MPEG-1 decoders, the DSC-HDTV decoder would require modification to decode MPEG-1. MPEG-1 decoders will not decode DSC-HDTV.

[10] See Section 8.3.8 for a discussion of MPEG, the MPEG-1 standard, and the MPEG-2 development effort.

11.4.5.10.4 With Still Image

The proponent suggests that conversions with JPEG, Photo CD and CD-I are possible with straightforward spatial filtering after decompression without the flicker that might be introduced by an interlaced display. In simple cases, line and sample doubling or sub-sampling may suffice.

11.4.5.11 Scalability

It is possible to process the 2-level data only and display the images corresponding to that portion of the video information. Decoding only 2-level data will result in a substantially reduced-quality image for scenes that are difficult to encode (requiring large amounts of 4-level data). In such a case, the loss of the 4-level data affects both the temporal and spatial resolution. Where temporal scaling is needed, the process is simplified by the progressive scan used in DSC-HDTV. The proponent has suggested using the motion vectors available at the decoder to perform motion-compensated frame interpolation. The proponent suggests that picture-in-picture be done by windowing on slice (64H x 48V) boundaries.

11.5 SYSTEM IMPROVEMENTS

11.5.1 Already Implemented

11.5.1.1 Vertical Noise Coring in Video Source

The purpose of this improvement was to increase overall coder efficiency and improve picture quality by reducing the number of bits wasted on coding noise. Vertical source-noise coring has been added to the existing horizontal source-noise coring.

11.5.1.2 Improved Quantizer Vector Selection Codebook

To reduce twinkle in still pictures and visible artifacts in noisy or complex pictures, entries have been added to tables contained in the encoder and decoder. There were no hardware changes.

11.5.1.3 Modified Quantizers, Perceptual Weights, Scale Factors, and Variable Length Codes

To reduce artifacts in saturated color regions, in complex or noisy pictures, and for iso-luminance patterns, entries in a variety of tables in the encoder and decoder have been modified. There were no hardware changes.

11.5.1.4 Improved Leak Calculation

The purpose of this improvement was to remove temporal breathing, reduce buffer oscillations, and improve overall coding efficiency. The method of fixing “limit cycles” associated with leak has been replaced.

11.5.1.5 Improved Error Concealment via Unity Leak

The purpose of this improvement was to conceal errors in still pictures and, where accurate motion vectors are available, in motion pictures. In the presence of heavy errors, unity leak is used to replace blocks with errors. Only the decoder was affected.

11.5.1.6 Modified Buffer Control, Increased Decoder Efficiency and Controlled Audio/Video Delay

To provide faster scene changes and a better distribution of 2-level and 4-level segments, parameter changes have been made in the encoder. To control the relative delay between the audio and video display, modifications have been made in the encoder and decoder.

11.5.1.7 Reduction of Pilot Level

To improve upper-adjacent ATV-into-NTSC interference and to lower transmitted signal power, the pilot level for both 2-level and 4-level data has been reduced by 3 dB.

11.5.1.8 Changes in Offset Frequency and Dispersion

To eliminate a color stripe observed in ATV-into-NTSC co-channel interference tests, the transmitter carrier frequency has been offset an additional 30 Hz.

To lower the peak-to-average power ratio by 1.5 dB, a change has been made in the dispersion.

11.5.1.9 Correction of Slice Error Problem

The purpose of this improvement was to correct a hardware problem in the decoder that caused a timing fault in the compressed video data deformatter, giving occasional undetected errors in a given slice (64H x 48V pixel block).

11.5.1.10 Filtering of Input to Motion Estimator

The purpose of this improvement was to overcome a “half-pel” flashing block problem that occurred when an accumulator overflow condition caused erroneous motion vectors to be computed for several 32H x 16V blocks in a scene.

11.5.1.11 Adaptive Two-Dimensional Source Filtering

To improve picture quality, especially for complex pictures, a slight spatial two-dimensional frequency roll-off is performed in the input to the encoder based on an estimate of picture complexity. Only the encoder was affected.

11.5.1.12 Optimization of Decimation Filter for Coarse Motion Estimation

To reduce “swarming” artifacts in high frequency regions, e.g., high frequency zone plates, the decimation filter has been relaxed providing better coarse motion estimators. Only the encoder was involved.

11.5.1.13 Optimized Selection of Segments for 2-Level Transmission

The purpose of this improvement was to provide better picture quality when only 2-level data can be received. Parameters have been adjusted to change the selection of segments sent as 2-level data. Only the encoder was involved.

11.5.1.14 Two DSC-HDTV Programs in One 6 MHz Cable Channel

The purpose of this improvement was to provide two DSC-HDTV programs on a single cable channel. A 16-VSB transmission format is used to achieve a 43 Mbits/sec data rate.

11.5.2 Implemented in Time for Field Testing

11.5.2.1 Spatially Adaptive Leak

To improve the coding of pictures that contain partial scene changes, extreme amounts of uncovered background, or very high amplitude source noise, changes will be made to the encoder and decoder to permit the encoder to vary the leak value on a block-by-block basis.

11.5.2.2 Faster Adaptive Equalizer that Adapts on Data

To be faster and have better tracking of time-varying multipath signals in the receiver, the adaptive equalizer will adapt on data.

11.5.2.3 ATSC T3/186 Audio and Flexible Assignment of Audio, Video, Ancillary and Conditional Access/Encryption Data

To fulfill the audio requirements of T3/186, a 5.1-channel sound system will be implemented using the Dolby AC-3 system, and two additional independent audio channels will be implemented using the Dolby AC-2A system. This choice may be revisited if another audio sub-system becomes available before testing begins.

To allow flexible allocation of data, headers will be included. Flexible allocation capability will be implemented to the extent that the interfaces to the various services to be carried are adequately specified.

12. ADVANCED DIGITAL HDTV

12.1 SYSTEM OVERVIEW

AD-HDTV, proposed by the Advanced Television Research Consortium (ATRC) is a digital simulcast system that requires a single 6 MHz television transmission channel.[1] The ATRC includes: David Sarnoff Research Center, North American Philips, Thomson Consumer Electronics, NBC, and Compression Labs, Incorporated. The AD-HDTV video source is an analog RGB signal with 1050 lines, 2:1 interlaced, a 59.94 Hz field rate, and an aspect ratio of 16:9. A matrix converts the RGB color signals to Y-Cr-Cb components, conforming to the SMPTE 240M representation and colorimetry specification. The luminance video sampling frequency is 56.64 MHz. The source and display format is interlaced with 960 lines by 1500 pixels per line. To create the internal progressive scan format used by the system's frame based coding, the interlaced source is transcoded into a 960 line by 1248 pixels per line, progressively scanned, 29.97 frames per second format. After format conversion, the two color-difference signals are decimated by a factor of two both horizontally and vertically, resulting in a sampling density one fourth that of the luminance signal. The video compression uses an adaptation of the MPEG-1 (Moving Picture Experts Group) standard.[2] The system uses two separate transmission channels, each with 32 QAM modulation, totaling 24 Mbits/sec. The high priority (HP) channel carries 4.8 Mbits/sec of data and is of higher power than the standard priority (SP) channel with 19.2 Mbits/sec of data. The purpose of the two-channel approach is to provide a measure of "graceful degradation" and to reduce co-channel interference from and into NTSC. The audio channels are compressed using a proprietary standard called MUSICAM that is related to layers 1 and 2 of the 3-layer MPEG audio standard. The audio is sampled at 48 kHz with 16 bit precision. Audio in the tested system supported two stereo pairs of 256 kbits/sec each; they were transmitted in the HP channel. An additional 256 kbits/sec was provided for data.

12.2 SPECTRUM UTILIZATION

The AD-HDTV analysis was conducted under two allotment scenarios (using both VHF and UHF channels for ATV stations, and using only UHF channels) and two sets of interference constraints (considering only co-channel interference, and both co-channel and adjacent-channel interference). In addition, the impact of taboos was assessed by re-calculating coverage and interference for each case assuming the taboo performance measured in the laboratory.

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[1] The ATRC was unable to deliver its AD-HDTV system to the test laboratories at the beginning of the scheduled test slot. The resulting delay slightly truncated testing performed on the system. In addition, an incorrectly included filter in the AD-HDTV tuner was discovered during testing. The Advisory Committee decided to rerun certain tests after the proponent replaced the incorrect filter. Subsequently, SS/WP2 agreed that the data from the retest, not from the corresponding original test, should be used by the Advisory Committee for analysis and evaluation of the proponent's system.

[2] See Section 8.3.8 for a discussion of MPEG, the MPEG-1 standard, and the MPEG-2 development effort.

Figure 12-1 shows planning factors, specific to the AD-HDTV system, as derived from test results.[3] The numbers in the figure are desired-to-undesired ratios (D/U) in dB. The values for interference into NTSC are based on CCIR Impairment Grade 3 (slightly annoying) as determined from the ATEL subjective tests.[4] Because the ATV service is intended to be an improvement over NTSC, interference into ATV is based on CCIR Impairment Grade 4 (perceptible but not annoying) if the range between TOV and POA exceeds 5 dB. Otherwise, the TOV power level is used. AD-HDTV demonstrated a "cliff effect" and thus D/U values are based on TOV data. Also, the data show that AD-HDTV can support collocation on both the upper and lower adjacent-channels.

Co-Channel	D/U (dB)
ATV-into-NTSC	+34
NTSC-into-ATV	+0.50
ATV-into-ATV	+19.1

Carrier-to-Noise	+18.4

Adjacent-Channel	D/U (dB)
Lower ATV-into-NTSC	-16.0
Upper ATV-into-NTSC	-8.9
Lower NTSC-into-ATV	-38
Upper NTSC-into-ATV	-36
Lower ATV-into-ATV	-33
Upper ATV-into-ATV	-16.8

Figure 12-1. Planning factors specific to AD-HDTV.

12.2.1 Accommodation Percentage

AD-HDTV could provide a 100% accommodation of all NTSC assignments for co-channel only, and co-channel and adjacent-channel constraints, under both the VHF/UHF and UHF scenarios. The accommodation is achieved at the expense of reducing the ATV and NTSC service areas. No attempt was made to reduce interference to NTSC service by adjusting either ATV or NTSC power.

12.2.2 Service Area

Figure 12-2 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 both co-channel and adjacent-channel constraints. In this

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[3] As determined by SS/WP2, spot check data are not included in Figure 12-1; however, spot check data, marginally different from the original data, were used in spectrum utilization analyses. The spot check data used by PS/WP3 were for Co-Channel NTSC-into-ATV (0.82 dB), Co-Channel ATV-into-ATV (18.4 dB), and Carrier-to-Noise (18.1 dB). Spot check data were used also for the effect of taboo interference. Use of the original data would have affected all the spectrum utilization results. For example, use of spot check data is believed to affect co-channel interference results by slightly improving ATV-into-NTSC and ATV-into-ATV, and to a lesser degree, worsening NTSC-into-ATV.

[4] For spectrum utilization analysis, a correction factor was applied to weak signal level TOV data to estimate a CCIR Impairment Grade 3 for Adjacent-Channel Upper ATV-into-NTSC because subjective assessment was not performed at weak signal level.

graph, the 1,657 current NTSC stations are placed in order of decreasing ATV to NTSC service area ratio. Examination of the graph reveals that 10.3% (170) of the ATV stations under this scenario would have an ATV service area at least 20% larger than their companion NTSC service area and 95% (1,579) 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 39.2 million square kilometers.

Figure 12-3 shows the interference statistics for the VHF/UHF scenario. During the transition period, 46.5% of ATV stations would receive no interference. This would rise to 55.2% after the transition period ends. Also during the transition period 3.4% of the ATV stations would receive interference in more than 35% of their noise-limited coverage area. This would fall to 3.2% after the transition period ends. The total interference area created within the ATV noise-limited coverage area during the transition period is 2.94 million square kilometers. This would decrease to 2.45 million square kilometers after the transition period ends. Of the existing NTSC stations, 55.7% would not receive any new interference because of the ATV service, while 2.8% would receive new interference in more than 35% of their Grade B area. The total new interference into NTSC created under this plan is 1.77 million square kilometers.

When taboos are included in the interference calculations for the VHF/UHF scenario, the number of ATV stations with no interference during the transition period is 43.2%; the number of ATV stations with interference in more than 35% of their noise-limited coverage area is 3.4%. The number of NTSC stations receiving no new interference is 50.0%; the number of NTSC stations with interference in more than 35% of their Grade B area is 3.1%.

When the adjacent-channel constraints of Figure 12-1 are not included in the VHF/UHF scenario, the allotment/assignment table is different. In that case, 17.5% (290) of the ATV stations would have an ATV service area at least 20% larger than their companion NTSC service area and 99% (1,633) would have an ATV service area at least 80% of their companion NTSC service area. During the transition period, 76.0% of ATV stations would receive no interference. This would rise to 80.1% after the transition period ends. Also during the transition period, 0.9% of the ATV stations would receive interference in more than 35% of their noise-limited coverage area. This would remain at 0.9% after the transition period ends. Of the existing NTSC stations, 62.6% would not receive any new interference because of the ATV service, while 2.3% would receive new interference in more than 35% of their Grade B area.

Figure 12-4 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 UHF scenario, taking into account both co-channel and adjacent-channel constraints. In this graph, as before, the 1,657 current NTSC stations are placed in order of decreasing ATV to NTSC service area ratio. Examination of the graph reveals that 10.7% (178) of the ATV stations under this scenario would have an ATV service area at least 20% larger than their companion NTSC service area and 92% (1,531) 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 37.8 million square kilometers.

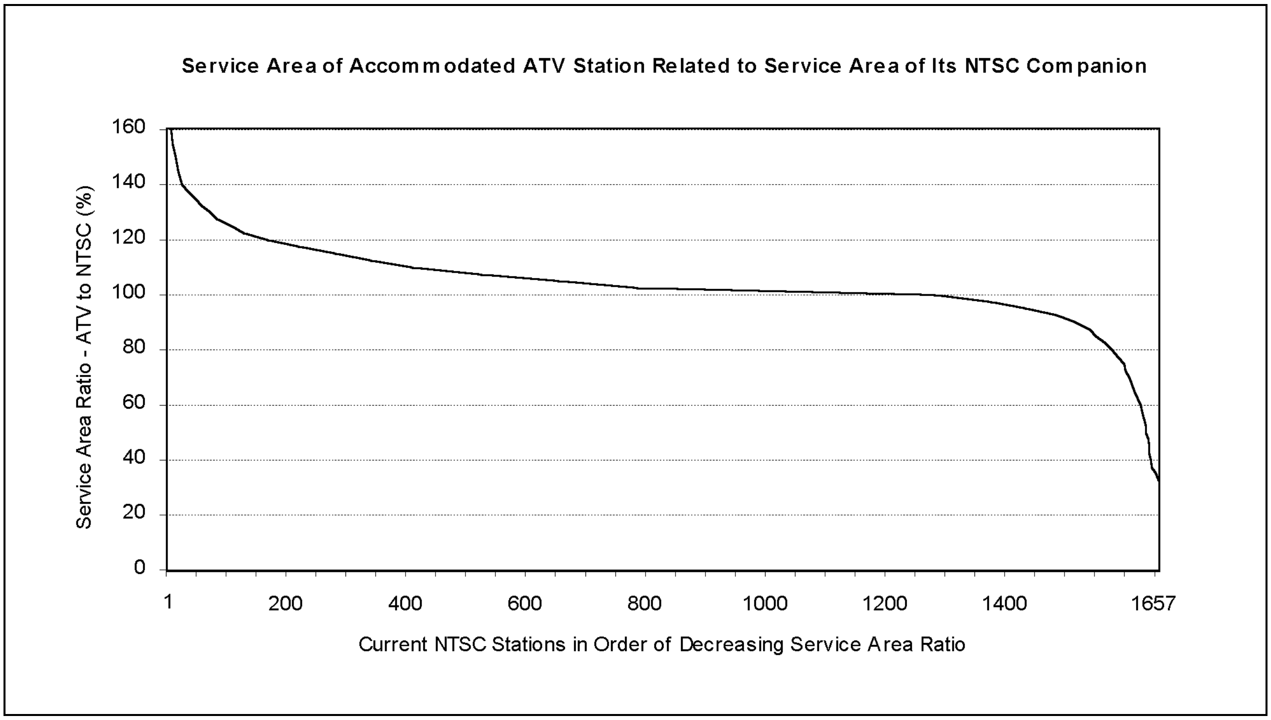

Figure 12-2. AD-HDTV VHF/UHF Scenario — Interference-limited service area of each ATV station relative to the interference-limited service area of its companion NTSC station (co-channel and adjacent-channel constraints).

Interference Area Compared to Coverage Area	ATV Stations with Interference		NTSC Stations with Added Interference Due to ATV
	During Transition	After Transition	
No Interference	46.5 %	55.2 %	55.7 %
0 - 5 %	20.5 %	18.5 %	15.9 %
5 - 10 %	13.5 %	10.0 %	9.0 %
10 - 15 %	7.6 %	6.3 %	6.5 %
15 - 20 %	3.9 %	2.8 %	4.0 %
20 - 25 %	2.3 %	1.9 %	3.0 %
25 - 30 %	1.6 %	1.4 %	1.5 %
30 - 35 %	0.7 %	0.6 %	1.6 %
> 35 %	3.4 %	3.2 %	2.8 %

Figure 12-3. AD-HDTV VHF/UHF Scenario — Interference characteristics (co-channel and adjacent-channel constraints).

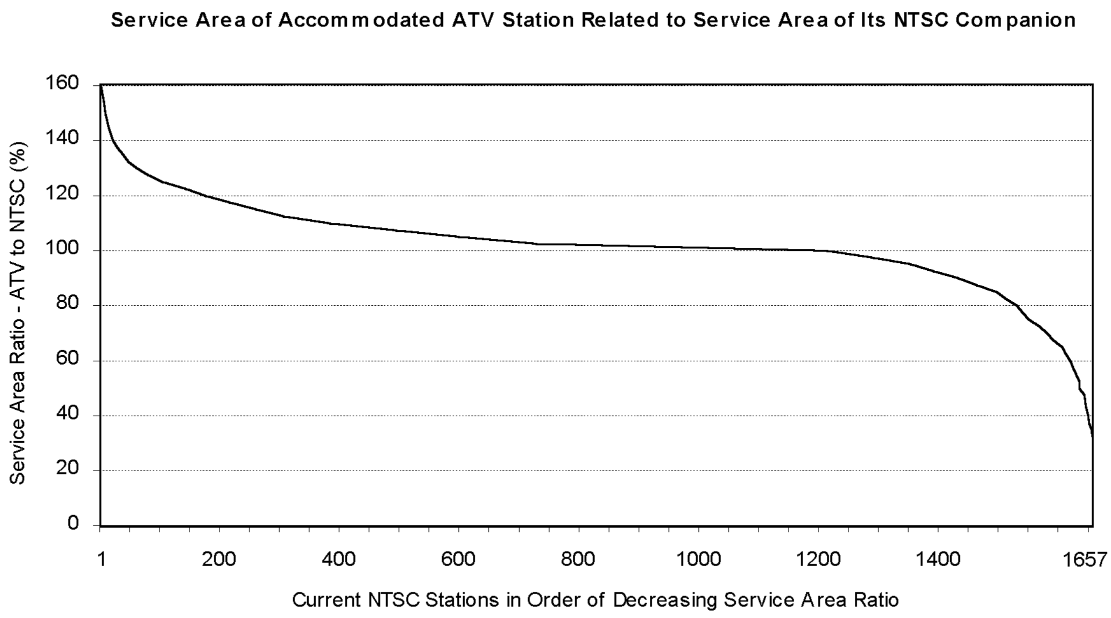

Figure 12-4. AD-HDTV UHF Scenario — Interference-limited service area of each ATV station relative to the interference-limited service area of its companion NTSC station (co-channel and adjacent-channel constraints).

Interference Area Compared to Coverage Area	ATV Stations with Interference		NTSC Stations with Added Interference Due to ATV
	During Transition	After Transition	
No Interference	46.8 %	52.7 %	59.7 %
0 - 5 %	17.0 %	16.5 %	9.4 %
5 - 10 %	10.4 %	8.9 %	6.0 %
10 - 15 %	7.6 %	5.8 %	4.1 %
15 - 20 %	5.0 %	4.5 %	2.9 %
20 - 25 %	3.4 %	2.6 %	3.0 %
25 - 30 %	2.5 %	2.1 %	2.8 %
30 - 35 %	1.9 %	1.8 %	2.4 %
> 35 %	5.3 %	5.2 %	9.7 %

Figure 12-5. AD-HDTV UHF Scenario — Interference characteristics (co-channel and adjacent-channel constraints).

Figure 12-5 shows the interference statistics for the UHF scenario. During the transition period, 46.8% of ATV stations would receive no interference. This would rise to 52.7% after the transition period ends. Also during the transition period, 5.3% of the ATV stations would receive interference in more than 35% of their noise-limited coverage area. This would fall to 5.2% after the transition period ends. The total interference area created within the ATV noise-limited coverage area during the transition period is 3.43 million square kilometers. This would decrease to 3.00 million square kilometers after the transition period ends. Of the existing NTSC stations, 59.7% would not receive any new interference because of the ATV service, while 9.7% would receive new interference in more than 35% of their Grade B coverage area. The total new interference created under this plan is 2.53 million square kilometers.

When taboos are included in the interference calculations for the UHF scenario, the number of ATV stations with no interference during the transition period is 43.8%; the number of ATV stations with interference in more than 35% of their noise-limited coverage area is 5.3%. The number of NTSC stations receiving no new interference is 54.0%; the number of NTSC stations with interference in more than 35% of their Grade B area is 10.2%.

When the adjacent-channel constraints of Figure 12-1 are not included in the UHF scenario, the allotment/assignment table is different. In that case, 15.2% (252) of the ATV stations would have an ATV service area at least 20% larger than their companion NTSC service area and 96% (1,587) would have an ATV service area at least 80% of their companion NTSC service area. During the transition period, 63.3% of ATV stations would receive no interference. This would rise to 70.1% after the transition period ends. Also during the transition period, 2.9% of the ATV stations would receive interference in more than 35% of their noise-limited coverage area. This would remain at 2.9% after the transition period ends. Of the existing NTSC stations, 63.9% would not receive any new interference because of the ATV service, while 8.6% would receive new interference in more than 35% of their Grade B area.

The frequency distribution of ATV station average effective radiated power levels needed to achieve ATV noise-limited coverage comparable to NTSC Grade B coverage was calculated. The maximum average effective radiated power level was 40.42 dBk (11,000 kW). The results are shown in Figure 12-6.

12.3 ECONOMICS

12.3.1 Cost to Broadcasters

The estimated equipment cost for an AD-HDTV transitional station is shown in Figure 12-7. The total cost of the transitional station was estimated to be $1,785,500. The total cost of a minimal station was estimated to be $1,169,100. A general description of the methods used to develop the cost data is contained in Section 8.2.1.

12.3.2 Cost to Alternative Media

Information on this topic was not provided.

Average Effective Radiated Power Level		Number of TV Stations			
		VHF/UHF Scenario			UHF Scenario
(dBk)	(kW)	Low VHF	High VHF	UHF	UHF
Less than 5	Less than 3.2	10	20	89	89
5 - 10	3.2 - 10.0	3	12	44	44
10 - 15	10.0 - 31.6	4	10	55	60
15 - 20	31.6 - 100		5	227	237
20 - 25	100 - 316			289	296
25 - 30	316 - 1,000			315	335
30 - 35	1,000 - 3,160			298	308
35 - 40	3,160 - 10,000			268	280
> 40	> 10,000			8	8
TOTAL		17	47	1,593	1,657

Figure 12-6. AD-HDTV power level distribution.

Subsystem	Cost (thousands)
Satellite Receiver, Demodulator, Decoder	$ 13.5
Character Generator, Still Store, Two 28” Monitors	200.0
Routing Switcher (10 x 10), Master Control	125.0
2 ATV VTRs and Monitors	170.0
NTSC Upconverter, including Line Doubler	19.0
ATV-to-NTSC Downconverter	15.0
34” Monitor, Seven 17” Monitors, Eight Decoders	110.0
ATV Encoder	280.0
STL Subsystem	92.5
ATV Modulator, ATV Exciter	35.0
ATV Transmission Subsystem	725.5
TOTAL COST	$1,785.5

Figure 12-7. Equipment cost for an AD-HDTV transitional station.

12.3.3 Cost to Consumers

The estimated material cost data for an AD-HDTV receiver are shown in Figure 12-8. A general description of the methods used to develop the cost data is contained in Section 8.2.2.

Using a 2.5 multiplier, the resulting estimated retail price for a AD-HDTV receiver is $2,515 for a 34” direct view receiver and $3,805 for a 56” projector receiver.

Subsystem	34" Widescreen Direct View Receiver	56" Widescreen CRT Type Projector
Signal Processing Components	$ 127	$ 127
Audio Amplifiers, Speakers	30	30
Scan System, Power Supply, Video Amps	63	176
Display	700	1,050
Cabinet	90	140
TOTAL MATERIAL COST	$1,006	$1,522

Figure 12-8. Material cost data for an AD-HDTV receiver.

12.4 TECHNOLOGY

12.4.1 Audio/Video Quality

In video subjective tests of AD-HDTV, the system performed consistently across segments of test material with no difference between still and moving materials. For 8 of the 9 stills and 14 motion sequences, AD-HDTV was judged, on average, to be about 0.3 grade lower in quality than the 1125-line studio reference. The remaining still, electronically generated, was judged to be better in quality than the reference.[5]

Problems were noted when the system was tested for video-coder and motion-compensation overload. No significant problems were reported when the system was subjected to scene cuts, noisy source material, and to a sudden stop in motion.

During system-specific tests, expert observers noted that the audio remained useful, but not unimpaired, over the range between the SP and HP thresholds. There was no evidence that the audio system failed before the accompanying video.

12.4.1.1 Video Quality

Subjective judgments of image quality by non-experts are summarized in Figure 12-9. Scores are the differences between judgments of the reference and judgments of AD-HDTV for 9 stills and 14 motion sequences. For 8 of the 9 stills, AD-HDTV was judged, on average, to be 0.3 grade (i.e., about 6 points on the 100-point scale) lower in quality than the 1125-line studio reference; for the remaining still (S14), the system was judged to be 0.9 grade higher in quality than the reference (this may reflect reduced visibility of interlacing artifacts in the AD-HDTV rendering of this picture). For motion sequences, AD-HDTV also was judged, on average, to be 0.3 grade (i.e., about 6 points) lower in quality than the reference.

[5] See Section 8.3.3.

AD-HDTV performed consistently across all segments of test material. Differences ranged from -0.1 to -0.7 grade (not counting S14). The variability among viewers was consistent across materials and within accepted limits. Expert commentary, supported by reports from the non-expert viewers, attributed the small differences between AD-HDTV and the reference primarily to quantization noise (experts judged this to be at a level low enough not to be objectionable to non-experts.) Expert observers noted an additional artifact for rapidly moving images, which sometimes showed jerky motion, severe blockiness, and contouring; sometimes the images would appear to break up.

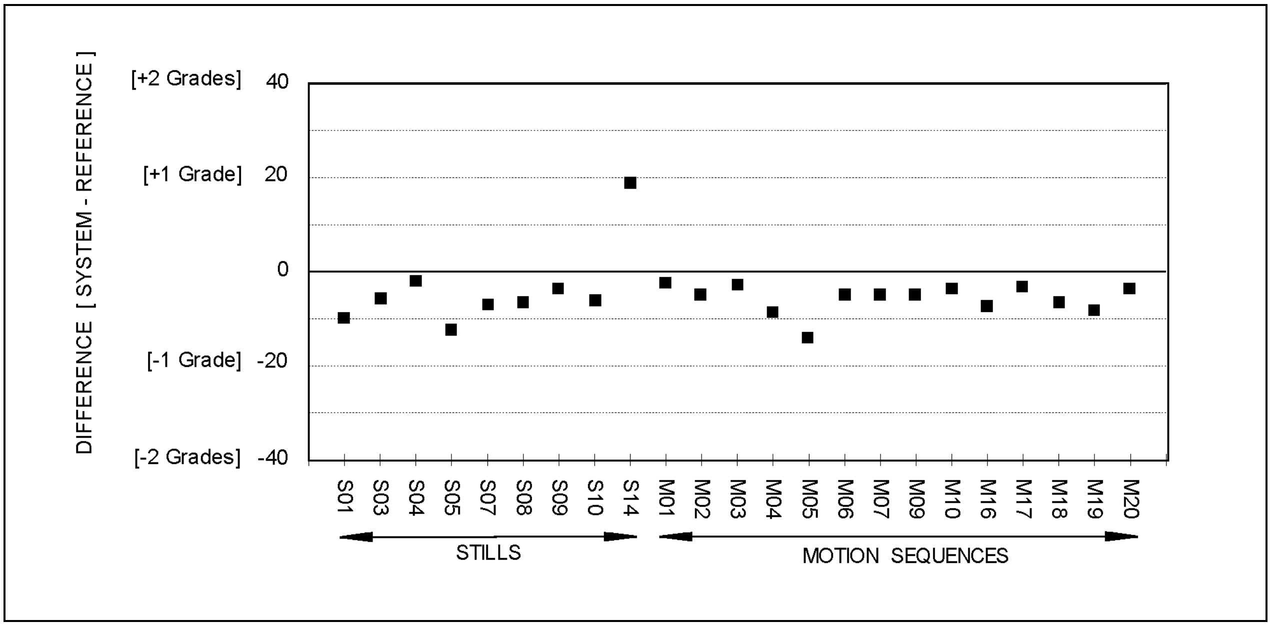

Figure 12-9. Average differences between quality judgments for the 1125-line studio quality reference and for AD-HDTV.

The results of objective tests of static and dynamic resolution show slight losses in vertical luminance resolution at high rates of movement.[6]

When subjected to noisy source material, adding noise to the source simply made the image noisier, except at the highest levels of noise where the picture exhibited a freeze frame effect, or highly visible blocks and jerky motion.

In general, scene cuts were rendered very well, including deliberate test sequences designed to stress the 9-frame MPEG-1 group-of-picture data structure used in AD-HDTV. When viewed in real time, some expert observers saw very slight noise immediately following some of the cuts. When observing still frames, AD-HDTV introduced only slight, localized artifacts and they were gone after a few frames.

[6] See Section 8.3.5.

When tested for video-coder overload, the image broke up severely into blockiness. When viewed as still frames one of the images persisted for 7 frames. When tested for motion-compensation overload at velocities of 0.4 picture height per second and greater, the system introduced quantization noise and blockiness. At a velocity of 0.8 picture height per second (a speed slow enough for eye tracking), the image was severely impaired by a “dirty window” of blocky noise. No artifacts were noted in response to a sudden stop in movement.

Slight system artifacts became visible when material was subjected to two encode/decode passes through the system. After the second pass, added noise did not cause pictures to be degraded substantially. The appearance of a momentary black panel at the top, after a scene cut from gray, was consistent and quite disagreeable.

The AD-HDTV system exhibited good chrominance dynamic range in red, green, and blue channels.

In examining video quality for gradual degradation, using sequences with very simple images to highly complex ones, expert observers saw very few images other than stills that could be rendered in “usable” form by HP data alone. The observers believed that, for most reasonably active images, the form of gradual degradation embodied in this system produced recognizable pictures having utility only for short, temporary, and infrequent signal fading.

12.4.1.2 Audio Quality

During system-specific tests, expert observers noted that the audio remained useful, but not unimpaired, over the range between the SP and HP noise impairment thresholds. There was no evidence that the audio system failed before the accompanying video.[7]

Objective tests for dynamic range, total harmonic distortion (THD), THD + noise (THD+N), intermodulation distortion (IMD), dynamic intermodulation distortion (DIM), frequency response, and overload versus frequency were not performed.

For co-channel interference of ATV-into-NTSC, at both moderate and weak signal levels, there was no degradation in THD + N over the range of interference tested. For upper adjacent-channel interference of ATV-into-NTSC, at moderate signal level, two receivers showed that BTSC audio began to degrade when the video quality was “unimpaired” while a third receiver showed that audio began to degrade when video quality was between “perceptible, but not annoying” and “slightly annoying.” In the test of co-channel ATV-into-NTSC, AD-HDTV caused no significant degradation of NTSC VBI data.

12.4.2 Transmission Robustness

In most regards, AD-HDTV performed as predicted by the proponent. Its performance equalled or exceeded that of NTSC in almost all impairment conditions. Typically the system exhibited immunity to

[7] See Section 8.3.1.

a variety of transmission impairments over a wide range of impairment levels. Beyond that range, the system exhibited a sharp degradation in performance when exposed to all impairments. At even higher levels of noise impairments, the system produced recognizable pictures and usable, but not unimpaired, audio over an additional range. This characteristic has utility only for short, temporary, and infrequent signal fading. In general, all transmission impairments had similar manifestations in the observed video, which were quite different than the effect they produce on NTSC. Transmission impairments and interference, when strong enough, produced display errors and caused jerkiness and randomly spaced rectangular patches of images either to freeze or to display erroneous information for a short duration.

AD-HDTV interference into NTSC had the characteristic of white noise, and produced a graceful degradation. Cable transmission had no adverse effect on AD-HDTV performance.

12.4.2.1 Noise Performance

When AD-HDTV was subjected to random channel noise (based on a 6 MHz noise bandwidth), the carrier-to-noise ratio[8] (C/N) at the TOV was measured and is shown in Figure 12-1. This was the noise threshold level for the SP data. The system had a sharp degradation: the range between the TOV and the Point of Unusability (POU) was 0.75 dB.

Expert observers concluded that the form of gradual degradation embodied in this system has utility only for short, temporary, and infrequent channel fading. The system continued to produce recognizable pictures and usable, but not unimpaired, audio with HP data alone over a range extending about 5 dB beyond TOV.

12.4.2.2 Static Multipath

The system performed well at levels which would be highly objectionable in NTSC. The TOV for echoes of +0.08 µsec, +0.32 µsec and +2.56 µsec were at D/U ratios of 2.1 dB (i.e., echo amplitude of 79%), 0.1 dB (98%), and 4.9 dB (57%), respectively. For an echo of -0.08 µsec, no impairment was observed up to the D/U limit of 0 dB.

12.4.2.3 Flutter

The TOV for airplane flutter of 2 Hz and 5 Hz were at D/U levels of 16.1 dB (16%) and 17.6 dB (13%) respectively.

12.4.2.4 Impulse Noise

Impulse noise performance was judged to be better than NTSC by approximately 10.5 dB for TOV. The range between TOV and POU was about 4 dB.

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[8] Caution must be exercised in comparing C/N between analog and digital systems, as definition of carrier levels is not consistent. Measurement of power level is consistent, however, among digital systems. (See Section 8.3.6.)

In the gated noise test at a fixed 10 Hz repetition rate, TOV was reached when the pulse width was increased to 17 µsec. Pulse width at POU was greater by approximately a factor of 3. When the pulse width was decreased to 13 µsec, TOV was reached when the pulse repetition rate was increased to 20 Hz.

12.4.2.5 Discrete Frequency Interference

The D/U ratio at the TOV for discrete frequency interference was -42 (+12, -3) dB in the first adjacent channels, and +20 dB in-band, except at one test frequency in the notch between SP and HP signals where 0 dB was measured.

12.4.2.6 Cable Transmission

The subjective tests show that cable transmission *per se* has no adverse effect on AD-HDTV performance.

Among the cable-specific tests conducted, the system performed better than NTSC when subjected to hum (TOV @ 11%); composite triple beat, or CTB, (TOV @ -16 dBc); and composite second order, or CSO, (TOV @ -26 dBc). Its performance was poorer than NTSC when subjected to phase noise (TOV @ -84 dBc), residual FM (TOV @ -0.6 kHz), and local oscillator instability (TOV @ +0.45 kHz, -0.55 kHz).

The threshold values for the ancillary data channel were consistent with the values found in other tests for Gaussian noise, CTB, and hum modulation, and 1 dB worse for phase noise.

12.4.2.7 Co-Channel Interference into ATV

AD-HDTV was much more robust than NTSC to co-channel interference from either NTSC or ATV.

Results are summarized in Figure 12-1. The system performance exhibited a sharp degradation when ATV co-channel interference was increased beyond TOV. The range from TOV to POA was less than 1.6 dB for NTSC-into-ATV co-channel interference, and about 1 dB for ATV-into-ATV co-channel interference.

In subjective tests, NTSC-into-ATV impairment ratings varied from “perceptible, but not annoying” to “very annoying” over a range of 2.6 dB.

12.4.2.8 Co-Channel Interference into NTSC

For co-channel interference into NTSC, impairment ratings varied gradually from “imperceptible” to “very annoying” over a range of 27 dB at weak desired signal level. (See Figure 12-10.) The D/U for a mean impairment rating of 3 is about 34 dB. The interference appeared as random noise in the NTSC picture.

12.4.2.9 Adjacent-Channel Interference

The D/U ratio at the TOV for adjacent-channel interference into ATV is given in Figure 12-1. The D/U ratio for a mean impairment rating of 3 for adjacent-channel interference into NTSC is given also in Figure 12-1. Note that the more negative the D/U ratio, the better the performance. In practice, it is expected that the AD-HDTV signal would be transmitted with an average power at least 10 dB lower than NTSC peak power. Under this assumption, the data indicate that AD-HDTV supports collocation.

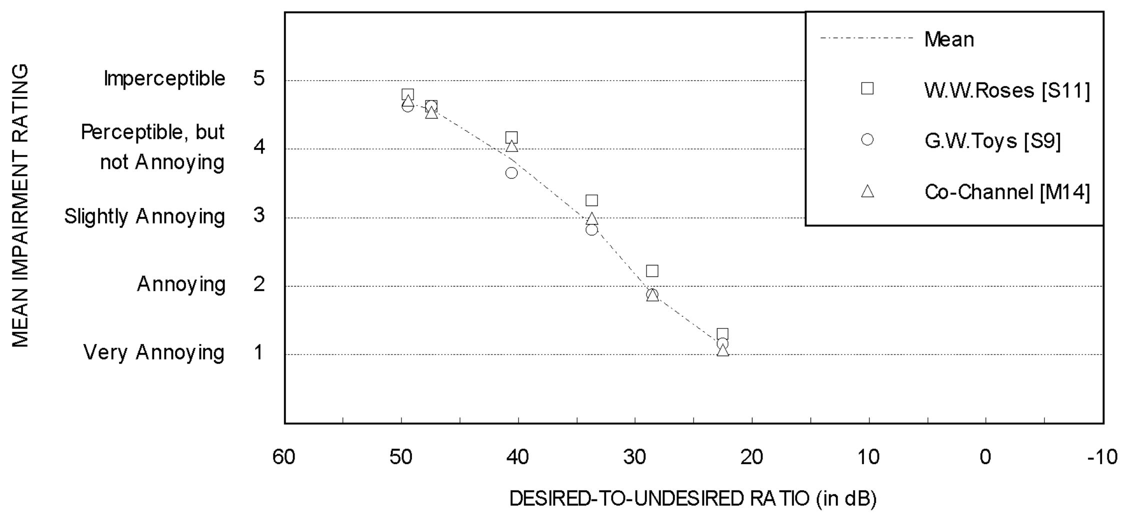

Figure 12-10. Impairment to NTSC when subjected to AD-HDTV co-channel interference for weak signal condition (-55 dBm).

The system exhibited a sharp degradation when subjected to adjacent-channel interference from NTSC and ATV. The range from TOV to POU was about 1 dB.

ATV-into-NTSC impairment ratings varied from “imperceptible” to “very annoying” over a range of about 16 dB. Mean impairment ratings varied from “perceptible, but not annoying” to “annoying” over a range of 5 dB for the upper adjacent-channel and 9 dB for the lower adjacent-channel.

12.4.2.10 Taboo Interference

The taboo performance of AD-HDTV, based on TOV is given in Figure 12-11. Note that the more negative the D/U ratio, the better the performance.

In practice, it is expected that the AD-HDTV signal would be transmitted with an average power at least 10 dB lower than NTSC peak power. Under this assumption, the data show that AD-HDTV can support collocation on the basis of taboo channel interference requirements.

12.4.2.11 Channel Acquisition

Under a variety of channel conditions, the AD-HDTV system fully acquired the signal and displayed a recognizable picture within 2.5 to 5.8 seconds. Due to AD-HDTV hardware implementation limitations, channel change testing was modified by interrupting the carrier; therefore, the measured times do not include tuner synthesizer frequency changes.

CHANNEL	ATV-into-NTSC		NTSC-into-ATV		ATV-into-ATV	
	Strong	**Weak**	**Strong**	**Weak**	**Strong**	**Weak**
n+2	< +1*	-25	-32	-51	-30	-50
n-2	< 0*	-23	-32	-51	-29	-49
n+4	< -2*	-23	<-33*	<-58*	<-33*	-63
n+7	< -2*	-32	<-33*	<-58*	<-33*	<-63*
n-7	< -1*	-31	<-33*	<-58*	<-31*	<-61*
n+8	< 0*	-37	<-33*	<-58*	<-33*	<-63*
n-8	< -1*	-28	<-33*	<-58*	<-32*	<-62*
n+14	< +1*	-25	**	**	**	**
n+15	< -1*	-15	<-30*	<-58*	<-29*	<-59*

* Determination of TOV level was beyond the limits of ATTC's RF test bed range. Consequently, the system has a better performance than the indicated result.

** Test not performed.

Figure 12-11. Taboo threshold of visibility for AD-HDTV (D/U in dB).

12.4.2.12 Failure and Recovery Appearance

In general, all transmission impairments had similar manifestations in the observed video. When transmission path impairments were strong enough to be visible in the observed picture, they caused blockiness and jerky motion. The visible blocks tended to cluster around moving areas, but there were often other, more scattered, blocks of impairments. There was occasional spatial displacement of blocks of the image. When impairments were strong enough that images were constructed solely from HP data, i.e., beyond POU, the general nature of the impairments remained the same — they became worse and led to significant image freezing and occasional complete loss of large areas of the image.

In all cases the picture disturbances had well defined straight boundaries, and in most cases matched the shapes and sizes of system blocks (e.g. 8x8, 16x16, or 16x208 pixels); and did not change appearance while present. System recovery from picture disturbances was rapid (much less than one second).

12.4.2.13 Peak-to-Average Power Ratio

The peak-to-average power ratio was less than 6 dB 99% of the time, and less than 6.7 dB 99.9% of the time.

12.4.2.14 Multiple Impairments

The performance of AD-HDTV, when simultaneously subjected to multiple impairments, is shown in Figure 12-12 for two cases:

(1) The POA for NTSC co-channel interference versus random noise, and

(2) The TOV for composite triple beat versus random noise.

Asymptotes are shown reflecting the measured single impairment performance. The operating region lies above and to the right of the respective curves.

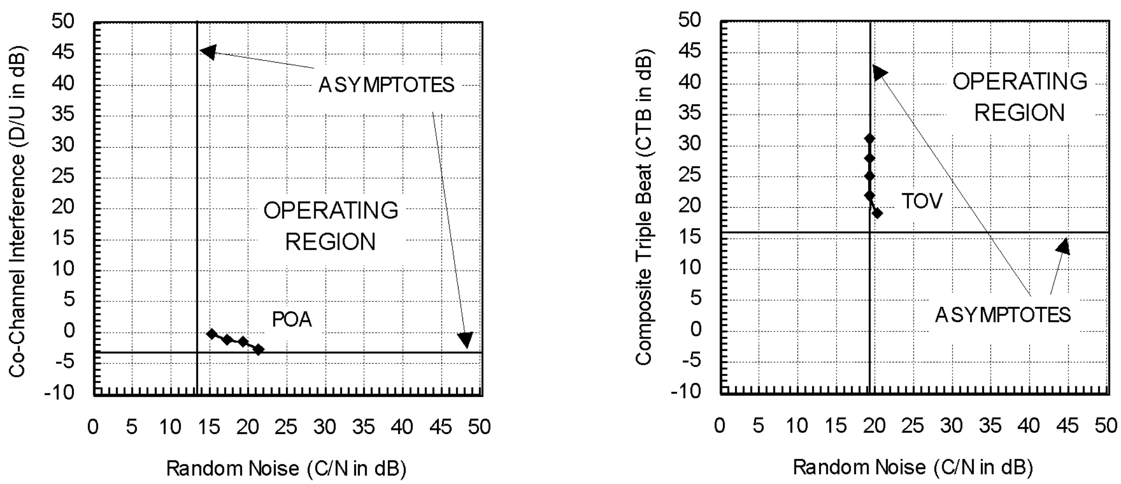

Figure 12-12. Multiple impairments into AD-HDTV. (Left) POA for NTSC co-channel interference and random noise. (Right) TOV for composite triple beat and random noise.

12.4.3 Scope of Services and Features

12.4.3.1 Data

Because of AD-HDTV's asynchronous data multiplexing, there is no hard partitioning of ancillary data. Unassigned service types provide for the delivery of many types of ancillary data. For example, AD-HDTV has provision for carrying text and graphics overlay data that can be sent as a separate service type and superimposed on the display at the receiver. For testing, an allocation of 256 kbits/sec was made for ancillary data, and those data were set aside as SP data. A standard communications interface port for these ancillary data was provided.

12.4.3.2 Encryption

The tested system did not include encryption. The proponent claims that the packet structure has been designed to accommodate encryption and expects to detail the encryption method with industry participation.

12.4.3.3 Addressing

The system provides opportunities for flexible high-data-rate burst-mode delivery of ancillary data. As a limit, the entire channel capacity, 18.5 Mbits/sec, could be dedicated to addressing receivers with decryption keys. Conditional access data can be treated as a special service type and packaged into its own transport cells, or included within the video and audio data.

12.4.3.4 VCR Capability

Although hardware development of VCRs has been reported, hardware has yet to be demonstrated. AD-HDTV has periodically occurring frames that are entirely spatially coded. This is said to provide the ability to reconstruct pictures in fast-forward and reverse scanning modes from digital storage media. Splices and inserts could be made on GOP boundaries. Limited picture cropping can be handled in compressed form if it aligns with macroblock boundaries.

12.4.4 Extensibility

12.4.4.1 To No Visible Artifacts

The proponent points out that AD-HDTV at 17.7 Mbits/sec is already an extension of the baseline MPEG-1 parameters which encode low-resolution video at 1.5 Mbits/sec and believes that it can be extended to virtually any data rate.

12.4.4.2 To Studio Quality Data Rate

AD-HDTV was designed with the anticipation of several levels of related compression. The proponent suggests that a studio standard could be set at 216 Mbits/sec (the data rate of existing studio D-1 recorders) using the same MPEG-1 syntax as AD-HDTV.

12.4.4.3 To Higher Resolution

The proponent claims that AD-HDTV potentially supports the delivery of other video and image formats over appropriate bandwidth channels to special receivers with increased memory. The MPEG-1 core allows resolution up to 4095 x 4095. The proponent has discussed the possibility of introducing ultra-high-definition television by sending augmentation data packets assigned to a unique service type that will be disregarded by older receivers but processed by new receivers.

12.4.4.4 Provision for Future Compression Enhancement

The proponent suggests improved calculation of motion vectors and improvements in bit allocation and prioritization as likely means for picture quality improvement without changing receivers or the data rate.

12.4.5 Interoperability Considerations

12.4.5.1 With Cable Television

Information on the performance of AD-HDTV over cable can be found in Section 12.4.2.6.

12.4.5.2 With Digital Technology

Since this system is all-digital, the advantages of all-digital systems apply.

12.4.5.3 Headers/Descriptors

The AD-HDTV system includes headers and descriptors as defined in the MPEG-1 syntax. In addition, after synchronization, the data link layer identifies the service type. Within the adaptation level, the adaptation header contains information governing the packing of variable-length code words for video, and information used in recovery after channel changes or errors. The video service level includes the actual encoded video information.

All data sent by the AD-HDTV system are grouped into fixed-length cells that contain data of a single particular type. The cells are 148 bytes long including synchronization, service header, adaptation level header, 120-byte information payload, and forward-error-correction (FEC).

The adaptation layer pointers and slice identification information provide re-entry points within the codec video data making it possible to begin decoding at a known point after an error event or channel change that requires a restart for some or all of the video decoding.

12.4.5.4 With NTSC

The proponent selected the field rate of 59.94 Hz for compatibility with NTSC. The number of active video lines was selected to be double the number of active NTSC lines. Down-conversion involves interpolation between HDTV pixels in a line and between HDTV lines.

12.4.5.5 With Film

The proponent claims that AD-HDTV will support an “electronic film” format that eliminates the redundant field to achieve more efficient coding and thus higher quality. Because film has a lower temporal rate, AD-HDTV scans progressively at 24 frames per second with the same format used with video sources. However, in film productions where computer graphics are used extensively, square pixels may be more desirable in the image representation. The proponent claims that AD-HDTV will also provide a progressively scanned 1440 x 810 square pixel format to accommodate film. Most receivers will perform 3:2 pull-down to convert to their 59.94 Hz field rate, but higher-cost receivers could use 3:1 frame repeat to display at 72 Hz.

12.4.5.6 With Computers

Encoding and transmission in AD-HDTV are done in progressive form with a frame rate of 29.97 Hz, favoring interoperability with computers, although testing of this system has been done with interlaced sources and displays requiring format conversions. Pixels are 18.5% wider than high. The proponent has suggested that the system will eventually use progressive sources and displays, and that square pixels can be provided by reduction of the number of active lines to 810.

12.4.5.7 With Satellites

For satellite operation, the proponent has suggested removing the 0.9-rate trellis code used with SS-QAM, reducing the net data rate 21.6 Mbits/sec. The proponent does not anticipate the need for any additional error correction for satellite transmission, although convolutional coding is normally used. The proponent stated that three AD-HDTV programs may be carried in a transponder. However, it is unlikely that more than two will be carried in a typical 36-MHz transponder. The proponent also stated that it is possible to carry AD-HDTV and NTSC signals on the same transponder.

12.4.5.8 With Packet Networks

The data link packet format is based on a "cell relay" asynchronous time-division multiplexing concept similar to the asynchronous transfer mode (ATM) standard that was designed for the broadband integrated services digital network (B-ISDN). The packet header contains information such as priority indicator, service ID and cell sequence number. This provides service-independent transport services such as priority support, service multiplexing, and cell-error detection and correction. For the received bit stream, the transport decoder performs Reed-Solomon decoding and a cyclic redundancy check (CRC) for error detection. Cells received in error after correction are discarded by the demultiplexer. Packet headers include pointers to slices (208H x 16V), so that packet loss results in loss of, at most, a few slices prior to error concealment.

12.4.5.9 With Interactive Systems

According to the proponent, the encoder requires 4 frames of latency. An additional frame is needed for interlaced-to-progressive conversion. Similar delays are present at the receiver and the total latency is 333 msec. The proponent claims that for interactive applications where latency is a concern, an encoder can provide an MPEG-1 bit stream using only forward motion compensation to reduce the coding part of the latency. Acquisition time is reported in Section 12.4.2.11.

12.4.5.10 Format Conversion

12.4.5.10.1 With 1125/60

Up-converting to the Common Image Format (1920 x 1080) requires 8:9 vertical interpolation and 3:4 horizontal interpolation.[9] SMPTE 240M uses 1035 active lines and would require 14:15 vertical interpolation. Colorimetry used by AD-HDTV is intended to be consistent with SMPTE 240M.

[9] The 3:4 ratio is based on 1440 pixels per line as proposed by the proponent. The system tested used 1500 pixels per line.

12.4.5.10.2 With 1250/50

This difficult conversion is not simplified by the fact that both the source system and the target system are interlaced 2:1.

12.4.5.10.3 With MPEG[10]

AD-HDTV's use of MPEG-1 video and audio compression provides the possibility of interoperability with MPEG computer multimedia applications directly in the compressed bit stream format. The underlying video compression algorithm adheres to the MPEG-1 standard in that parameters allowable within the MPEG-1 definition are used although they are not the MPEG-1 default parameters. Prior to entering the prioritization and transport processors, the compressed video conforms to the MPEG-1 specification. An MPEG-1 bit stream can be obtained from the output of the compression encoder at the interface to the priority processor. Because the tested system used an internal fixed-length representation for MPEG-1 code words at the interface between its compression and prioritization stages, a standard MPEG-1 bit stream was not available as an output. In general, commercially available MPEG-1 decoders are not fast enough to decode the AD-HDTV signal.

12.4.5.10.4 With Still Image

AD-HDTV's compression, based on the DCT, is generally compatible with JPEG. The CD-I format is directly compatible with AD-HDTV because CD-I uses the MPEG-1 compression syntax. Photo CD decoding would be possible with straightforward spatial filtering after decompression.

12.4.5.11 Scalability

The picture produced by AD-HDTV's HP signal alone is a substantially reduced-quality image. The decoded artifacts observed in an HP-only reconstruction will depend on the exact priority processing algorithm. Typical priority processor operation results in lower spatial and temporal resolution. The proponent claims that for low cost picture-in-picture and picture-out-of-picture, only the HP signal needs to be processed.

For multiple programs in a single channel, AD-HDTV's prioritized data transport layer provides for asynchronous delivery of multiple service types. Multiple video streams can be assigned individual service types.

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[10] See Section 8.3.8 for a discussion of MPEG, the MPEG-1 standard, and the MPEG-2 development effort.

12.5 SYSTEM IMPROVEMENTS

12.5.1 Already Implemented

12.5.1.1 Receiver Carrier Recovery Pull-In Range

The purpose of this improvement was to increase the frequency pull-in range of the receiver. The first-order carrier recovery circuit has been upgraded to second-order carrier recovery.

12.5.1.2 Improved Data Prioritization

The purpose of this improvement was to correct difficulties that were noticed during testing.

Occasional difficulties were experienced with the motion compensation hardware which did not perform with full accuracy in the left third of the picture. The motion compensation hardware has been repaired.

The “squelching” circuit that manages the transition between full use of both HP and SP data and the use of only HP data during severely impaired transmission conditions was not working optimally. This circuit has been modified to improve the picture quality that is obtained around the threshold of the SP carrier.

The tested system selected high spatial resolution (but low temporal resolution) codewords for transmission of the HP carrier, a relatively simple approach. Improvements to the prioritization approach have been developed.

12.5.1.3 Tuner Adjustments

To improve upper adjacent-channel rejection, internal tuner adjustments have been made.

12.5.1.4 Receiver Adaptive Equalizer Range

The range of the adaptive equalizer has been increased from ±4 µsec to ±8 µsec.

12.5.2 Implemented in Time for Field Testing

12.5.2.1 Trellis Coding

The trellis coding will be modified in order to improve random noise performance, ATV-into-ATV co-channel performance, and performance in the presence of other noise, interference and impairments. Since full implementation of trellis coding hardware was not complete in time for ATTC testing, the tested system used a simpler set partition code. The hardware will be modified to provide the trellis code described in the certification document.

12.5.2.2 Tuner SAW Filter

The purpose of this improvement is to improve both lower and upper adjacent-channel rejection. A new SAW filter will be designed for the tuner.

12.5.2.3 Adjustment of HP/SP Power Ratio

The purpose of this improvement is to allow the HP/SP power ratio to be increased or decreased at a given broadcast station based on the precise terrain and the co-channel and interference environment involved. The ratio will be made variable; two separate automatic gain control (AGC) circuits will be provided in the receiver.

12.5.2.4 Receiver Adaptive Equalizer Range

The range of the adaptive equalizer will be increased further to ±16 µsec.

12.5.2.5 QAM for Cable

The purpose of this improvement is to allow the choice of transmitting QAM or SS-QAM over cable. For broadcast-originated programming, the SS-QAM signal may be transmitted directly over cable. As an alternative, or for satellite-based distribution of programming, the signal can be remodulated as a QAM signal. The AD-HDTV receiver will be modified to receive either signal form.

12.5.2.6 Multi-Channel Audio

The purpose of this improvement is to comply with the ATSC T3/186 recommendations for multi-channel audio. The ISO-MPEG audio committee is in the process of defining a five channel composite coding extension to MUSICAM, the audio system currently used by AD-HDTV. The MPEG five channel audio system will be incorporated into AD-HDTV. In the event this hardware is not available at the time of field testing, AD-HDTV will incorporate an alternate multi-channel audio system.

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13. CHANNEL COMPATIBLE DIGICIPHER

13.1 SYSTEM OVERVIEW

CCDC, proposed by the American Television Alliance (Massachusetts Institute of Technology and General Instrument Corporation) is a digital simulcast system that requires a single 6 MHz television transmission channel. The video source is an analog RGB signal with alternate 787/788 lines, progressively scanned, a 59.94 Hz frame rate, and an aspect ratio of 16:9. A matrix converts the RGB color signals to YUV signals. The display format is 720 lines by 1280 pixels per line. The video sampling frequency is 75.52 MHz. Chrominance signals are decimated by a factor of two both horizontally and vertically, resulting in a sampling density of one fourth that of the luminance signal. Eight-bit precision is employed for all luminance and chrominance samples. The video compression uses an adaptive form of motion-compensated predictive coding in which prediction differences are spatially transformed using a Discrete Cosine Transform (DCT). A selected subset of the resultant transform coefficients is entropy coded to represent the image that will be reconstructed at the receiver. Information related to the compressed video is entropy coded for transmission, including motion vectors and parameters related to decisions on intra-frame and inter-frame coding. The video encoder uses four processors, each working on one-fourth of the image (full height and one-fourth width panels), with intraframe refresh moving continuously from right to left. Two transmission modes are supported: 32 QAM, the primary transmission mode, and 16 QAM, both with a symbol rate of 5.29 M-symbols per second. The 32 QAM primary mode has a video data rate of 18.88 Mbits/sec and a total transmission rate of 26.43 Mbits/sec. Concatenated trellis coding, Reed-Solomon block coding, and adaptive equalization are used to protect against channel errors. The CCDC system provided six independent digital audio channels using the MIT Audio Coder system for compression. The audio is sampled at 48 kHz. The compressed audio rate is 252 kbits/sec per pair of channels. In addition, a combined auxiliary and control data capacity of 252 kbits/sec is provided

13.2 SPECTRUM UTILIZATION

The CCDC analysis was conducted under two allotment scenarios (using both VHF and UHF channels for ATV stations, and using only UHF channels) and two sets of interference constraints (considering only co-channel interference, and both co-channel and adjacent-channel interference). In addition, the impact of taboos was assessed by re-calculating coverage and interference for each case assuming the taboo performance measured in the laboratory.

Figure 13-1 shows planning factors, specific to the CCDC system, as derived from test results. The numbers in the figure are desired-to-undesired ratios (D/U) in dB. The values for interference into NTSC are based on CCIR Impairment Grade 3 (slightly annoying) as determined from the ATEL subjective tests. Because the ATV service is intended to be an improvement over NTSC, interference into ATV is based on CCIR Impairment Grade 4 (perceptible but not annoying) if the range between the threshold of visibility (TOV) and the point of acquisition (POA) exceeds 5 dB. Otherwise, the TOV power level is used. CCDC demonstrated a “cliff effect” and thus D/U values are based on TOV data.

Also, the data show that CCDC can support collocation on both the upper and lower adjacent-channels.

Co-Channel	D/U (dB)
ATV-into-NTSC	+36
NTSC-into-ATV	+8.1
ATV-into-ATV	+16.6

Carrier-to-Noise	+15.4

Adjacent-Channel	D/U (dB)
Lower ATV-into-NTSC	-17.8
Upper ATV-into-NTSC	-17.0
Lower NTSC-into-ATV	-37
Upper NTSC-into-ATV	-37
Lower ATV-into-ATV	-32
Upper ATV-into-ATV	-32

Figure 13-1. Planning factors specific to CCDC.

13.2.1 Accommodation Percentage

CCDC could provide a 100% accommodation of all NTSC assignments for co-channel only, and co-channel and adjacent-channel constraints, under both the VHF/UHF and UHF scenarios. The accommodation is achieved at the expense of reducing the ATV and NTSC service areas. No attempt was made to reduce interference to NTSC service by adjusting either ATV or NTSC power.

13.2.2 Service Area

Figure 13-2 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 both co-channel and adjacent-channel constraints. In this graph, the 1,657 current NTSC stations are placed in order of decreasing ATV to NTSC service area ratio. Examination of the graph reveals that 10.9% (180) 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% (1,616) 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 39.9 million square kilometers.

Figure 13-3 shows the interference statistics for the VHF/UHF scenario. During the transition period, 54.1% of ATV stations would receive no interference. This would rise to 72.3% after the transition period ends. Also during the transition period, 1.8% of the ATV stations would receive interference in more than 35% of their noise-limited coverage area. This would fall to 0.8% after the transition period ends. The total interference area created within the ATV noise-limited coverage area during the transition period is 2.32 million square kilometers. This would decrease to 1.11 million square kilometers after the transition period ends. Of the existing NTSC stations, 59.4% would not receive any new interference because of the ATV service, while 2.3% would receive new interference in more than 35% of their Grade B area. The total new interference into NTSC created under this plan is 1.54 million square kilometers.

When taboos are included in the interference calculations for the VHF/UHF scenario, the number of ATV stations with no interference during the transition period is 51.2%; the number of ATV stations with interference in more than 35% of their noise-limited coverage area is 1.8%. The number of NTSC stations receiving no new interference is 54.9%; the number of NTSC stations with interference in more than 35% of their Grade B area is 2.5%.

When the adjacent-channel constraints of Figure 13-1 are not included in the VHF/UHF scenario, the allotment/assignment table is different. In that case, 15.0% (248) of the ATV stations would have an ATV service area at least 20% larger than their companion NTSC service area and 98% (1,626) would have an ATV service area at least 80% of their companion NTSC service area. During the transition period, 70.0% of ATV stations would receive no interference. This would rise to 84.6% after the transition period ends. Also during the transition period, 1.2% of the ATV stations would receive interference in more than 35% of their noise-limited coverage area. This would fall to 0.5% after the transition period ends. Of the existing NTSC stations, 62.6% 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.

Figure 13-4 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 UHF scenario, taking into account both co-channel and adjacent-channel constraints. In this graph, as before, the 1,657 current NTSC stations are placed in order of decreasing ATV to NTSC service area ratio. Examination of the graph reveals that 10.0% (165) of the ATV stations under this scenario would have an ATV service area at least 20% larger than their companion NTSC service area and 94% (1,563) 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 39.3 million square kilometers.

Figure 13-5 shows the interference statistics for the UHF scenario. During the transition period, 51.3% of ATV stations would receive no interference. This would rise to 66.1% after the transition period ends. Also during the transition period, 3.0% of the ATV stations would receive interference in more than 35% of their noise-limited coverage area. This would fall to 2.1% after the transition period ends. The total interference area created within the ATV noise-limited coverage area during the transition period is 2.97 million square kilometers. This would decrease to 1.60 million square kilometers after the transition period ends. Of the existing NTSC stations, 62.3% would not receive any new interference because of the ATV service, while 8.7% would receive new interference in more than 35% of their Grade B coverage area. The total new interference created under this plan is 2.29 million square kilometers.

When taboos are included in the interference calculations for the UHF scenario, the number of ATV stations with no interference during the transition period is 48.9%; the number of ATV stations with interference in more than 35% of their noise-limited coverage area is 3.2%. The number of NTSC stations receiving no new interference is 58.7%; the number of NTSC stations with interference in more than 35% of their Grade B area is 8.7%.

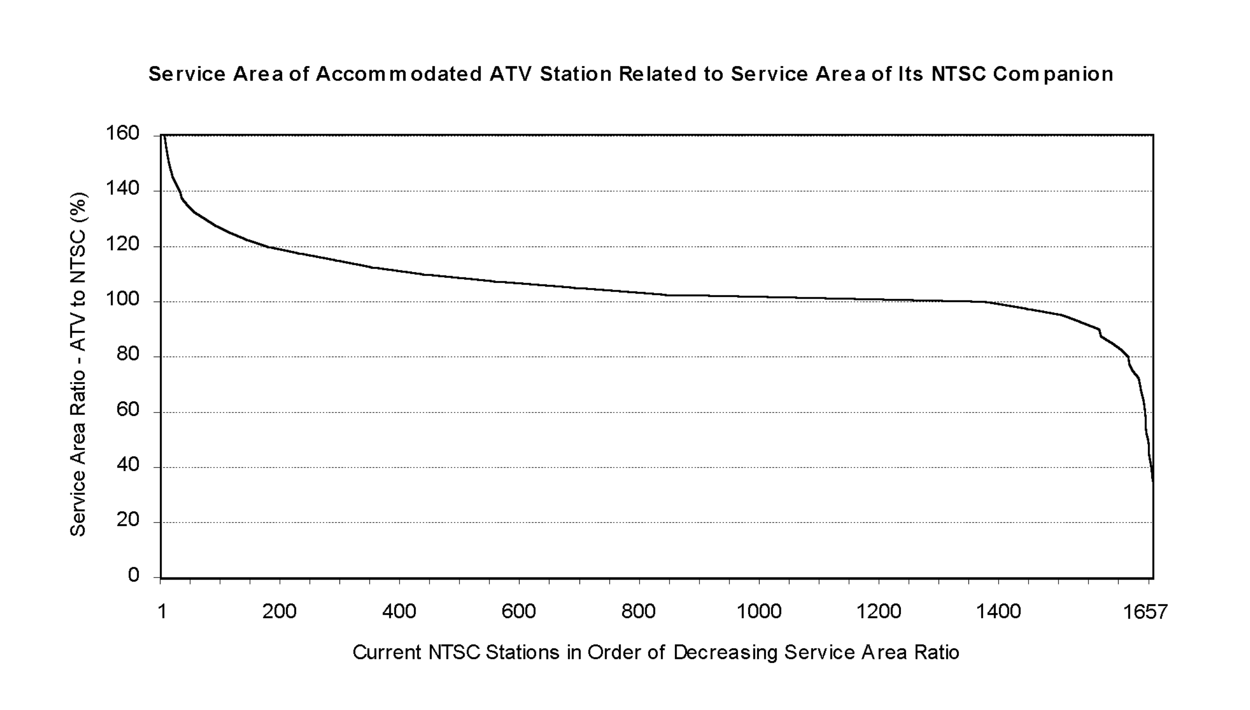

Figure 13-2. CCDC VHF/UHF Scenario — Interference-limited service area of each ATV station relative to the interference-limited service area of its companion NTSC station (co-channel and adjacent-channel constraints).

Interference Area Compared to Coverage Area	ATV Stations with Interference		NTSC Stations with Added Interference Due to ATV
	During Transition	After Transition	
No Interference	54.1 %	72.3 %	59.4 %
0 - 5 %	19.6 %	16.0 %	15.7 %
5 - 10 %	11.3 %	6.0 %	8.0 %
10 - 15 %	5.3 %	2.2 %	5.6 %
15 - 20 %	3.7 %	1.3 %	3.5 %
20 - 25 %	2.0 %	0.5 %	2.8 %
25 - 30 %	1.2 %	0.4 %	1.5 %
30 - 35 %	1.0 %	0.4 %	1.2 %
> 35 %	1.8 %	0.8 %	2.3 %

Figure 13-3. CCDC VHF/UHF Scenario — Interference characteristics (co-channel and adjacent-channel constraints).

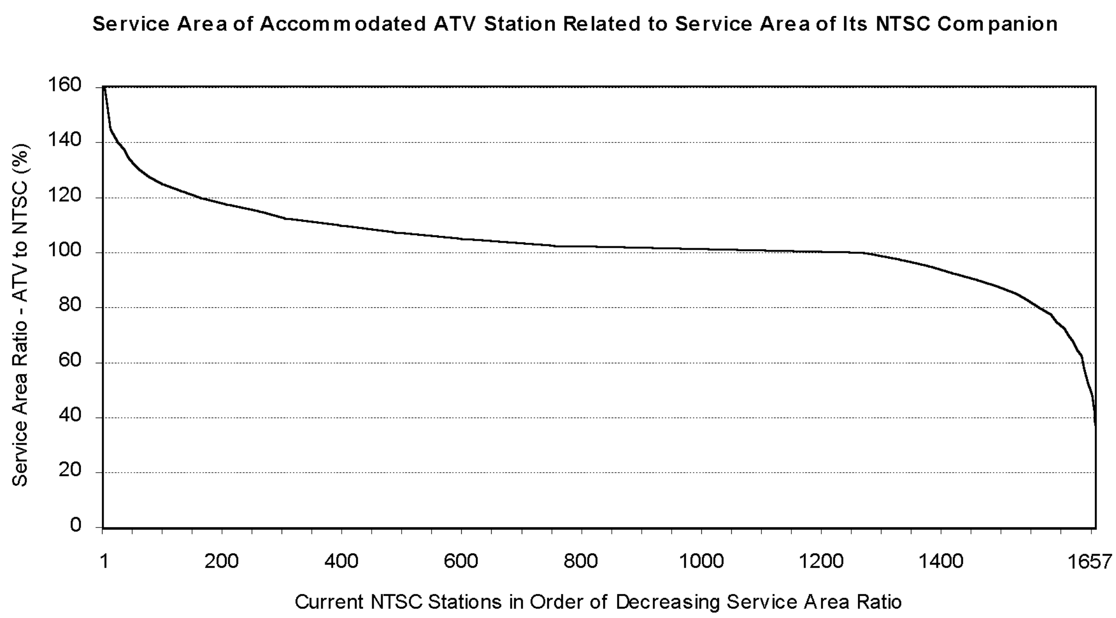

Figure 13-4. CCDC UHF Scenario — Interference-limited service area of each ATV station relative to the interference-limited service area of its companion NTSC station (co-channel and adjacent-channel constraints).

Interference Area Compared to Coverage Area	ATV Stations with Interference		NTSC Stations with Added Interference Due to ATV
	During Transition	After Transition	
No Interference	51.3 %	66.1 %	62.3 %
0 - 5 %	13.5 %	14.5 %	8.8 %
5 - 10 %	10.3 %	7.2 %	5.4 %
10 - 15 %	7.7 %	4.3 %	4.5 %
15 - 20 %	5.9 %	2.5 %	2.9 %
20 - 25 %	3.8 %	1.0 %	2.5 %
25 - 30 %	2.5 %	1.4 %	2.8 %
30 - 35 %	2.1 %	0.8 %	2.1 %
> 35 %	3.0 %	2.1 %	8.7 %

Figure 13-5. CCDC UHF Scenario — Interference characteristics (co-channel and adjacent-channel constraints).

When the adjacent-channel constraints of Figure 13-1 are not included in the UHF scenario, the allotment/assignment table is different. In that case, 12.3% (203) of the ATV stations would have an ATV service area at least 20% larger than their companion NTSC service area and 95% (1,579) would have an ATV service area at least 80% of their companion NTSC service area. During the transition period, 57.5% of ATV stations would receive no interference. This would rise to 74.7% after the transition period ends. Also during the transition period, 2.8% of the ATV stations would receive interference in more than 35% of their noise-limited coverage area. This would fall to 2.0% after the transition period ends. Of the existing NTSC stations, 64.1% would not receive any new interference because of the ATV service, while 8.3% would receive new interference in more than 35% of their Grade B area.

The frequency distribution of ATV station average effective radiated power levels needed to achieve ATV noise-limited coverage comparable to NTSC Grade B coverage was calculated. The maximum average effective radiated power level was 37.66 dBk (5,830 kW). The results are shown in Figure 13-6.

Certain analyses also were performed for the 16 QAM Alternate Mode. In general, the ATV service area is slightly greater and interference is less for both ATV and NTSC. The results are shown in the PS/WP3 final report.

Average Effective Radiated Power Level		Number of TV Stations			
		VHF/UHF Scenario			UHF Scenario
(dBk)	(kW)	Low VHF	High VHF	UHF	UHF
Less than 5	Less than 3.2	12	26	106	106
5 - 10	3.2 - 10.0	5	6	46	47
10 - 15	10.0 - 31.6		11	132	141
15 - 20	31.6 - 100		4	269	277
20 - 25	100 - 316			291	306
25 - 30	316 - 1,000			221	233
30 - 35	1,000 - 3,160			378	390
35 - 40	3,160 - 10,000			150	157
> 40	> 10,000				
TOTAL		17	47	1,593	1,657

Figure 13-6. CCDC power level distribution.

13.3 ECONOMICS

13.3.1 Cost to Broadcasters

The estimated equipment cost for a CCDC transitional station is shown in Figure 13-7. The total cost of the transitional station was estimated to be $1,739,500. The total cost of a minimal station was estimated to be $1,124,100. A general description of the methods used to develop the cost data is contained in Section 8.2.1.

Subsystem	Cost (thousands)
Satellite Receiver, Demodulator, Decoder	$ 13.5
Character Generator, Still Store, Two 28" Monitors	200.0
Routing Switcher (10 x 10), Master Control	125.0
2 ATV VTRs and Monitors	170.0
NTSC Upconverter, including Line Tripler	24.0
ATV-to-NTSC Downconverter	20.0
34" Monitor, Seven 17" Monitors, Eight Decoders	119.0
ATV Encoder	220.0
STL Subsystem	92.5
ATV Modulator, ATV Exciter	30.0
ATV Transmission Subsystem	725.5
TOTAL COST	$1,739.5

Figure 13-7. Equipment cost for a CCDC transitional station.

13.3.2 Cost to Alternative Media

Information on this topic was not provided.

13.3.3 Cost to Consumers

The estimated material cost data for a CCDC receiver are shown in Figure 13-8. A general description of the methods used to develop the cost data is contained in Section 8.2.2.

Using a 2.5 multiplier, the resulting estimated retail price for a CCDC receiver is $2,543 for a 34" direct view receiver and $3,863 for a 56" projector receiver.

Subsystem	34" Widescreen Direct View Receiver	56" Widescreen CRT Type Projector
Signal Processing Components	$ 124	$ 124
Audio Amplifiers and Speakers	30	30
Scan System, Power Supply, and Video Amps	73	201
Display	700	1,050
Cabinet	90	140
TOTAL MATERIAL COST	$1,017	$1,545

Figure 13-8. Material cost data for a CCDC receiver.

13.4 TECHNOLOGY

13.4.1 Audio/Video Quality

In video subjective tests of CCDC, the system performed differently across segments of test material. For 8 of the 9 stills, CCDC was judged, on average, to be about 0.5 grade lower in quality than the 1125-line studio reference. For 13 of the 14 motion sequences, CCDC was judged to be about 1.3 grades lower in quality than the reference. The remaining still and the remaining motion sequence, both electronically generated, were judged to be better in quality than the reference.[1]

Problems were noted when the system was subjected to noisy source material. Some problems were noted when the system was tested for motion-compensation overload at high rates of motion. No significant problems were reported when the system was subjected to a sudden stop in motion, to scene cuts, or to two encode/decode operations or when the system was tested for video-coder overload.

Certain tests also were carried out for the 16 QAM Alternate Mode. When judged by non-experts, the 16 QAM mode exhibited a greater reduction in quality than the 32 QAM mode for some moving sequences. Expert observers found little difference between 32 QAM and 16 QAM modes.

During system-specific tests, expert observers noted that the audio remained useful, but not unimpaired, beyond the video POU. There was no evidence that the audio system failed before the accompanying video.

13.4.1.1 Video Quality

Subjective judgments of image quality by non-experts are summarized in Figure 13-9. Scores are the differences between judgments of the reference and judgments of CCDC for 9 stills and 14 motion sequences. For 8 of the 9 stills, CCDC was judged, on average, to be 0.5 grade (i.e., about 11 points on the 100-point scale) lower in quality than the 1125-line studio reference; for the remaining still (S14), the system was judged to be 1.4 grades higher in quality than the reference (this may reflect the absence of interlacing artifacts in the 787/788 source and in the CCDC rendering of this picture). For 13 of the 14 motion sequences, CCDC was judged, on average, to be 1.3 grades (i.e., about 26 points) lower in quality than the reference;[2] for the remaining sequence (M16), the system was judged to be 0.9 grade higher in quality than the reference (this probably reflects the absence of interlacing artifacts in the 787/788 source and in the CCDC rendering of this picture).

CCDC performed differently for different segments of test material. For stills, differences ranged from +0.l to -1.2 grades (not including S14); for moving sequences, differences ranged from -0.7 to -2.0 (not including M16). The variability among viewers was high and differed somewhat across materials, but

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[1] See Section 8.3.3.

[2] The 787/788 progressively scanned camera material used in testing CCDC exhibited horizontally coherent noise and increased random noise as compared with the cameras used for the 1125-line reference images. See Section 8.3.4.

was within acceptable limits. For stills, expert commentary, supported by reports from non-expert viewers, attributed differences between CCDC and the reference to quantization noise, which was particularly visible in saturated reds and which appeared as "busy-ness" that pulsed at about 3 Hz, and to noise and raggedness on high-contrast edges. For motion sequences, expert commentary, again supported by reports from non-expert viewers, attributed differences between CCDC and the reference to the same effects observed in stills, and to exaggeration of source noise and increased quantization noise for the most rapid motion. Expert observers felt that the exaggeration of source noise was a serious artifact. Expert observers noted blockiness only in the most rapid motion.

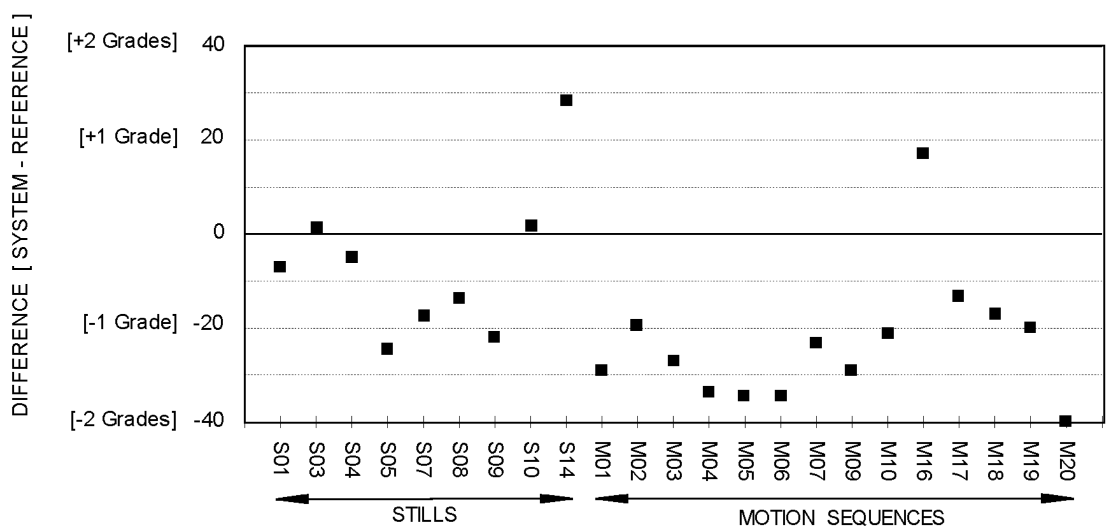

Figure 13-9. Average differences between quality judgments for the 1125-line studio quality reference and for CCDC.

Comparison of objective tests of static and dynamic resolution showed slight losses in horizontal, vertical, and diagonal luminance resolution at high rates of movement.[3]

When subjected to noisy source material, the system introduced an increase in noise at the output (which tended to be significantly more visible than at source). In addition, as the level of source noise was increased, the system introduced progressively more visible "blockiness" and the four "panels" used by the system became more visible.

When subjected to scene cuts and viewed in real time, the system performed well, with transient effects visible only on cuts to a highly detailed still and, then, lasting only about 1/3 second. Examination of freeze frames showed that it took about 1/10 second for "blockiness" to subside.

[3] See Section 8.3.5.

Artifacts appeared when material was subjected to two encode/decode passes through the system. During the first pass, the system introduced slight levels of noise in most pictures. During the second pass, the noise was increased. In addition, "blockiness" was introduced in the highly saturated areas in one picture.

The CCDC system exhibited good chrominance dynamic range in red, green, and blue channels.

When tested for video-coder overload, CCDC exhibited no significant failures, introducing slight increases in noise and "blockiness." When tested for motion-compensation overload at a velocity of 0.8 picture height per second, the system introduced coarse quantization and, for vertical motion, some blockiness. At 0.6 picture height per second, coarse quantization was visible only for vertical motion. No artifacts were noted in response to a sudden stop in movement.

In system-specific tests designed to stress the compression algorithm, images exhibited coarse quantization, panel wiping, and busy-ness.

Subjective judgments of the image quality of the 16 QAM Alternate Mode also were made by non-experts. The system again performed differently across segments of test material; on average, stills were judged to be about 0.7 grade lower in quality than the reference, while motion sequences were judged to be about 1.6 grades lower in quality than the reference.[4] In general, picture quality differences between the 16 QAM and 32 QAM modes were small and confined to motion sequences. In these cases, the difference in unimpaired video quality was evident to non-expert observers. Expert observers noted that the 16 QAM and 32 QAM modes were similar in image quality. Expert commentary attributes the slightly lower performance of the 16 QAM mode to increased noise and "raggedness" at high-contrast edges, increased quantization noise and "busy-ness," occasional "blockiness," and occasional visibility of the four "panels" used by the system. Experts also noted a longer duration for transients following a scene cut and increased visibility of "blockiness" in tests of video-coder overload.

13.4.1.2 Audio Quality

During system-specific tests, expert observers noted that the audio remained useful, but not unimpaired, beyond the video POU. There was no evidence that the audio system failed before the accompanying video.[5]

Objective tests were performed for dynamic range, total harmonic distortion (THD), THD + noise (THD+N), intermodulation distortion (IMD), dynamic intermodulation distortion (DIM), frequency response, and overload vs. frequency. The dynamic range was 94 dB. THD was less than 0.04%. For high level signals, THD + N was less than 0.02% for frequencies from 20 Hz to 20 kHz. IMD was less

[4] For the electronically generated still (S14), 16 QAM CCDC was judged better than the reference. The average difference reported here does not include this value.

[5] See Section 8.3.1.

than 0.01% for both channels. Frequency response was extremely flat, within 0.05 dB, over the entire range from 20 Hz to 20 kHz for both channels.

For co-channel interference of ATV-into-NTSC at moderate signal level, when video was at “annoying,” BTSC audio began to degrade. For co-channel at weak signal level, one receiver indicated interference before the video began to fail. For the remaining two receivers, audio began to degrade when the video was rated “very annoying.” For upper adjacent-channel interference of ATV-into-NTSC at moderate signal level, the audio began to degrade for one receiver when the video was rated between “imperceptible” and “perceptible, but not annoying”; for a second receiver, the audio began to degrade when the video was rated between “annoying” and “very annoying”; the third receiver never showed any audio degradation. For upper adjacent-channel interference at weak signal level, audio began to degrade when the video was rated between “annoying” and “very annoying.”

In the test of ATV co-channel interference into NTSC, CCDC caused no significant degradation of NTSC VBI data.

13.4.2 Transmission Robustness

Generally, CCDC performed as predicted by the proponent. Its performance equalled or exceeded that of NTSC in almost all impairment conditions. Typically the system exhibited immunity to a variety of transmission impairments over a wide range of impairment levels. Beyond that range, the system exhibited a sharp degradation characteristic when exposed to all impairments. In general, all transmission impairments had similar manifestations in the observed video, which were quite different than the effect they produce on NTSC. Transmission impairments and interference when strong enough, produced display errors which caused randomly spaced rectangular patches of the image to freeze or to display erroneous information, for a short duration.

CCDC interference into NTSC had the characteristic of white noise, and produced a graceful degradation. Cable transmission had no adverse effect in CCDC performance.

13.4.2.1 Noise Performance

When CCDC was subjected to random channel noise (based on a 6 MHz noise bandwidth), the carrier-to-noise ratio[6] (C/N) at the TOV was measured and is shown in Figure 13-1. The carrier-to-noise ratio at the TOV was measured for the 16 QAM Alternate Mode also and found to be 11.5 dB. The system had a sharp degradation: the range between the TOV and the point of unusability (POU) was 0.5 dB for both 32 QAM and 16 QAM.

[6] Caution must be exercised in comparing C/N between analog and digital systems, as definition of carrier levels is not consistent. Measurement of power level is consistent, however, among digital systems. (See Section 8.3.6.)

13.4.2.2 Static Multipath

The system performed well at levels which would be highly objectionable in NTSC. The TOV for echoes of - 0.08 µsec, +0.08 µsec, +0.32 µsec and +2.56 µsec were at D/U ratios of 8.7 dB (i.e., echo amplitude of 37%), 12.2 dB (25%), 8.9 dB (36%), and 10.2 dB (30.9%) respectively.

13.4.2.3 Flutter

The TOV for airplane flutter of 2 Hz and 5 Hz were at D/U levels of 9.4 dB (34%) and 11.4 dB (27%) respectively.

13.4.2.4 Impulse Noise

Impulse noise performance was judged to be better than NTSC by approximately 8 dB for TOV. The range between TOV and POU was about 3 dB.

In the gated noise test at a fixed 10 Hz repetition rate, TOV was reached when the pulse width was increased to 5 µsec. Pulse width at POU was greater by approximately a factor of 3. When the pulse width was decreased to 3 µsec, TOV was reached when the pulse repetition rate was increased to 400 Hz.

13.4.2.5 Discrete Frequency Interference

The D/U ratio at the TOV for discrete frequency interference was -40 (+11,-6) dB in the first adjacent channels, and +7 (±1) dB in-band.

13.4.2.6 Cable Transmission

The subjective tests showed that cable transmission *per se* had no adverse effect on CCDC performance.

Among the cable-specific tests conducted, the system performed better than NTSC when subjected to hum (TOV > 15%); composite triple beat, or CTB, (TOV @ -33 dBc); and composite second order, or CSO, (TOV @ -13 dBc). Its performance was poorer than NTSC when subjected to phase noise (TOV @ -83 dBc), residual FM (TOV @ ±5.8 kHz), and local oscillator instability (TOV @ +35 kHz, -60 kHz).

The threshold values measured for the third audio channel were consistent with the values found in other tests for Gaussian noise, CTB, hum modulation, and phase noise.

13.4.2.7 Co-Channel Interference into ATV

CCDC was much more robust than NTSC to co-channel interference from either NTSC or ATV. Results are summarized in Figure 13-1. The system performance exhibited a sharp degradation when co-channel interference was increased beyond TOV. The range from TOV to POA was less than 1.6 dB for NTSC-into-ATV co-channel interference, and less than 0.2 dB for ATV-into-ATV co-channel interference.

13.4.2.8 Co-Channel Interference into NTSC

For co-channel interference into NTSC, impairment ratings varied gradually from “imperceptible” to “very annoying” over a range of 26 dB at weak desired signal level. (See Figure 13-10). The D/U for a mean impairment rating of 3 was about 36 dB. The interference appeared as random noise in the NTSC picture.

13.4.2.9 Adjacent-Channel Interference

The D/U ratio at the TOV for adjacent-channel interference into ATV is given in Figure 13-1. The D/U ratio for a mean impairment rating of 3 for adjacent-channel interference into NTSC is given also in Figure 13-1. Note that the more negative the D/U ratio, the better the performance. In practice, it is expected that the CCDC signal would be transmitted with an average power at least 10 dB lower than NTSC peak power. Under this assumption, the data indicate that CCDC supports collocation.

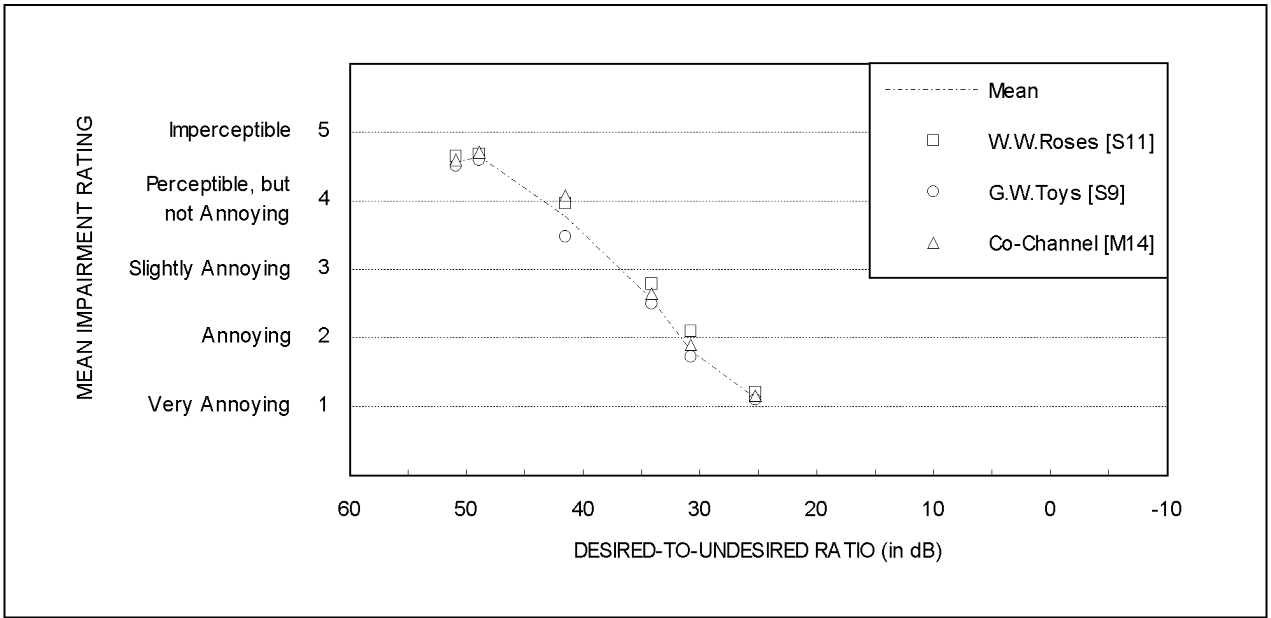

Figure 13-10. Impairment to NTSC when subjected to CCDC co-channel interference for weak signal condition (-55 dBm).

The system exhibited a sharp degradation when subjected to adjacent-channel interference from NTSC and ATV. The range from TOV to POU was about 1 dB.

ATV-into-NTSC impairment ratings varied from “imperceptible” to “very annoying” over a range of about 15 to 19 dB. Mean impairment ratings varied from “perceptible but not annoying” to “annoying” over a range of 6 dB for the upper adjacent-channel and 6 dB for the lower adjacent-channel.

13.4.2.10 Taboo Interference

The taboo performance of CCDC, based on TOV, is given in Figure 13-11. Note that the more negative the D/U ratio, the better the performance.

In practice, it is expected that the CCDC signal would be transmitted with an average power at least 10 dB lower than NTSC peak power. Under this assumption, the data show that CCDC can support collocation on the basis of taboo channel interference requirements.

13.4.2.11 Channel Acquisition

Under a variety of heavy impairment conditions, the CCDC system fully acquired the signal and displayed a recognizable picture within 3.7 seconds. Under a variety of moderate impairment conditions, a recognizable picture was displayed within 1 second.

	ATV-into-NTSC		NTSC-into-ATV		ATV-into-ATV	
CHANNEL	Strong	Weak	Strong	Weak	Strong	Weak
n+2	< 0*	-30	-33	-56	<-33*	-56
n-2	< -3*	-23	<-33*	-58	-32	-57
n+4	< -6*	-27	<-33*	<-58*	<-33*	-59
n+7	< -6*	-34	<-33*	<-58*	<-33*	-60
n-7	< -5*	-35	<-33*	<-58*	<-33*	-58
n+8	< -3*	<-43*	<-33*	<-58*	<-33*	<-63*
n-8	< -5*	-30	<-33*	<-58*	<-33*	-59
n+14	< -4*	-27	<-33*	<-58*	<-33*	<-63*
n+15	< -4*	-18	<-33*	<-58*	<-32*	<-62*

* Determination of TOV level was beyond the limits of ATTC's RF test bed range. Consequently, the system has a better performance than the indicated result.

Figure 13-11. Taboo threshold of visibility for CCDC (D/U in dB).

13.4.2.12 Failure and Recovery Appearance

In general, all transmission impairments had similar manifestations in the observed video. When transmission path impairments were strong enough to be visible in the observed picture, they caused randomly spaced superblocks (16 x 16 pixels) or macroblocks (320H x 16V pixels) to lose their video and to be displayed as areas of fixed luminance or chrominance unrelated to the video. At higher levels of impairments, the damaged areas became more prevalent, sometimes becoming organized into rows of superblocks and columns of up to a macroblock wide and up to ¾ picture height, and eventually overwhelmed the image. Sometimes the impaired video formed four distinct, equal-sized panels whose boundaries moved right to left. In addition, impairments also caused picture disturbances which seemed related to movement which appeared as shimmering areas, clusters of small grey blocks, or areas of high, and hue-shifted, chroma. Errors generally lasted less than ½ second, but could persist up to 1 1/3 seconds.

At the video POU, audio remained usable but not unimpaired.

13.4.2.13 Peak-to-Average Power Ratio

The peak-to-average power ratio for the 32 QAM mode was less than 5.2 dB 99% of the time, and less than 6.2 dB 99.9% of the time. For 16 QAM, these ratios were 5.0 dB and 6.3 dB respectively.

13.4.2.14 Multiple Impairments

The performance of CCDC, when simultaneously subjected to multiple impairments, is shown in Figure 13-12 for two cases:

(1) The POA for NTSC co-channel interference versus random noise, and

(2) The TOV for composite triple beat versus random noise.

Asymptotes are shown reflecting the measured single impairment performance. The operating region lies above and to the right of the respective curves.

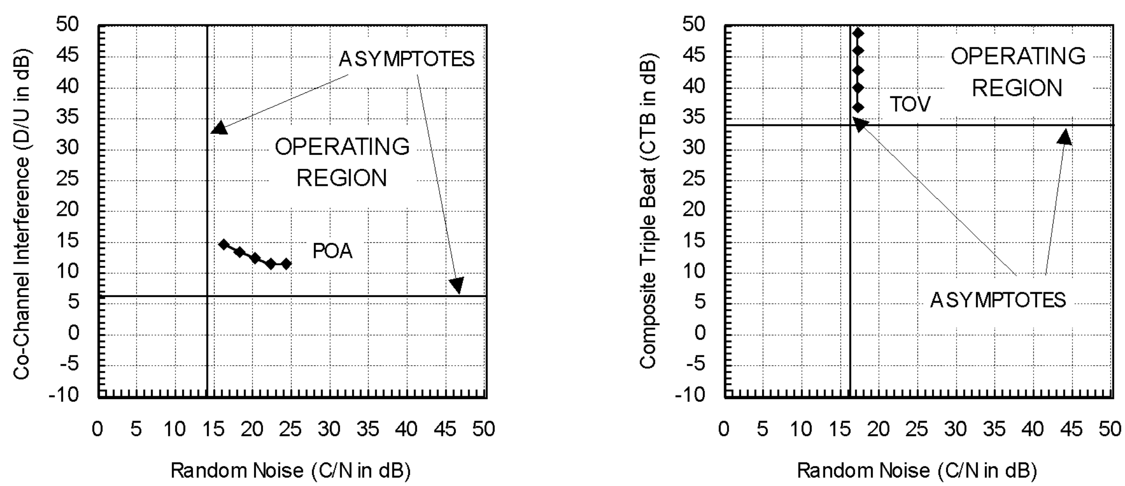

Figure 13-12. Multiple impairments into CCDC. (Left) POA for NTSC co-channel interference and random noise. (Right) TOV for composite triple beat and random noise.

13.4.3 Scope of Services and Features

13.4.3.1 Data

Ancillary and control data have been allocated 252 kbits/sec. In the tested system, the only access to the ancillary data channel was via four asynchronous 9600-bits/sec RS-232 interfaces. Teletext and captioning are sent in the ancillary data channel.

13.4.3.2 Encryption

Encryption has not yet been implemented.

13.4.3.3 Addressing

The first byte in each data line is reserved for control information, described as including decryption keys and subscriber data. There are 525 data lines per frame and 59.94 frames per second. Thus, there are about 252 kbits/sec of capacity for this kind of data.

13.4.3.4 VCR Capability

The proponent reports no hardware development of VCRs specific to CCDC, but refers to the DigiCipher/Toshiba VCR that has been demonstrated by ATVA. The CCDC data stream, about 20 Mbits/sec, is within the capability of current technology for consumer use. It is claimed that a rapid search mode can be implemented by reconstructing images from blocks coded with no temporal predictor. This gives at least three displayable frames for every 60. Additional intra-coded blocks may be used also as they occur. The resultant picture would have full resolution, but may include artifacts. The reverse playback cannot be done with full quality because predicted frames cannot be generated. Splice and insert could be handled by forcing the receiver to re-acquire. Crop and overlay would require that the data stream be decompressed first. Square pixels and progressive scanning simplify the implementation of special effects such as zooming and panning.

13.4.4 Extensibility

13.4.4.1 To No Visible Artifacts

Based on simulation tests, the proponent believes that the compression algorithm will produce no visible artifacts at a data rate of 50 Mbits/sec, regardless of the difficulty of the camera-generated source material.

13.4.4.2 To Studio Quality Data Rate

According to the proponent, the intraframe encoding mode for the whole frame can be used for a production standard. Here, every frame is encoded without motion prediction. The proponent claims that, using the intraframe compression method included in this system, production-quality video with a resolution of 1280 x 720 can be stored with 3 Mbits/frame. At 60 frames per second, the bit rate is 180 Mbits/sec, an acceptable rate for studio use. The proponent claims that the frame can be decoded and re-encoded many times with little degradation.

13.4.4.3 To Higher Resolution

Currently the system is designed to display 1280 x 720 image sequences, but larger sizes can be specified as part of the frame header.

13.4.4.4 Provision for Future Compression Enhancement

The proponent claims that the compression algorithm can be improved by performing better motion estimation and including better perceptual criteria at the transmitter. These involve no changes at the receiver.

13.4.5 Interoperability Considerations

13.4.5.1 With Cable Television

Information on the performance of CCDC over cable can be found in Section 13.4.2.6.

13.4.5.2 With Digital Technology

Since this system is all-digital, the advantages of all-digital systems apply.

13.4.5.3 Headers/Descriptors

A frame header identifies the video source material, the frame rate, resolution, aspect ratio, and other system data.

13.4.5.4 With NTSC

As the CCDC system line-rate is directly related to NTSC, transcoding to NTSC is straightforward. Up-conversion from NTSC requires line tripling, horizontal line-rate conversion and interpolation.

13.4.5.5 With Film

Film is displayed with the 3:2 pull-down process for 24 fps film and with simple frame repetition for 30 fps film. The proponent claims to have actual frame rates of 59.94, 29.97, and 23.98 frames/second. The encoder automatically detects the presence of 24 fps or 30 fps scene material from film sources. When a film source is detected, an alternate buffer control algorithm is used which takes advantage of repeated frames in the source. With the scanning method used in CCDC, only two out of each five TV frames need to be transmitted for 24 fps film, and only one of each two for 30 fps film.

13.4.5.6 With Computers

Progressive scanning and square pixels, both used in this system, are important factors for interoperability of an HDTV system with computers. The frame rate used in CCDC is 59.94 Hz.

13.4.5.7 With Satellites

The proponent suggests that 8-PSK modulation would permit two CCDC signals per 36 MHz transponder. However, normal transmission by satellite is QPSK (4-phase). Nevertheless, using the 19.9-Mbits/sec information rate of CCDC, Reed-Solomon coding, and rate 7/8 convolutional coding, two channels can probably be transmitted in a 36-MHz transponder.

13.4.5.8 With Packet Networks

CCDC data is organized into 525 data lines per frame. These data lines could be used as packets if augmented with packet assembly information. Error concealment, already implemented, would ensure some resistance to packet loss. Each line of video data contains a pointer to the next macroblock (320H x 16V), so the largest amount of variable-length data that can be lost by a bit error is limited to one macroblock.

13.4.5.9 With Interactive Systems

The proponent reports a video delay of 5 or 6 frames, corresponding to 83 to 100 msec. The exact time is said to depend on how the frame buffer is used, with the video/film selection a factor. Acquisition time is reported in Section 13.4.2.11.

13.4.5.10 Format Conversion

13.4.5.10.1 With 1125/60

Up-converting to the Common Image Format (1920 x 1080) requires 2:3 interpolation horizontally and vertically. SMPTE 240M uses 1035 active lines and would require 16:23 vertical interpolation. Colorimetry is the same as SMPTE 240M.

13.4.5.10.2 With 1250/50

This difficult conversion is somewhat easier with a progressive system such as CCDC than with an interlaced system.

13.4.5.10.3 With MPEG[7]

There is no direct compatibility in terms of bit stream. The CCDC decoder would require modification to decode MPEG-1. The proponent claims that there would be a modest increase in complexity because CCDC shares many commonalties with MPEG-1. MPEG-1 decoders will not decode CCDC.

13.4.5.10.4 With Still Image

The capture of still images from video is favored by progressive scan.

13.4.5.11 Scalability

Although scalability by picture interpolation can be implemented in any proposed system, it is simplified by the progressive scanning in this system. Picture-in-picture and picture-out-of-picture are handled by standard methods in the receiver.

[7] See Section 8.3.8 for a discussion of MPEG, the MPEG-1 standard, and the MPEG-2 development effort.

13.5 SYSTEM IMPROVEMENTS

13.5.1 Already Implemented

13.5.1.1 Improvement in Table Entries

To improve video quality, the quantization tables and codeword assignment tables have been modified. The table entries may be adjusted further after video material generated by the 720-line progressive scan camera is available. This improvement involved no structural change in hardware.

13.5.1.2 Peak-to-Average Ratio Reduction

The peak-to-average ratio can be reduced by clipping the IF output of the encoder at variable levels before it is passed through the SAW filter. This improvement involves a clipping amplifier in the encoder before the SAW filter and has already been implemented.

13.5.1.3 Adaptive Window Size to Eliminate Audio Pre-Echo Effect

A slight pre-echo effect may occur for audio material that has very rapid temporal transients. The purpose of this improvement was to eliminate the pre-echo effect by varying the window size depending on the temporal characteristics of the audio. This improvement involved no hardware change.

13.5.1.4 Use of Reserved Bits to Improve Audio

Some capacity has been reserved in each frame for possible future use. In order to enhance the system's future extensibility, these reserved bits can be used to encode the dynamic bit allocation explicitly. This improvement involved no hardware change.

13.5.1.5 ATSC T3/186 Functionality

The proponent believes that the 6-channel independent audio system, as previously tested, is fully responsive to the audio requirements of the T3/186 document. The proponent also stated that the CCDC system has the available bit capacity to add the Dolby AC-3 audio system.

13.5.2 Implemented in Time for Field Testing

13.5.2.1 Packetized Transmission

The purpose of this improvement is to enhance flexibility, interoperability, and extensibility. The current data multiplexing within a line will be replaced with packets organized by data type with a header at the beginning of the packets.

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14. COMPARISONS AND RECOMMENDATIONS

14.1 SPECTRUM UTILIZATION COMPARISONS

14.1.1 Introduction

The Special Panel considered two spectrum utilization selection criteria: 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. PS/WP3 examined factors influencing these criteria for each of the ATV proponent systems. The methodology employed by PS/WP3 is described in Chapter 8. A summary of some of its analysis is provided in Chapters 9-13. This section presents the findings of the Special Panel regarding the systems’ performance with respect to these two criteria and offers suggestions for further Advisory Committee work.

14.1.2 Accommodation Percentage

With the exception of one system — Narrow-MUSE — PS/WP3 was able to create allotment/assignment schemes which accommodate 100% of existing NTSC broadcast stations. Narrow-MUSE allotment/assignment plans accommodated 77.2% or 73.7% under the VHF/UHF and UHF only channel availability options, respectively. Tradeoffs exist in the process of allotting ATV channels. While attempts were made to match the ATV coverage with that of companion NTSC stations, the provision of ATV allotments was accomplished by reducing ATV coverage areas for some stations and introducing some new interference to the coverage areas of a portion of the set of existing NTSC stations. The severity of the consequences of these tradeoffs are considered in the next section in which systems are grouped based on service area and interference performance.

14.1.3 Service Area

PS/WP3 analyzed the service area and interference performance of all five systems under two different ATV channel availability conditions (UHF and VHF/UHF). For both of these conditions, coverage and interference performance was assessed by examining three different interference conditions: co-channel only; co-channel and adjacent-channel; and co-channel, adjacent-channel and taboo channel. The Special Panel concluded that system performance groupings should be conducted using the co-channel and adjacent-channel interference condition, as emphasized by PS/WP3. Furthermore, inasmuch as the all-digital systems were certified with a primary transmission mode, the Special Panel only considered spectrum analyses using primary transmission mode data.

System performance groupings have been made based on three factors: ATV service area during the transition from NTSC to ATV, ATV service area after the transition period ends, and ATV-into-NTSC interference during the transition period. These groupings are based on the work of PS/WP3 as summarized in Figure 14-1.[1] Figure 14-2 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 and under the UHF Scenario, taking into account both co-channel and adjacent-channel constraints. The system-specific planning factors which were used as inputs in the PS/WP3 analysis are shown in Figure 14-3.

Examination of the ATV coverage during and after the transition revealed that the performance of the DSC-HDTV and CCDC systems was slightly better than the DigiCipher and AD-HDTV systems. The performance of the Narrow-MUSE system in this category was significantly worse than the four all-digital systems.

With regard to ATV interference into NTSC, the performance of the DigiCipher, DSC-HDTV and CCDC systems was slightly better than the AD-HDTV system.

The Special Panel also recognized that the degree of interference from ATV-into-NTSC, as reflected in the test results and the PS/WP3 report, is an area of significant concern in certain markets.[2] The practical extent of this interference is not known, however. The Special Panel noted that the PS/WP3 computer allotment/assignment model was designed for the purpose of comparing competing ATV systems, not for generating optimum allotment tables. As indicated above, because in its allotment/assignment plans PS/WP3 attempted to maximize ATV coverage area, the result produced some new NTSC interference areas. Thus, a plan which reduced ATV coverage by some small degree from the existing plan could minimize or eliminate new NTSC interference.

It also should be noted that the PS/WP3 report did not take into account interference into BTSC audio service. Future analysis should include this relevant test data.

Accordingly, the Special Panel believed that the Advisory Committee should direct that the issue of ATV-into-NTSC interference be addressed in the remaining stages of the system selection process. This further study could include the gathering of additional data through laboratory tests of system improvements, field tests and/or special post-recommendation tests, and the use of refined allotment/assignment techniques.

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[1] The Special Panel noted that, for the purposes of the performance groupings discussed below, decisional significance has not been accorded to small differences in the numbers presented in Figure 14-3.

[2] In this regard, the Special Panel observed that the PS/WP3 analysis suggests that less ATV-into-NTSC interference would be created under the VHF/UHF ATV channel availability condition.

Stations With ATV Service Area Equal To or Greater Than NTSC (%)	N-MUSE	DigiCipher	DSC-HDTV	AD-HDTV	CCDC
VHF/UHF Co- & Adjacent-Channel	7.1	71.9	87.4	77.4	83.2
UHF Co- & Adjacent-Channel	5.9	70.2	80.3	73.3	76.7

ATV Stations With No ATV or NTSC Interference (%)	N-MUSE	DigiCipher	DSC-HDTV	AD-HDTV	CCDC
VHF/UHF Co- & Adjacent-Channel	8.6	42.4	59.9	46.5	54.1
UHF Co- & Adjacent-Channel	7.8	45.7	54.3	46.8	51.5

ATV Stations With 35% of Coverage Area Having ATV or NTSC Interference (%)	N-MUSE	DigiCipher	DSC-HDTV	AD-HDTV	CCDC
VHF/UHF Co- & Adjacent-Channel	61.6	4.2	1.3	3.4	1.8
UHF Co- & Adjacent-Channel	64.0	4.6	3.0	5.3	3.0

ATV Stations With No ATV Interference (%)	N-MUSE	DigiCipher	DSC-HDTV	AD-HDTV	CCDC
VHF/UHF Co- & Adjacent-Channel	16.4	60.2	71.7	55.2	72.3
UHF Co- & Adjacent-Channel	14.2	60.3	64.8	52.7	66.1

ATV Stations With 35% of Coverage Area Having ATV Interference (%)	N-MUSE	DigiCipher	DSC-HDTV	AD-HDTV	CCDC
VHF/UHF Co- & Adjacent-Channel	49.5	1.8	1.1	3.2	0.8
UHF Co- & Adjacent-Channel	52.7	3.0	2.9	5.2	2.1

NTSC Stations With No ATV Interference (%)	N-MUSE	DigiCipher	DSC-HDTV	AD-HDTV	CCDC
VHF/UHF Co- & Adjacent-Channel	74.4	60.1	58.2	55.7	59.4
UHF Co- & Adjacent-Channel	77.7	62.9	61.1	59.7	62.3

NTSC Stations With 35% of Coverage Area Having ATV Interference (%)	N-MUSE	DigiCipher	DSC-HDTV	AD-HDTV	CCDC
VHF/UHF Co- & Adjacent-Channel	0.5	2.1	2.4	2.8	2.3
UHF Co- & Adjacent-Channel	0.2	7.8	8.0	9.7	8.7

New NTSC Interference (million square kilometers)	N-MUSE	DigiCipher	DSC-HDTV	AD-HDTV	CCDC
VHF/UHF Co- & Adjacent-Channel	0.78	1.41	1.51	1.77	1.54
UHF Co- & Adjacent-Channel	0.77	2.12	2.26	2.51	2.29

Figure 14-1. ATV service area, ATV interference, and NTSC interference calculated in the PS/WP3 analysis.

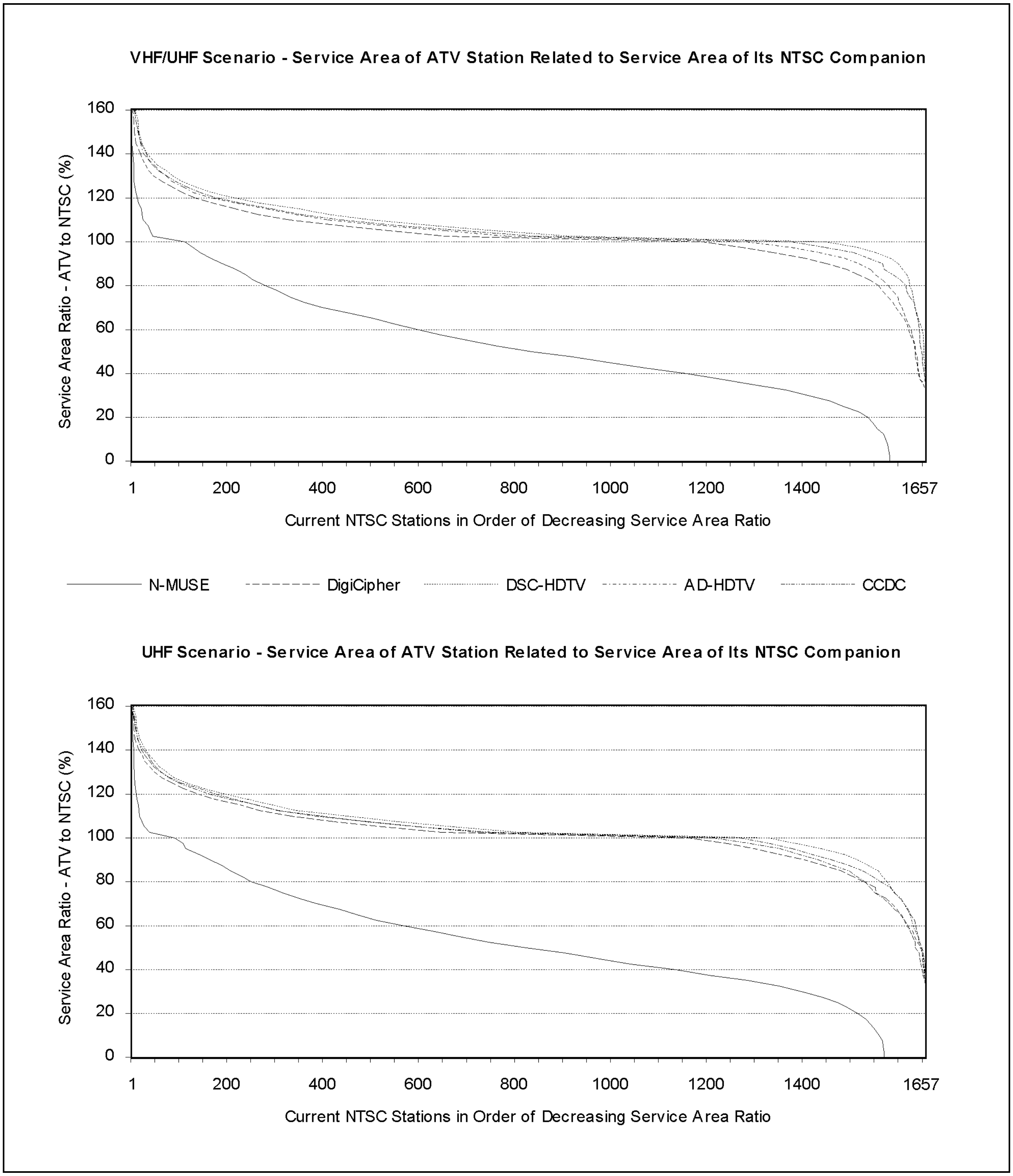

Figure 14-2. Interference-limited service area of each ATV station relative to the interference-limited service area of its companion NTSC station (co-channel and adjacent-channel constraints).

CARRIER-TO-NOISE	N-MUSE	DigiCipher	DSC-HDTV	AD-HDTV	CCDC
	+38	+16.0	+16.0	+18.4	+15.4

CO-CHANNEL	N-MUSE	DigiCipher	DSC-HDTV	AD-HDTV	CCDC
ATV-into-NTSC	+16.8	+35	+35	+34	+36
NTSC-into-ATV	+21	+7.6	+3.5	+0.50	+8.1
ATV-into-ATV	+31	+16.4	+18.2	+19.1	+16.6

ADJACENT-CHANNEL	N-MUSE	DigiCipher	DSC-HDTV	AD-HDTV	CCDC
Lower ATV-into-NTSC	-31	-13.5	-17.2	-16.0	-17.8
Upper ATV-into-NTSC	-12.0	-21	-7.5	-8.9	-17.0
Lower NTSC-into-ATV	+28	-30	-43	-38	-37
Upper NTSC-into-ATV	-11.8	-24	-42	-36	-37
Lower ATV-into-ATV	-15.5	-23	-35	-33	-32
Upper ATV-into-ATV	+16.6	-23	-36	-16.8	-32

Figure 14-3. System-specific planning factors (D/U in dB).

14.1.4 Spectrum Utilization Findings

Based on its analysis of spectrum utilization characteristics of the five proponent ATV systems, the Special Panel arrived at the following findings and conclusions:

1. The analysis conducted by the Advisory Committee clearly demonstrates that a substantial difference exists in spectrum utilization performance between Narrow-MUSE and the four all-digital systems. The differences among the four digital systems generally are far less pronounced, however. Based on this analysis, it would appear that Narrow-MUSE will not prove to be a suitable terrestrial broadcasting ATV system for the United States.

2. The Special Panel noted that many system proponents have proposed improvements to their systems in the area of spectrum utilization. The Special Panel found that the system improvements, primarily those identified by its Technical Subgroup as ready for implementation in time for testing, may lead to improvements in spectrum utilization and should be subjected to testing as soon as possible.

3. The Special Panel found that the degree of interference from ATV into NTSC, as reflected in the test results and the PS/WP3 report, is recognized as an area of concern in certain markets. The Special Panel found that the issue of ATV-into-NTSC interference, including interference to BTSC audio, should be addressed in the remaining stages of the system selection process, including the examination of refined allotment/assignment techniques, the study of possible beneficial effects of system improvements, and the consideration of any mitigations which might be achieved by transitional implementation policies.

14.2 ECONOMICS COMPARISONS

14.2.1 Cost to Consumers and Broadcasters

Based on the work of PS/WP5 and SS/WP3, a review of the costs to consumers and broadcasters was conducted for each system. The work of the working parties was found to be acceptable and helpful. There were some nominal cost differences among the systems in both the estimated costs to consumers and broadcasters, as noted in previous chapters. However, these differences in costs are of a minor magnitude and thus judged to be indistinguishable for practical purposes.

14.2.2 Economics Findings

No significant cost differences among the five proponent systems, either in costs to consumers or to broadcasters, are evident. Thus, based on cost alone, there is no basis to discriminate among systems. However, the additional benefits offered to broadcasters and others by the digital systems were noted as significant.

14.3 TECHNOLOGY COMPARISONS

14.3.1 Introduction

The Special Panel examined[3] five selection criteria (of the overall ten) under the heading Technology: Quality, Transmission, Scope of Services and Features, Extensibility, and Interoperability Considerations. These particular criteria are all closely bound up in the specific technologies employed in the various ATV system designs. This section sets forth the Special Panel's analysis and conclusions regarding these technical criteria.

Of the five selection criteria, the first two — quality and transmission, were based on actual system testing. The other three were primarily the subject of detailed analyses of the systems as certified.

The Special Panel concluded that four excellent digital HDTV systems were developed as the result of this process. Digital ATV transmission is completely viable for over-the-air broadcasting and for transmission by the alternative media of cable and satellite. The overall picture quality of two systems came remarkably close to the quality of the high-definition studio reference.

However, the extensive measured data and subjective assessments of the systems nevertheless revealed the magnitude of the challenges associated with achievement of high overall picture and sound quality,

[3] To facilitate discussion and to aid in the identification of proponent advantages for each attribute, the Special Panel developed a comparison matrix. This matrix served as an important tool to facilitate discussion and identification of proponent advantages for each attribute. Specifically, the matrix employed line item checks for those systems exhibiting a distinct advantage for any particular attribute based on the Special Panel's examination and consideration of test data and analysis of the proposed systems. The systems were considered as they were at the time of testing; however, the Special Panel noted that many system proponents have proposed improvements to their systems.

while also ensuring adequate coverage, transmission robustness, and acceptably low interference in a simulcast environment — all within the bounds of a reasonable average effective radiated power.

The Special Panel's examination further revealed that there are likely to be pragmatic tradeoffs required between the fundamental ATV requirements (under the criteria quality and transmission) and the sometimes conflicting but desirable capabilities described in the criteria of scope of services and features, extensibility and interoperability.

This report summarizes the comparative results determined by the Special Panel for each of the five technological criteria. The panel also agreed on key findings for each of these selection criteria. These findings recognize the degree of conflict among many listed attributes. The Special Panel emphasized the importance of these findings as guidelines to those system proponents who seek to revise and improve their system design.

14.3.2 Audio/Video Quality

14.3.2.1 Video Quality

The image quality achieved by the systems under ideal conditions, and under other circumstances relevant to the quality of the received image, was determined in a number of tests involving judgments by experts and by non-experts.

Transmission of ATV in the 6-MHz channel inevitably requires compression of the video data. This process introduces picture-related impairments in that small number of images and image-sequences which stress the compression scheme used. The designer therefore must optimize the scheme to handle the range of material likely to be transmitted, while ensuring that, under worst-case conditions, the impairments introduced are minimally objectionable.

In Basic Received Quality, DigiCipher and AD-HDTV were judged, on average, only about 0.3 CCIR grades lower in quality than the 1125-line studio reference for most segments of test material; the other systems exhibited lower performance (see Figure 14-4). However, all systems exhibited visible weaknesses in one or more tests designed to address other matters relating to quality (e.g., noisy source material, multiple encode/decode operations, etc.).

For still material, the ATV systems did not differ significantly overall. For live video and for film, however, the DigiCipher and AD-HDTV systems exhibited significantly better performance than the other systems. For a graphic sequence that stressed vertical and temporal performance, the DSC-HDTV and CCDC systems performed best.

For material with source noise the DigiCipher and AD-HDTV systems performed significantly better than the other systems. For scene cuts, the AD-HDTV system performed best. For material subjected to concatenated encode/decode operations, the DigiCipher system performed best. For material designed to stress the source-coding algorithms of the four all-digital systems, the DigiCipher and CCDC systems performed best. And, finally, examinations of quality achieved under extended coverage conditions, made only for Narrow-MUSE, DSC-HDTV, and AD-HDTV, revealed a clear superiority for the Narrow-MUSE system.

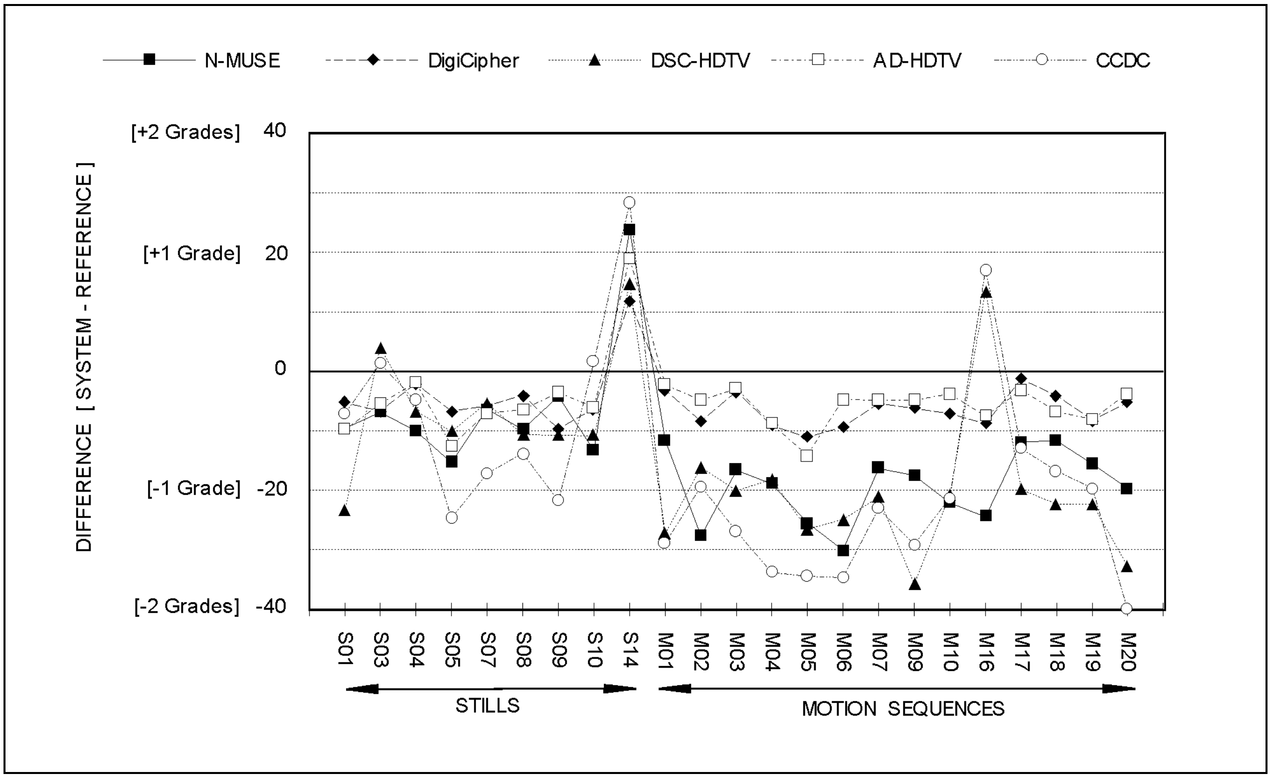

Figure 14-4. Average differences between quality judgments for the 1125-line studio quality reference and for each of the proposed ATV systems.

Overall, these results show a clear advantage for the DigiCipher and AD-HDTV systems in terms of video quality. However, they also point to the necessity for improvement, even in the two leading systems.

In interpreting the results, three mitigating factors should be considered. First, the video and film material used in tests of the progressively scanned ATV systems (i.e., DSC-HDTV and CCDC) exhibited high levels of random noise, as well as horizontally coherent noise (see Section 8.3.4). Although this may have affected adversely the performance of these two systems, it is not possible to quantify the extent to which their performance would have been affected. Second, it is likely that all systems suffered from deficiencies in the prototype hardware brought to test. And, finally, since the time of test, all system proponents claim to have made improvements in image quality.

14.3.2.2 Audio Quality

The sensitivity of the audio subjective test results was impaired by many irregularities including high variability and inconsistency among the judges. A special SS/WP2 audio Task Force reviewed the data and the corresponding audio test tapes, and recommended against the use of the data in this report. The

Task Force observed, however, that even though in some instances audio POU was not determined under conditions with transmission impairment, there was no evidence that audio failed before the accompanying video in any system.

Traditional audio objective tests were conducted for frequency response, dynamic range, THD, THD+N and IMD. AD-HDTV objective audio tests were not performed due to that system's late arrival for testing. In the objective tests, that of the CCDC audio system yielded measurement data which were significantly better than that of Narrow-MUSE, DigiCipher, or DSC-HDTV. Caution is advised in the interpretation of objective measurements of these compressed digital audio systems because sophisticated perceptual audio coding techniques can cause them to be quite misleading.[4]

System improvements for DigiCipher and DSC-HDTV include the implementation of ATSC document T3/186 audio features including 5.1 channel sound, incorporating two Dolby Laboratories AC-3 encoders for DigiCipher and an AC-3 encoder for DSC-HDTV. DigiCipher will incorporate a single AC-3 decoder while DSC-HDTV will incorporate both an AC-3 decoder and a 2-channel AC-2A decoder. System improvements for AD-HDTV include the implementation of T3/186 audio features including 5 channel sound. If the MUSICAM based 5-channel system is defined in time for implementation before further testing, AD-HDTV will incorporate it. If not, another unspecified multichannel system will be utilized. Dual mode composite and independent coding will be implemented in DigiCipher; DSC-HDTV will have both composite and independent channel coding, while independent coding of six channels has been implemented in CCDC.

14.3.3 Audio/Video Quality Findings

14.3.3.1 Video Quality Findings

1. The DigiCipher and AD-HDTV systems showed an overall advantage over other systems. However, all systems exhibited weaknesses in tests designed to assess the quality of the received image.
2. Since the time of test, all systems have declared refinements that may have implications for image quality. The impact of these refinements, which may be significant for the selection of an ATV standard, cannot be established without further laboratory testing. These improvements must be fully implemented before such tests.
3. In advance of any further testing, system proponents should attempt to improve Basic Quality and to minimize the occurrence of visible impairments. As well, proponents should give due consideration to performance on other matters relating to the quality of received image (e.g., source noise, concatenated processing, diverse program material, and momentary signal fades).

[4] Perceptual coding techniques take advantage of specific psychoacoustic properties and deliberately seek to create material that matches the source subjectively rather than objectively.

Existing test plans and test materials should be reviewed and, if necessary, enhanced to ensure consideration of these issues.

4. Excellent image quality is fundamental to success in providing HDTV programming within the ATV signal. The ability to achieve this, without jeopardizing the viability (e.g., coverage) of ATV and NTSC broadcast service, should be given the most serious attention.

5. It is to be expected that, as technologies mature, techniques for image compression will improve. It is essential that the system ultimately selected allow for compatible enhancements in image coding and for efficient re-deployment of any capacity thereby made free.

6. The systems tested were based on two different image scanning approaches: interlaced and progressive scanning. The choice of an approach is a complex trade-off of factors at capture, processing, and display. These factors include: efficiency at capture (e.g., camera sensitivity), static and dynamic resolution, accuracy of motion estimation in processing, inter-field/inter-line artifacts at display, etc. Information concerning optimum trade-offs at various stages in the television chain, given practical considerations such as data rate and cost, is needed urgently.

14.3.3.2 Audio Quality Findings

1. Audio subjective tests of the new multichannel audio systems should be conducted, preferably in compliance with recent CCIR subjective test recommendations.

2. The desirability of composite versus independent channel coding should be examined.

3. Complete audio systems should be implemented in hardware before further testing is conducted on any system.

14.3.4 Transmission Robustness

14.3.4.1 Noise Performance

The carrier-to-noise ratio (C/N) at the TOV for this impairment is listed below for each of the digital systems:

DigiCipher	16.0 dB
DSC-HDTV	16.0 dB
AD-HDTV	18.4 dB
CCDC	15.4 dB

For analog Narrow-MUSE, a subjective impairment rating of 4.0 (perceptible, but not annoying) was obtained at C/N = 38 dB.

The Special Panel concluded that the digital systems have a significant advantage over the analog system for this attribute. Among the digital systems, a 2-3 dB difference in threshold performance is significant. Therefore, the threshold C/N performance of DigiCipher, DSC-HDTV, and CCDC is significantly superior to that of the other systems.

14.3.4.2 Static Multipath

Ability to tolerate discrete, static echoes was measured at several delay times, ranging from -0.08 microseconds (i.e., a “pre-echo”) to a delay of +2.56 microseconds. The combination of echo-canceling hardware and inherent system immunity showed an advantage of about 20 dB to the digital systems. Among the digital systems, AD-HDTV was judged significantly superior for this attribute.

14.3.4.3 Flutter

Flutter is time-varying multipath. DigiCipher and CCDC exhibited significantly superior tolerance of this impairment.

14.3.4.4 Impulse Noise

The test compares proponent system performance to that of NTSC. All digital systems performed better than NTSC and Narrow-MUSE performed the same as NTSC. DSC-HDTV was significantly better than the other systems.

14.3.4.5 Discrete Frequency Interference

CCDC performed best for in-band discrete frequency rejection for the frequencies tested because its worst case (most vulnerable) frequencies tolerated significantly more undesired signal than the other systems at their most vulnerable frequencies.

DSC-HDTV performed best for out of band discrete frequency rejection for the same reason.

14.3.4.6 Cable Transmission

14.3.4.6.1 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 DigiCipher and CCDC systems each exhibited resistance to composite second order intermodulation distortion that was significantly greater than that of the other systems.

14.3.4.6.2 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 DSC-HDTV and AD-HDTV systems revealed significantly greater immunity to composite triple beat products than did the remaining systems. The system design measures taken to protect the signals from co-channel interference are also effective in providing immunity to composite triple beat.

14.3.4.6.3 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. All of the digital systems exhibited substantially greater immunity from phase noise than did the Narrow-MUSE system.

14.3.4.6.4 Residual FM

Residual frequency modulation is another form of deviation in oscillators used in frequency conversion equipment. The DigiCipher and CCDC systems tolerated considerably greater residual frequency modulation than did the remaining systems.

14.3.4.6.5 Local Oscillator Pull-In Range

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.

The DigiCipher, DSC-HDTV, and CCDC systems demonstrated a substantially wider local oscillator pull-in range than the other systems. The DSC-HDTV system range exceeded +/- 100 kHz, the maximum value prescribed in the formal test procedure.

System performance in the presence of phase noise, residual FM and received signals that are offset in frequency, is largely a function of tuner design and implementation and therefore may be expected to improve with a second iteration of prototype equipment delivered for testing.

14.3.4.6.6 Channel Change

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 DigiCipher, DSC-HDTV, and CCDC systems completed a channel change in approximately one second, versus substantially longer times recorded for Narrow-MUSE and for AD-HDTV.

14.3.4.7 Co-Channel Interference into ATV

DigiCipher and CCDC were most robust to co-channel interference from ATV. AD-HDTV was best at rejecting co-channel interference from NTSC. (See Figure 14-3.)

14.3.4.8 Co-Channel Interference into NTSC

Narrow-MUSE performed significantly better than the digital systems for ATV-into-NTSC co-channel interference. All digital systems required about the same signal level to cause co-channel interference into NTSC. (See Figure 14-3.)

14.3.4.9 Adjacent-Channel Interference

Narrow-MUSE performed significantly better than the digital systems on lower adjacent-channel ATV-into-NTSC interference by causing the least interference.

Among the digital systems, DSC-HDTV performed best in rejecting ATV-into-ATV and NTSC-into-ATV adjacent-channel interference. DigiCipher and CCDC caused the least upper adjacent-channel ATV-into-NTSC interference. DSC-HDTV, AD-HDTV and CCDC caused the least lower adjacent-channel ATV-into-NTSC interference. (See Figure 14-3.)

14.3.4.10 Taboo Interference

Narrow-MUSE performed significantly better than the digital systems for ATV taboo interference into NTSC. Among the digital systems, DSC-HDTV had the best all-around ability to reject taboo interference on the nine channels tested; however, the performance of all digital systems was close.

14.3.4.11 Channel Acquisition

The test measured the time required to acquire the signal and display a recognizable picture under a variety of impairment conditions; signal conditions were always above TOV. The performance of DigiCipher, DSC-HDTV, and CCDC was judged superior to the other systems. The three cited systems were able to deliver a recognizable image within about one second under conditions of moderate impairment.

14.3.4.12 Failure and Recovery Appearance:

The test simulated signal fading in fringe areas for digital systems. Signal strength was reduced below threshold level and then increased above threshold; the resulting image behavior was observed. In general, all systems “froze” the image as the signal fell below threshold. Typically, the image became “blocky” and dissolved into other characteristic artifacts. Recovery was most rapid for AD-HDTV (much less than one second). DigiCipher recovered with characteristic panel wiping, lasting about 1/3 second. CCDC recovery generally consumed about 1/2 second but could last longer than one second. DSC-HDTV required the longest recovery period, generally 2-5 seconds. The speed and subjective appearance of AD-HDTV’s recovery were judged significantly superior to the other systems.

14.3.4.13 Power

14.3.4.13.1 Peak-to-Average Power Ratio

The ratios of peak-to-average power for the digital modulation schemes are listed below:

	DigiCipher	DSC-HDTV	AD-HDTV	CCDC
99% of time	4.8 dB	6.3 dB	<6 dB	<5.2 dB
99.9% of time	<6 dB	7.6 dB	<6.7 dB	<6.2 dB

The peak-to-average power ratios of DigiCipher and CCDC were judged significantly superior among the digital systems.

14.3.4.13.2 Average ERP

The maximum average ERP for each digital system required to achieve ATV noise limited coverage comparable to NTSC Grade B coverage is listed below:

DigiCipher	38.23 dBk
DSC-HDTV	38.25 dBk
AD-HDTV	40.42 dBk
CCDC	37.66 dBk

It is noted that AD-HDTV required significantly more average ERP than the other systems.

14.3.4.14 Multiple Impairments

The broadcast portion of this test determined POA (which needed only to be a “recognizable” image, not a “watchable” one) under different conditions of random noise and co-channel impairments. The test results show that DSC-HDTV could acquire signal under the worst combination of these impairments, with AD-HDTV very close in performance. DigiCipher and CCDC required a significantly more favorable combination of conditions for signal acquisition.

The cable portion of this test measured TOV under different combinations of random noise and composite triple beat. The test results show that DigiCipher, DSC-HDTV, and AD-HDTV exhibited better performance than CCDC. All digital ATV systems, however, are expected to operate with adequate margins to noise and CTB on existing cable systems designed for carriage of NTSC signals for the nominal ATV power levels tested.

14.3.4.15 Threshold Characteristics

Narrow-MUSE, as expected from its analog signal format, exhibited gradual degradation of image quality with decreasing C/N. All of the digital systems had sharp thresholds, with image quality degrading from TOV to POU over less than a 2 dB change in C/N. Based on certification documents, this performance was expected for DigiCipher and CCDC. The claimed gradual thresholds of DSC-HDTV and AD-HDTV were judged to have utility only for short, temporary, and infrequent signal fading. The actual values of TOV for each system are contained elsewhere in the report.

Audio threshold performance was also characterized. For all of the digital systems, there was no evidence that audio failed before the accompanying video.

14.3.5 Transmission Robustness Findings

1. A variety of different modulation and signal formats was evaluated. In general, the analysis conducted by the Advisory Committee clearly indicates that an all-digital approach is important in satisfying the selection criteria. Of the four digital transmission systems tested, the Special Panel was unable to recommend a single system.
2. Among the digital systems, both sharp and claimed gradual thresholds were tested. No video performance advantages were found in the forms of gradual signal degradation tested.

3. It is desirable to maintain audio service during momentary disruptions in the picture.
4. The four digital systems tested provided adequate levels of operating margin with respect to composite second and third order impairments.
5. Special attention will need to be paid to the final design of tuners in ATV receivers to achieve immunity to typical levels of phase noise and residual frequency modulation. Although the digital systems performed better, as a class, than the Narrow-MUSE system, none performed adequately for typical levels of these impairments in conventional cable equipment.
6. Careful tuner design is required to assure the acquisition of signals that are offset from their nominal assigned frequencies. As tested, three of the digital systems achieved acceptable performance.
7. While three of the digital ATV systems tested exhibited channel change performance close to that required, none demonstrated optimal performance. Current television viewers expect channel change to be completed nearly instantaneously. Minimizing consumer dissatisfaction with ATV service will require similar performance, certainly well below one second.
8. While the subjective quality tests of cable distribution indicated no degradation, the transmission conditions simulated were not representative of a wide range of real-world cable television plant. Only the field tests will provide final data regarding cable transmission performance.
9. DigiCipher's ability to reject an undesired adjacent or second adjacent signal was significantly worse than the other systems. The proponent has identified an improvement in the system's IF filter which should be verified.
10. Taboo and adjacent-channel performance are dependent on tuner and IF selectivity. Important design information can be obtained from the systems' blackbox tuner/IF characteristics. The proponents should submit both the tuner characteristics of the test hardware and their suggestions for minimum tuner performance.
11. Improvements to the transmission system suggested by the digital proponents include better error correction and concealment, improved receiver RF filters, and techniques to reduce transmitter peak power. Each of these improvement categories addresses specific shortcomings cited in the test results.

14.3.6 Scope of Services and Features

Scope of Services and Features considered the need of an ATV system to support features and capabilities beyond those explicit in other selection criteria. The following were considered as a basis of differentiating among the proponent systems: initial use of ancillary data, audio, data, text, captioning, encryption, addressing, low cost receiver, and VCR capability.

All systems provided for data transmission. With respect to data, the AD-HDTV system was judged better than the others because it used a packetized data structure with headers and descriptors that has been determined, in general, to be important to providing system flexibility. With respect to addressing, the AD-HDTV system was considered better than the other digital systems due to its ability to reassign its entire 18.5 Mbits/s to addressing keys.

Low cost receiver and VCR capability did not expose substantive differences among the five systems.

The remaining five features did not show significant differences among the four digital systems, but overall the digital systems ranked better than the Narrow-MUSE system (though the difference was small).

14.3.7 Extensibility

Extensibility considered the ability of a transmission system to incorporate extended functions and future technology advances. The following were considered as a basis of differentiating among the proponent systems; extensibility to: no visible artifacts, studio-quality data rate, higher resolution, VHDTV, UHDTV, and provision for future compression enhancements.

It was concluded that the use of a packetized data structure with universal headers and descriptors provides important flexibility in meeting this selection criteria. For example, if a higher data rate channel is used to distribute programming to television stations, additional packets (with appropriate headers and descriptors) could provide higher quality images for post-production processing.

Overall, the digital systems ranked better than the Narrow-MUSE system; however, there were no significant differences among the digital systems.

14.3.8 Interoperability Considerations

Interoperability considered delivery over alternative media (cable, satellite, packet networks), transcoding (with NTSC, film, and format conversion to other video standards), integration with computers and digital technology, interactive systems, the use of headers/descriptors, and scalability.

Progressive scan and square pixels are important for computer and other image applications. For interoperability with computers, DSC-HDTV and CCDC ranked better than the other systems.

Only AD-HDTV had its final proposal for a packetized data structure and headers and descriptors fully implemented at the time the system was tested by ATTC, and it received the highest rating on these characteristics. All digital system proponents now recognize the importance of a packetized data structure combined with headers and descriptors as a critical enabling concept for ATV flexibility. As cited in the comparative analysis, examples are SMPTE Header/Descriptor, flexible channel reallocation, compatibility with telecommunications and computer networks.

With respect to format conversion, Narrow-Muse does not require conversion to 1125/60, and AD-HDTV’s use of MPEG-1 provides the possibility of interoperability with MPEG applications.

The four digital systems were judged better than Narrow-Muse for interoperability with digital technology, NTSC, film, still images, and interactive systems. Note that latency and acquisition time are important for interactive systems, but have not been completely determined.

All five systems were judged suitably interoperable with satellite and cable.

14.3.9 Findings for Scope of Services and Features, Extensibility, and Interoperability Considerations

In consideration of the comparative analysis and the PS/WP4 conclusions in Section 4.4, the following recommendations are offered.

1. The analysis conducted by the Advisory Committee clearly indicates that an all-digital approach is important in satisfying these selection criteria.
2. All four digital proponents have implemented, or now commit to implement, both a flexible packetized data transport structure and universal headers/descriptors. Their design and implementation need to be verified consistent with relevant industry standards and practices and with respect to the ATV selection criteria.
3. DSC-HDTV and CCDC are progressive at 60 Hz and square pixel in format. AD-HDTV provides progressive-scan transmission at 30 Hz and claims a potential migration path to square pixels. DigiCipher claims a possible option for progressive scan transmission at 30 Hz. A transmission format based on progressive scan and square pixel is beneficial to creating synergy between terrestrial ATV and national public information initiatives, services, and applications. The ATV design, implementation, and migration paths need to be fully documented by the proponents and analyzed for suitability in addressing these needs.
4. None of the systems achieved the desirable degree of scalability at the transmission data stream that would permit trade-offs in “bandwidth on demand” network environments.

14.4 RECOMMENDATIONS

The Special Panel recognized that enormous progress has been made in the development of ATV systems for the United States.

While all the proponents produced advanced television systems, the Special Panel noted that there were major advantages in the performance of digital HDTV systems in the United States environment and recommended that no further consideration be given to analog-based systems.[5] The proponents of all four digital HDTV systems — DigiCipher, DSC-HDTV, AD-HDTV, and CCDC — have provided practical digital HDTV systems that lead the world in this technology. Because all four systems would benefit significantly from further development, the Special Panel did not recommend any one of the four excellent systems for adoption as a United States terrestrial ATV transmission standard at that time. Rather, the Special Panel recommended that these four finalist proponents be authorized to implement their improvements as submitted to the Advisory Committee and approved by the Special Panel’s Technical Subgroup.

[5] However, the Special Panel wished to express appreciation to NHK for its numerous contributions to the Advisory Committee and the overall effort to establish an ATV standard in the United States.

The Special Panel further recommended that the approved system improvements be ready for testing not later than March 15, 1993, and that these improvements be laboratory and field tested as expeditiously as possible. The results of the supplemental tests, along with the already planned field tests, would provide the necessary additional data needed to select a single digital system for recommendation as a United States terrestrial ATV transmission standard.

15. FUTURE WORK

15.1 DEVELOPMENT OF STANDARDS

The Advisory Committee recognizes that detailed technical specifications and disclosures need to be developed and distributed in a timely manner to the affected industries following the selection of a winning ATV system. The Advisory Committee also realized early on in the process that the documentation effort is not within the purview of the Advisory Committee itself. As early as April 1989, SS/WP4 agreed that the working party would not document a standard in the manner of SMPTE or EIA, but rather its role was to recommend a standard documented by others. The Fifth Interim Report of the Advisory Committee stated that development of a completely specified technical standard would be best handled by organizations other than the Advisory Committee, whose principal goal was "to counsel the FCC and proffer a recommendation on the best available ATV system."[1] The Fifth Interim Report expressed confidence that the appropriate organization would volunteer to conduct this assignment.

On June 5, 1992, the Advanced Television Systems Committee (ATSC) filed information with the FCC to outline proposed industry actions to fully document the selected ATV system. ATSC reviewed the areas where documentation of ATV standards is required when the FCC selects the United States terrestrial ATV transmission system. Some areas require joint cooperation among a wide variety of industries while other areas can best be accomplished by individual standard-setting organizations. Following a recommendation on an ATV system by the Advisory Committee, ATSC said it would immediately begin to document standards for that system. This information will be needed by the FCC in adopting an ATV standard.

In addition to documenting the standard for the FCC, ATSC has suggested which portions of the ATV broadcasting system standard should be incorporated into the FCC Rules and which portions should be voluntary and documented by other organizations such as EIA, IEEE, NAB, NCTA and SMPTE. The FCC's Memorandum Opinion and Order/Third Report and Order/Third Further Notice of Proposed Rule Making encouraged the ATSC and its member groups to begin the documentation process as soon as they have sufficient data. It is expected that this plan will be aggressively pursued by the television industry to speed the implementation of ATV service to the public.

15.2 FIELD TESTING

Prior to convening of the Advisory Committee to select a system to recommend to the FCC, only laboratory results, both objective and subjective, were available. Field testing of the selected system will follow.

[1] Fifth Interim Report of the Advisory Committee on Advanced Television Service, March 24, 1992, page 21.

A test plan was developed by the Field Testing Task Force of Systems Subcommittee Working Party Two. Administrative support for the project has been assumed by the Public Broadcasting Service (PBS). With the hiring of a Test Manager in late summer, 1992, detailed planning and budget preparation were begun. An Executive Committee including the manager and representatives from PBS, the Association for Maximum Service Television (MSTV), and CableLabs provides guidance of the effort, and oversight is provided by the Field Test Technical Oversight Committee.[2]

The estimated cost of the field testing for terrestrial transmission, excluding the substantial contributions of equipment, building and tower, is $1,200,000. That sum is being provided by the proponents, with the selected system proponent assuming the major share. A building and tower, transmitters, antennas, transmission line, test equipment, field truck, and a translator to be used for interference testing have all been loaned by suppliers of such equipment. A manager and two additional technicians have been hired for installation and operation of the system. In addition to representatives of the system under test, there will be three observers, including one from the FCC. MSTV will provide analysis of the data collected.

The transmitter site is near Charlotte, North Carolina. In addition to the availability of a building and tower for the field testing, the location is well suited for the observations to be made. Both VHF (Channel 6) and UHF (Channel 53) channels were determined to be usable at that location without the likelihood of serious interference to existing television facilities. A variety of terrain conditions are present, ranging from quite level, through rolling to reasonably rugged. In addition, both rural and urban environments can be examined. Since transmission through cable systems is to be studied, as well as terrestrial transmission, the availability of a variety of cable systems is also a requirement. A review of the systems in the Charlotte area was undertaken by CableLabs. The conclusion of the review was that cable systems appropriate for the testing program were available and willing to cooperate.

A comparison will be made of NTSC and ATV reception, both video and audio, at approximately 200 locations. Both objective measurements and subjective evaluations will be made of the performance of the selected system in a terrestrial transmission environment. In addition, CableLabs will make objective and subjective evaluations at approximately 50 cable drops spread through a number of systems.

The terrestrial transmission observations will be made along selected radials providing a variety of terrain features, and in grid patterns to provide a measure of the consistency of service in both large and small communities. As recommended by the FCC, some smaller clusters of sites will be used also. In addition, partly by taking advantage of the closest Channel 6 NTSC station, and by use of a translator, NTSC/ATV and ATV/ATV interference will be observed.

At the conclusion of the accumulation and analysis of data, a report will be prepared.

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[2] The Field Test Technical Oversight Committee is chaired by Richard E. Wiley. The Vice Chair is Joel Chaseman. Other members are Wendell Bailey, Alex Best, Jules Cohen, Birney D. Dayton, Irwin Dorros, Alex D. Felker, Joseph Flaherty, Jack Fuhrer, George Hanover, James C. McKinney, Renville H. McMann Jr., Howard Miller, Robert Niles, Michael Rau, Henry Rivera, Andy Setos, Peter Smith, Craig Tanner, and Warren Williamson III. Ex officio members are FCC representatives, proponent representatives, Mark Richer and Edmund Williams.

GLOSSARY

Note: the words in this glossary are defined only for the purposes of this report.

Accommodation Percentage: Accommodation percentage is defined as the number of existing NTSC stations expressed as a percentage of the total number of NTSC stations that can each be assigned one additional simulcast ATV channel (independent of the resulting service area).

Adjacent-Channel Interference: Adjacent-channel interference is the interference from a signal in the first channel on either side of the one desired.

Allocation: An allocation is the specification of a frequency band for use by a particular service.

Allotment: An allotment is the designation of a particular channel, or group of channels, to a community.

Assignment: An assignment is the designation of a channel to be used by a particular licensee.

ATEL: Advanced Television Evaluation Laboratory is a testing facility for subjective evaluations of high definition video in Ottawa, Canada, which is sponsored by a consortium which includes the Department of Communication, Communication Research Centre, Tektronix Canada, Canadian Broadcasting Corporation, Leitch Video International, Rogers Engineering, Telesat Canada and Advanced Broadcasting Systems of Canada.

ATM: Asynchronous Transfer Mode is an emerging standard for advanced packet networks that was developed for high-speed data communications.

ATTC: Advanced Television Test Center is the facility in Alexandria, Virginia, which was designed to objectively measure high definition television as well as to collect expert viewer observations and commentary. ATTC is a private, non-profit organization sponsored by broadcasting companies and industry organizations including Capital Cities/ABC Inc., CBS Inc., NBC Inc., PBS, Association of Independent Television Stations (INTV), Association for Maximum Service Television (MSTV), Electronic Industries Association (EIA) and National Association of Broadcasters (NAB).

ATV: Advanced Television.

B-ISDN: Broadband Integrated Services Digital Network is a future high-speed fiber optic network intended to deliver switched audio, video and data.

Blockiness: Blockiness is an artifact of digital compression where blocks used to code the picture are visible.

Busy-ness: Busy-ness is an artifact of digital compression, defined as localized time varying noise correlated with image content. For example, the picture may seem to be moving in highly-detailed still areas, such as leaves on a tree, tile roofs, or flowers.

CableLabs: Cable Television Laboratories, Inc. (CableLabs) is the cable television industry's research and development organization. CableLabs' headquarters are in Boulder, Colorado, with an ATV testing office in Alexandria, Virginia. CableLabs, a not-for-profit organization, is governed by a Board of Directors and a Technical Advisory Committee. CableLabs' member companies represent approximately 85% of all U.S. cable subscribers and 60% of Canadian cable subscribers.

CCIR: The International Radio Consultative Committee is the permanent organ of the International Telecommunication Union (ITU) responsible "to study technical and operating questions relating specifically to radiocommunications without limit of frequency range, and to issue Recommendations on them with a view to standardizing telecommunications on a world-wide basis..." The ITU organization will change during 1993. The CCIR functions, for the most part, will fall within the new Radiocommunications Bureau (RCB).

CCIR Impairment Scale: Although there are several internationally-accepted impairment scales, the one used in this report is a five-point, four-interval scale with discrete ratings. The ratings are "imperceptible", "perceptible, but not annoying", "slightly annoying", "annoying" and "very annoying"; the numerical values, respectively, are 5, 4, 3, 2, and 1. Note that the CCIR impairment scale is not tied to the CCIR quality scale: no mapping is implied from an impairment grade to a quality grade.

CCIR Quality Scale: Although there are several internationally-accepted quality scales, the one used in this report is a five-point, five-interval quality scale with continuous ratings in five categories: excellent, good, fair, poor, bad. ATEL scored the ratings from 0 to 100 (where 0 is worst) so that 20 points represents one interval, or grade. Note that the CCIR quality scale is not tied to the CCIR impairment scale: no mapping is implied from an impairment grade to a quality grade.

Cliff Effect: Cliff effect refers to abrupt failure of a system over a few dB or less of increasing impairment.

C/N (also CNR): Carrier-to-Noise ratio.

C/N Threshold: The C/N at TOV for random noise.

Co-Channel Interference: Co-channel interference is the interference from a signal on the same channel.

Coding: Coding is a way to represent information, such as a picture or sound, electrically with a series of discrete (i.e., digital) codes. The goals are to represent information either efficiently (compression) or robustly (transmission and error correction).

Collocation: Collocation, as used in this report, is the employment of transmitter sites by two or more stations within a radius of ten kilometers.

Coverage Area: Coverage area is the area within an NTSC station's Grade B contour without regard to interference from other television stations which may be present. For an ATV station, coverage area is the area contained within the station's noise-limited contour without regard to interference which may be present.

CRC: Cyclic Redundancy Check is a standard error-detection code used to detect bit errors in a block of data.

CSO: Composite Second Order interference results from the generation of beats between pairs of signals. Processing signals through amplifiers, and other active devices having non-linear characteristics, introduces intermodulation distortions in clusters of beats with an offset of +1.25 MHz relative to the video-carrier frequency. CSO products dominate in single-ended amplifiers.

CTB: Composite Triple Beat interference results from the generation of beats between multiple signals. Processing signals through amplifiers, and other active devices having non-linear characteristics, introduces intermodulation distortions in clusters of beats normally located around the NTSC visual carrier.

dB: "dB" is the abbreviation for "decibel," a logarithmic ratio. When used to specify power ratios, the arithmetic ratios are converted to dB by the formula: $10 \log_{10} P1/P2$. When used to specify voltage ratios, the arithmetic ratios are converted to dB by the formula: $20 \log_{10} V1/V2$.

dBc: "dBc" is a unit of power level in decibels with reference to the power level of the carrier.

dBm: "dBm" is a unit of power level in decibels with reference to a power of one milliwatt. When preceded by a minus sign, dBm represents decibels below one milliwatt.

DCT: Discrete Cosine Transform is the method used in all the digital systems to spatially compress the video signal. DCT separates the signal into a DC component and higher spatial frequency components. The DCT is used in conjunction with motion compensation to further compress the information which changes from frame to frame.

Decimation: Decimation is the process of discarding information, commonly used to refer to reducing the number of video pixels or audio samples.

Digital System: In this report a digital system refers to a video compression and transmission system which includes motion compensation, DCT and the transmission of only digital data.

D/U: Desired-to-undesired signal ratio expressed in dB. D/U is used in this report to indicate a level of impairment.

Entropy Coding: Entropy coding is a statistically-based technique which assigns shorter bit-length codes to the most common values, and longer codes to the least common, as a function of the probabilities of their occurrence.

Error Rate (also called Alpha): The error rate is the level of error one is willing to accept in deciding that a difference between two statistics is real, when in fact the difference is due to chance. The standard rate is 5% or one chance in 20.

Field: In an interlaced-scanning format, a frame consists of a field of even scan lines and a field of odd scan lines captured or displayed at different times. (See Frame.)

Frame: A frame is one complete image in a sequence of images. In video, the frame captures and displays all pixels and lines of an image. In a progressive-scanning format, there is no decomposition into fields. In an interlaced-scanning format, the frame consists of odd and even line fields, captured or displayed at different times, which in combination contain all pixels and lines of an image. The frame rate of a progressive scan format is twice that of an interlace scan format.

Grade B: Grade B is an FCC definition of the generally considered outer limit of NTSC coverage.

GOP: Group of Pictures is the set of pictures in MPEG-1 compression between the intra-frames (I-frames), which are spatially encoded with no motion compensation.

IEC: International Electrotechnical Commission.

Interlaced Scanning: Interlace refers to a video format where spatially adjacent lines are not consecutively captured or displayed. (See Field and Frame.)

ISO: International Organization for Standardization.

JPEG: Joint Photographic Experts Group is an ISO group which has established a compression standard for digital representation of still pictures.

Latency: Latency is the delay between input and output of a system; the largest components are buffer and frame delays.

M-symbol: A symbol is the smallest temporal unit of RF transmission information. M-symbol, or Mega-symbol, is one million symbols.

Minimum Detectable Difference: The smallest difference between two statistics which would be statistically significant. This quantity depends on the standard deviation, the error rate and the sample size (number of measurements).

Moire: This undesired pattern results from the interaction between a desired, regular image pattern and other regular patterns or structures.

Motion Compensation: Motion compensation removes the frame-to-frame redundancy by predicting the picture content of one frame based on proceeding (and/or following) frames.

Motion Compensation Overload: A failure mode of motion compensated systems where the motion estimator range is exceeded, which was tested using a still image panned at increasing horizontal, vertical and diagonal speeds.

Mottling: Mottling is a localized visual artifact characterized by spots or blotches.

MPEG: Moving Pictures Experts Group is an ISO group which establishes standards for digital video.

Outlier: Outliers are data points that are far away from the rest of the data. In evaluating test results, a data point would be considered an outlier if it were separated from the rest of the data by a distance calculated from the 75th and the 25th percentiles.

Packet: A packet is a fixed-length self-contained block of data that includes all relevant header information to allow switching, routing and data recovery.

Pixel: "Pixel" is an abbreviation for "picture element," a spatial light intensity sample with a discrete value on a rectilinear grid. A color pixel is a triplet of values representing either red, green, and blue intensity, or luminance and two color-difference intensity values.

POA: Point of Acquisition is the maximum impairment level (or the D/U in dB) at or below POU at which a system can acquire a signal and display a recognizable image within five seconds, starting from a no-signal, no impairment condition. For all tests, POA was determined by expert observers.

POU: Point of Unusability is the impairment level (or the D/U in dB) where the picture was judged to be extremely annoying such that a typical viewer would not continue to watch an average program. For all tests, POU was determined by expert observers.

Progressive Scanning: Progressive scanning is a video format where spatially adjacent lines are consecutively captured or displayed. (See Frame.)

QAM: Quadrature Amplitude Modulation is a standard technique for digital communications that uses both amplitude and phase modulation (two carriers in quadrature).

Quantization Noise: This artifact of digital systems produces an apparent loss of resolution, and/or increased noise, typically noticeable in flat areas, on edges, and in areas of high detail.

Reed-Solomon Coding: Reed-Solomon coding is a standard error-correction code used to correct bit errors in a block of data.

Service Area: Service area is the resulting area when coverage area is reduced by interference.

Standard Deviation: The standard deviation is a statistic which describes the variability or spread of a group of numbers. It is similar to root mean square (RMS) error.

Statistically Significant Difference: A difference not likely due to chance is labeled "statistically significant." See error rate.

TOV: Threshold of Visibility is the impairment level (or D/U in dB) beyond which a source of impairment or interference may introduce visible deficiencies in more sensitive program material. For all tests, TOV was determined by expert observers.

Trellis Coding: Trellis coding is a combined digital modulation and coding scheme that can improve bit error probability for a given C/N ratio by transmitting redundant data that depends on data transmitted at an earlier time.

Video Coder Overload: Video coder overload is tested using rapid scene cuts, at most only a few frames apart, to stress digital compression systems by presenting them with a video signal that contains little or no temporal redundancy (frame-to-frame correlation). Buffer overload refers to the same condition.

VSB: Vestigial sideband modulation is a technique where amplitude modulation is applied to a single carrier and a portion of one of the resulting redundant sidebands (e.g., lower sideband) is eliminated for more efficient transmission.

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