FINAL TECHNICAL REPORT

Federal Communications Commission

Advisory Committee on Advanced Television Service

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1. INTRODUCTION

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

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

2. SCANNING FORMATS

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

Table 2.1 ATV system scanning formats.

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

2.1. RESOLUTION

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

Table 2.2 Target specifications for resolution.

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

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

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

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

2.1.1. Static Luminance Resolution

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

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

2.1.2. Static Chrominance Resolution

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

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

Table 2.3 Resolution of the Digital HDTV Grand Alliance system.

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

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

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

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

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

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

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

2.1.3. Dynamic Luminance Resolution

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

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

2.1.4. Dynamic Chrominance Resolution

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

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

2.2. FORMAT CONVERSION

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

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

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

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

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

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

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

3. COMPRESSION

3.1. VIDEO

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

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

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

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

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

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

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

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

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

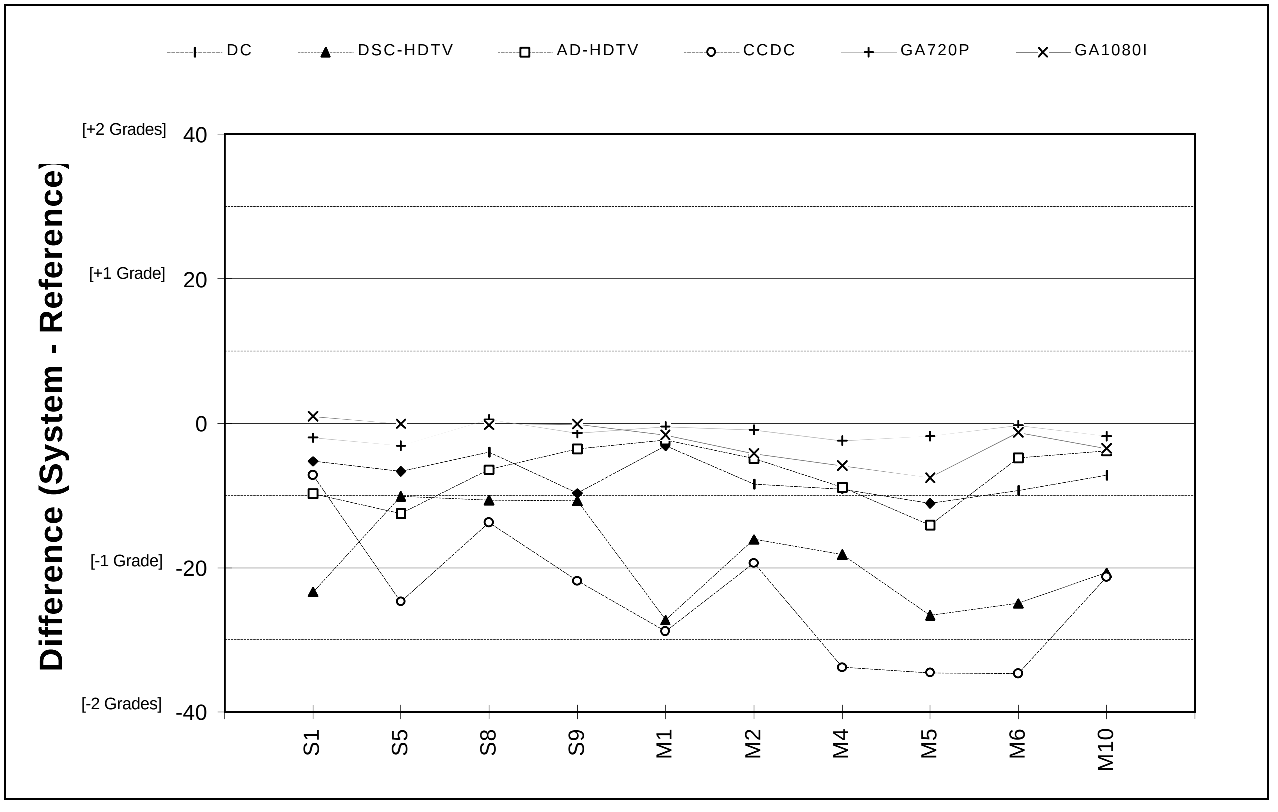

Figure 3.1 Quality of the Digital HDTV Grand Alliance system and the four original digital systems compared with the 1125-line studio quality reference.

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

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

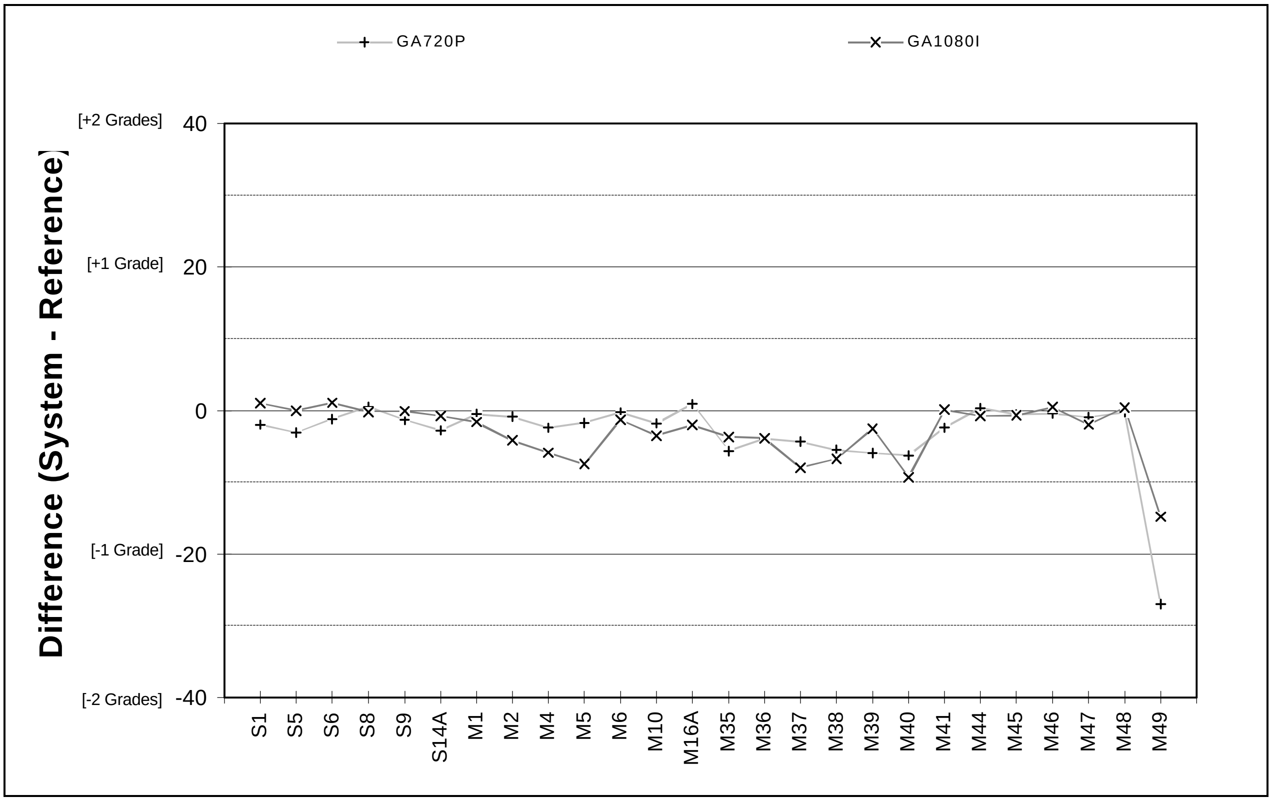

Figure 3.2 Quality of the Digital HDTV Grand Alliance system across all sequences compared with the 1125-line studio quality reference.

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

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

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

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

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

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

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

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

3.2. AUDIO

3.2.1. Audio and Long Form Entertainment Tests

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

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

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

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

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

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

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

Table 3.3 ATV subjective audio and long form entertainment tests.

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

3.2.2. Dual Stream Audio

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

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

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

3.2.3. References

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

4. TRANSPORT

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

Table 4.1 Interoperability and Packetization Target Specifications.

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

4.1. SWITCHING BETWEEN COMPRESSED DATA STREAMS

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

4.2. HEADER/DESCRIPTOR ROBUSTNESS

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

4.3. COMPRESSION AND TRANSPORT LAYER INTEROPERABILITY

4.3.1. Syntactic and Semantic Compliance of the ATV Bit Stream

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

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

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

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

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

4.3.2. Interoperability with ATM Networks

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

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

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

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

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

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

4.3.3. Multiple Ancillary Data Services

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

4.4. AUDIO/VIDEO/CAPTIONING LATENCY

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

4.4.1. Absolute Latency

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

4.4.2. Relative Latencies

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

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

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

For the 720P format, captioning latency essentially matched the video latency, leading the video by only1 ms.

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

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

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

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

5. TRANSMISSION

5.1. SPECTRUM UTILIZATION

5.1.1. Introduction

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

5.1.2. Accommodation Percentage

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

5.1.3. Service Area

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

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

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

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

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

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

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

5.1.3.1. Service Area Evaluation

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

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

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

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

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

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

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

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

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

[2] Based on upper adjacent video.

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

5.1.3.2. Comparison with Four Original Digital Systems

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

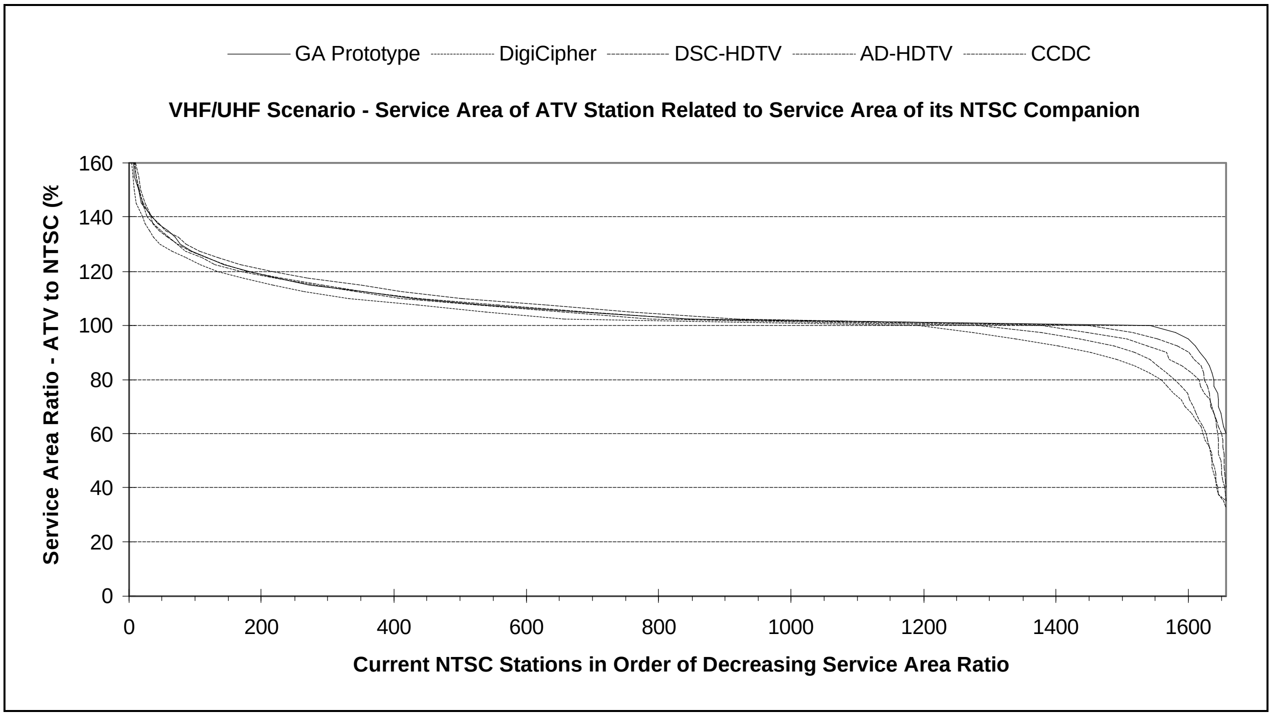

Figure 5.1 Interference-limited service area of each ATV station relative to the interference-limited service area of its companion NTSC station (VHF/UHF scenario, co-channel and adjacent-channel constraints).

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

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

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

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

5.1.4. Summary of Spectrum Utilization Findings

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

5.2. TRANSMISSION ROBUSTNESS

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

5.2.1. Random RF Noise Performance

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

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

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

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

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

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

5.2.2. Static Multipath

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

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

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

Table 5.5 Random RF noise performance of Grand Alliance prototype.

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

5.2.3. Flutter

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

5.2.4. Impulse Noise (Burst Error)

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

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

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

5.2.5. Discrete Frequency Interference

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

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

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

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

5.2.6. Co-channel Interference into ATV

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

5.2.7. Co-channel Interference into NTSC

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

5.2.8. Adjacent-Channel Interference

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

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

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

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

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

5.2.9. Taboo Interference

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

5.2.10. Peak-to-Average Power

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

5.2.11. Threshold Characteristics

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

5.2.12. Cable Transmission

5.2.12.1. Composite Second Order

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

Table 5.7 Taboo interference performance of Grand Alliance prototype.

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

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

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

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

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

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

5.2.12.2. Composite Triple Beat

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

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

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

5.2.12.3. Phase Noise

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

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

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

5.2.12.4. Residual FM

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

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

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

5.2.12.5. Fiber Optics

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

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

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

5.2.12.6. Channel Change and Channel Acquisition

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

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

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

5.2.12.7. Multiple Impairment — Second Order vs. Noise

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

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

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

5.2.12.8. Multiple Impairment — Third Order vs. Noise

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

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

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

5.2.12.9. Multiple Impairment — Phase Noise vs. Noise

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

5.2.12.10. Multiple Impairment — Residual FM vs. Noise

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

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

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

5.2.12.11. Local Oscillator Instability

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

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

5.2.12.12. Minimum Isolation between Receivers

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

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

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

5.2.12.13. Effect of High Level Sweep

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

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

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

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

5.2.12.14. Hum Modulation

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

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

5.2.13. Summary of Transmission Robustness Findings

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

5.3. FIELD TEST

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

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

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

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

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

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

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

6. CONCLUSIONS

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

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

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