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

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.

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.

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[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.)

13.4.2.4 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 ($\pm$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 @ $\pm$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.

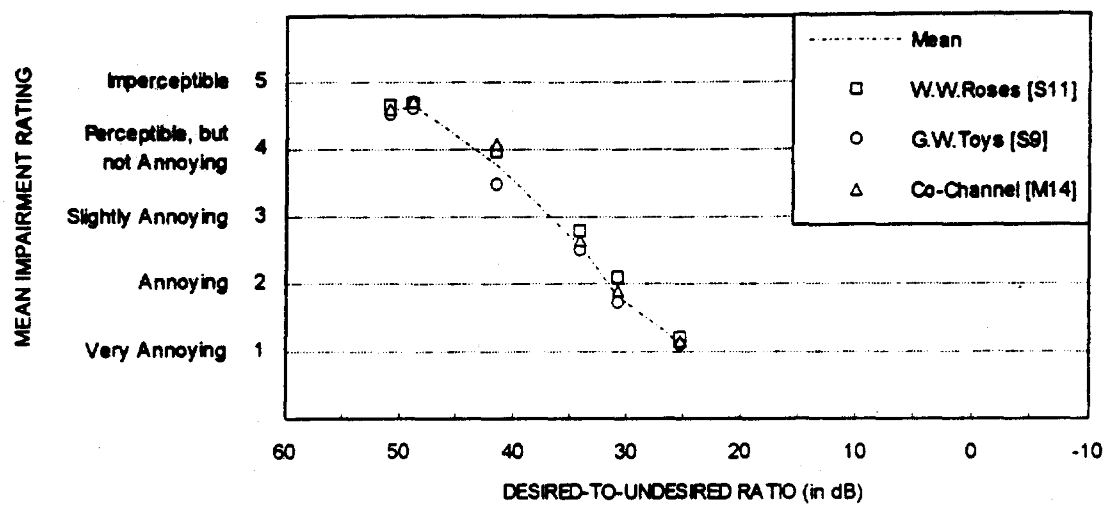

Figure 13-10. Impairment to NTSC when subjected to CCDC co-channel interference for weak signal condition (-55 dBm).

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.

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.

CHANNEL	ATV-into-NTSC		NTSC-into-ATV		ATV-into-ATV	
	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).

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.

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

At the video POU, audio remained usable but not unimpaired.

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 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.

13.4.5.10.3 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.

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.

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

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

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.

[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

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.

[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.

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, 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.

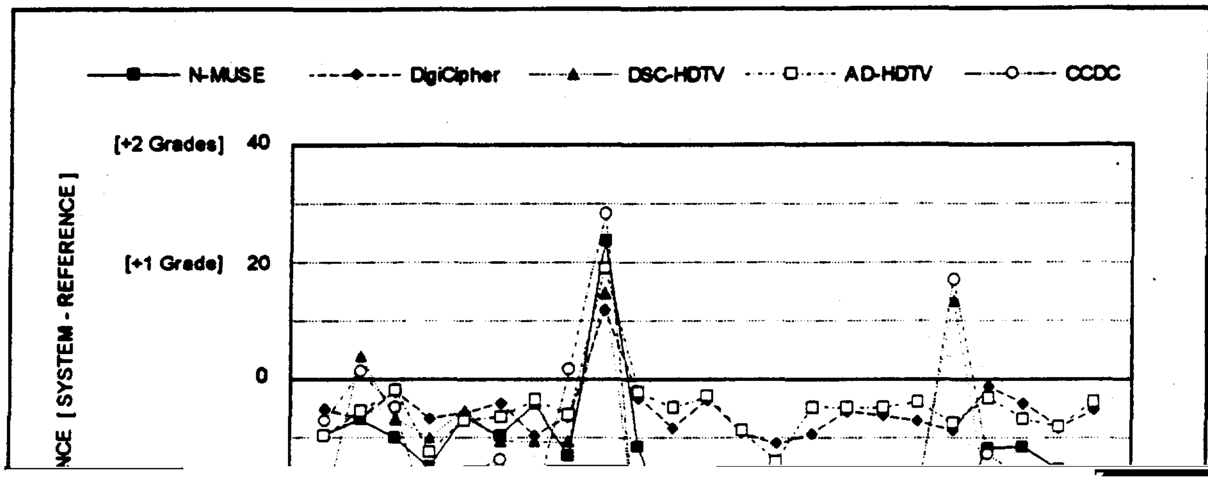
14.3.2 Audio/Video Quality

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.).



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

[4] Perceptual coding techniques take advantage of specific psychoacoustic properties and deliberately seek to create material that matches the source subjectively rather than objectively.

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). 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

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.)