

ADVANCED DIGITAL TELEVISION

SYSTEM DESCRIPTION

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**Advanced Digital Television has been developed by the
Advanced Television Research Consortium at:**

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Princeton, NJ*

*Philips Laboratories
Briarcliff Manor, NY*

Special thanks is due to the outstanding team of scientists and engineers in the Advanced Television Research Consortium. ADTV is the result of contributions by many individuals:

- at the David Sarnoff Research Center (Princeton, NJ) and Philips Laboratories (Briarcliff Manor, NY), who have conceived the ADTV system and are leading its development,
- at Thomson Consumer Electronics (Indianapolis, IN) and Philips Consumer Electronics Company (Knoxville, TN), who are partners in the development of ADTV and who have contributed invaluable expertise in the requirements and practical aspects of consumer electronics,
- at the National Broadcasting Company (New York, NY), who have contributed invaluable expertise in the requirements and practical aspects of television broadcasting,
- at Compression Labs, Inc. (San Jose, CA), who have contributed invaluable expertise in the requirements and practical aspects of other compressed video applications.

Their innovative ideas and dedicated efforts will undoubtedly contribute to establishing High Definition Television in America.

ADTV EXECUTIVE SUMMARY

Advanced Digital Television (ADTV) is an innovative digital HDTV system developed by the Advanced Television Research Consortium. ADTV has several unique attributes that contribute to its superior performance, flexibility and cost characteristics:

- MPEG video and audio compression
- Flexible video formats that provide choices of interlaced or progressive scan with rectangular or square pixels
- Separate video, audio and data packaging that allows a flexible mix of services
- A data format that is well-suited for both broadcast and data networks
- Receivers that disregard unrecognized types of data
- Two separate data carriers with different power levels
- A spectrally-shaped signal that *avoids* NTSC interference
- A high 24 Million bits per second total data rate

These unique attributes combine in powerful ways to give ADTV important advantages in the many important dimensions in which an HDTV system must be evaluated:

SUPERIOR HDTV PICTURE AND SOUND QUALITY

ADTV combines MPEG compression, a standard that is the consensus of the world's leading compression experts, and a high 24 Million bits per second data rate to achieve superior HDTV picture and sound quality.

HIGHLY RELIABLE AND ROBUST PERFORMANCE FOR BROADCASTING

ADTV transmits its sound and "viewable picture" data on a separate higher-power carrier, providing reliability and robustness against severely impaired transmission conditions that could temporarily disrupt reception of the additional data required for full HDTV quality pictures.

LOWEST INTERFERENCE WITH EXISTING NTSC SERVICE

ADTV's unique spectrally-shaped signal uses the simple and effective approach of *avoiding* the high-power portions of an NTSC signal to simultaneously achieve low interference into existing NTSC service and high immunity from NTSC interference.

COVERAGE BETTER THAN OR EQUAL TO NTSC AND HIGH ACCOMMODATION

The higher-power carrier in ADTV's unique spectrally-shaped signal is attenuated by NTSC receivers, allowing acceptable levels of NTSC interference with the increased simulcast transmission power and reduced co-channel spacing needed to provide outstanding coverage area and to accommodate most broadcasters with a simulcast channel.

MOST FLEXIBLE SCOPE OF SERVICES

ADTV's Prioritized Data Transport format separately packages video, audio and auxiliary data and allows their mix to vary dynamically, giving video service providers the flexible scope of services needed to innovate new services and new kinds of programming.

GREATER INTEROPERABILITY AND EXTENSIBILITY FOR FUTURE GROWTH

ADTV has flexible video formats that allow interlaced or progressive scanning with rectangular or square pixels, a layered architecture with data formats that are well-suited for both broadcast and data networks, and receivers that disregard unrecognized service types — features that provide greater interoperability and extensibility among consumer, computer and communication equipment and delivery media.

LOWER COST FOR BROADCASTERS, ALTERNATIVE MEDIA AND CONSUMERS

ADTV leverages the ISO-MPEG standard to achieve the most powerful economy of all — a single video compression standard for all consumer, computer and broadcast equipment, which will eliminate the need for multiple encoder and decoder types and create important synergies and economies of scale.

CONCLUSIONS

- ADTV has the outstanding HDTV picture and sound quality, transmission reliability and robustness, low-interference characteristics, and large coverage area required to be an effective HDTV simulcast system.
- ADTV has flexible operating characteristics that allow it to provide a broad scope of services, as well as the interoperability and extensibility needed to form the basis for new and innovative applications of HDTV in many industries.
- ADTV ensures low cost by its approach of building upon widely accepted standards.

ADTV will serve the public by providing high quality HDTV service at low cost, by enabling innovative new programming that will be delivered by broadcasters and other service providers, and by creating opportunities for innovative new consumer electronics and computer products. These attributes make Advanced Digital Television the best choice for an American HDTV simulcast standard.

ADTV TECHNICAL SUMMARY

ADTV consists of MPEG++ video compression, MUSICAM audio compression, Prioritized Data Transport format and Spectrally-Shaped Quadrature Amplitude Modulation, integrated to operate in unison as an effective simulcast system. This technical summary outlines the fundamental techniques used by ADTV to achieve:

- Outstanding HDTV Picture and Sound Quality
- Reliable and Robust Performance Characteristics for Broadcasting
- Low Interference with Existing NTSC Service
- Coverage Area Greater Than or Equal to NTSC and High Accommodation
- A Flexible Scope of Services
- Interoperability and Extensibility
- Low Cost for Broadcasters, Alternative Media and Consumers

OUTSTANDING HDTV PICTURE AND SOUND QUALITY

The combination of MPEG++ compression and SS-QAM's high 24 Mbps data rate achieves outstanding HDTV picture and sound quality. MPEG++ video data compression is based on the ISO-MPEG (International Standards Organization — Moving Picture Experts Group) standard. MPEG was developed by selecting and refining the best approaches for video data compression, based on side-by-side picture quality comparisons by video compression experts around the world. MPEG video compression achieves outstanding picture quality through several approaches:

- MPEG compression uses an adaptive motion-compensated Discrete Cosine Transform (DCT) that perceptually optimizes the picture encoding on a block-by-block basis.
- MPEG motion compensation uses bidirectional prediction (both forward and backward in time) to accurately predict frames. This allows more bits to be used for picture detail (instead of being used to correct motion prediction errors), which results in outstanding picture quality.
- MPEG has periodic frames that are always spatially coded. This preserves the ability to reconstruct pictures in fast-forward and reverse scanning modes from digital storage media.

ADTV's MPEG++ provides additional performance improvements for HDTV:

- ADTV's MPEG++ compression uses frame based coding. This is transparent to interlaced HDTV sources, and provides for *higher quality progressively scanned* film sources, with virtually no additional cost at the receiver.

- ADTV's MPEG++ compression uses a two-pass encoding scheme that allows bit allocation to be performed with perceptual weighting. This significantly reduces compression artifacts and improves picture quality.

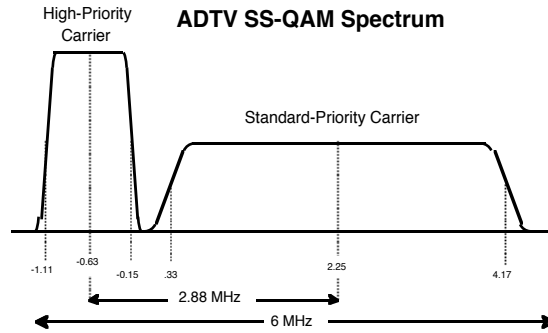
The excellent compression performance of MPEG++ and the high 24 Mbps data rate provided by ADTV's SS-QAM modulation operate in conjunction to produce outstanding picture quality.

ADTV's MUSICAM audio data compression is also based on the ISO-MPEG standard. It was similarly developed by selecting and refining the best approaches for audio data compression, based on side-by-side listening tests by experts.

RELIABLE AND ROBUST PERFORMANCE CHARACTERISTICS FOR BROADCASTING

ADTV transmits sound and "viewable picture" data with even greater reliability and robustness than the additional data required for full HDTV quality pictures. With this approach, ADTV achieves outstanding *availability*. ADTV will reliably deliver high-quality HDTV service to its entire coverage area under most transmission conditions, and it will deliver viewable pictures and sound to its entire coverage area even under severely impaired transmission conditions. ADTV achieves this reliability and robustness by its unique system design:

- ADTV separately transmits two classes of data — High-Priority data and Standard-Priority data. Its High-Priority data is transmitted with extremely high reliability.
- ADTV's MPEG++ video compression is *prioritized* -- it produces *high-priority data* that provides a viewable picture, and additional *standard-priority data* that provides full HDTV quality. ADTV is designed to deliver viewable pictures with extremely high reliability.
- ADTV's MUSICAM compressed audio is treated entirely as *high-priority data*, so that high-quality sound is delivered with extremely high reliability.
- ADTV's Spectrally Shaped-Quadrature Amplitude Modulation (SS-QAM) signal provides two-tiered transmission. It consists of two *separate* trellis-coded 32-QAM data carriers — a High-Priority carrier and a Standard-Priority carrier. Both carriers can be seen in the SS-QAM frequency spectrum shown below:



- ADTV coverage area is defined based on reliable reception of its Standard-Priority carrier, which provides full-quality HDTV service. The High-Priority carrier (containing viewable picture and sound data) is transmitted at a *higher power level*, providing transmission robustness.

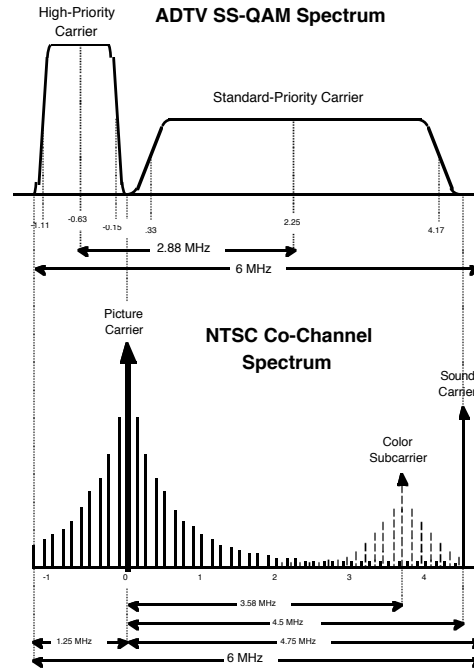
ADTV also has other features that contribute to its robust performance:

- ADTV's Prioritized Data Transport packages and synchronizes both high-priority and standard-priority data for separate transmission. It has several "safety nets" that perform error correction, error detection, and error recovery to protect against transmission errors.
- Both of SS-QAM's data carriers are trellis-coded, and provide additional robustness in the presence of noise and interference.

LOW INTERFERENCE CHARACTERISTICS REQUIRED FOR SIMULCASTING

Low-interference characteristics are essential in order to perform simulcasting with reduced co-channel separation. ADTV achieves its low-interference characteristics through the virtues of its SS-QAM signal structure:

- ADTV is designed to operate with much lower power than an NTSC station. This substantially eliminates interference with NTSC co-channel stations, even with the reduced co-channel separation needed to accommodate most broadcasters with a simulcast channel.
- SS-QAM provides ADTV with high immunity to interference from higher-power NTSC stations, resulting in a coverage area that is not eroded by NTSC interference. It uses the simple and effective approach of *avoiding* the high-power picture and sound carriers of a co-channel NTSC signal. ADTV's SS-QAM frequency spectrum and an NTSC co-channel frequency spectrum are shown below:



- Although SS-QAM’s High-Priority carrier has higher power level, NTSC receivers are relatively immune to it — their Nyquist filter attenuates those frequencies. ADTV interference into NTSC is limited by the power of its Standard-Priority carrier, which results in an effective increase in ADTV coverage area at a given total power.
- SS-QAM’s Standard-Priority carrier is friendly to co-channel NTSC receivers because it does not interfere with an NTSC co-channel signal’s sound carrier.

COVERAGE AREA GREATER THAN OR EQUAL TO NTSC AND HIGH ACCOMMODATION

In a simulcast HDTV environment, there are two factors that are of critical interest to broadcasters — how much coverage area a simulcast signal will reach, and how many broadcasters can be accommodated with a simulcast channel. The key approaches that allow ADTV to provide large coverage area and a high accommodation percentage are:

- SS-QAM’s High-Priority carrier is attenuated by the Nyquist filter in NTSC receivers. This allows ADTV to have a higher power than signals with uniform spectral density, while causing comparable interference in NTSC receivers. This allows increased transmission power for greater range, and/or reduced co-channel spacing.
- ADTV’s noise-limited coverage benefits from trellis coding each of SS-QAM’s carriers. The High-Priority carrier has a threshold CNR of 11.1 dB and the Standard-Priority carrier has a threshold CNR of 16.1 dB.

- ADTV's interference-limited coverage benefits from SS-QAM's spectral shaping. SS-QAM's NTSC immunity prohibits the erosion of simulcast coverage area by interfering NTSC co-channel stations. For ADTV-NTSC co-channel separation larger than about 112 miles, essentially none of the ADTV coverage area is lost as a result of NTSC interference.
- ADTV's two-tier transmission allows coverage area to be based on approximately 97.5% time availability of its High-Priority carrier and 90% time availability of its Standard-Priority carrier.

The goals of achieving a large coverage area and a high accommodation percentage are inherently at odds with one another. ADTV provides many good options for simultaneously satisfying both of these requirements, such as:

<u>ADTV-NTSC CO-CHANNEL SPACING</u>	<u>ACCOMMODATION PERCENTAGE</u>	<u>COVERAGE RANGE¹</u>
99 miles (160 km)	99.7 %	50.7 miles
112 miles (180 km)	98.4 %	54.5 miles
124 miles (200 km)	95.8 %	58.6 miles
136 miles (220 km)	91.3 %	62.5 miles

- A noise-limited range of 55.5 miles (the same as NTSC) can be provided with a co-channel spacing of 115 miles¹. This will accommodate 97.5% of the broadcasters with a simulcast channel. (By comparison, NTSC provides a range of 55.5 miles and a minimum co-channel spacing of 155 miles).

ADTV provides other important capabilities and options for broadcasters (see Chapter 5):

- Broadcasters in especially difficult co-channel situations can reduce their coverage area, or they can slightly reduce their picture quality and select ADTV's 16-QAM option. ADTV (16-QAM) provides a noise-limited range of 55.5 miles with a co-channel spacing of 105.6 miles¹, increasing the accommodation percentage to 98.8%.
- ADTV provides coverage area that is *superior* to NTSC in situations where co-channel interference constraints are not present.

Of course, the final tradeoffs involving the limit of acceptable NTSC interference, simulcast coverage area, and accommodation percentage for minimum-spaced co-channels are best made by the FCC in collaboration with broadcasters.

¹ Assuming that interference affects 15% of an adjacent NTSC co-channel's coverage area. This assumption is similar to the effect of 5 MW UHF NTSC-NTSC co-channel interference at the minimum allowed separation (155 miles).

A BROAD SCOPE OF SERVICES

ADTV's Prioritized Data Transport format separately packages video, audio and auxiliary data and allows their mix to vary dynamically, giving video service providers the flexible scope of services needed to innovate new services and new kinds of programming. Some of ADTV's important capabilities are:

- The basic service provided by ADTV is HDTV video, two stereo sound pairs and auxiliary data (256 kbps), which are reliably delivered in its total capacity of 24 Mbps.
- ADTV offers total flexibility in the mix of video, audio and data services that can be provided to appropriately-featured receivers. It separately packages each *type* of data (e.g., video, audio, etc.) in its own set of transmission cells. Each cell has a *service type* byte that identifies its contents, and an ADTV data stream has no constraint on its types or sequence of cells. This capability provides for a scope of services ranging from eight stereo channels of audio, to broadcast distribution of computer software, to the transmission of very high resolution still images to computers.
- ADTV's mix of services can be dynamically allocated. This will enable broadcasters to send multiple "streams" of video, audio and data programming to their audience, all complementing or enhancing the basic program content. This capability can fundamentally change the nature of television programming, since it enables software to be broadcast to "smart receivers" that can operate in conjunction with the HDTV picture and sound. With this capability, ADTV will likely become a more interactive medium than today's television, enabling new forms of educational programming, games and entertainment programming.

INTEROPERABILITY AND EXTENSIBILITY FOR FUTURE GROWTH

ADTV has been designed with interoperability and extensibility as important considerations. ADTV's features that provide interoperability among different types of media, as well as among a wide variety of consumer electronics, telecommunications, and computing equipment are:

- ADTV has two video formats (1440 x 960 and 1440 x 810) that respectively provide perceptually square pixels on an HDTV display or logically square pixels in the image.
- ADTV provides both interlaced and progressive scan video formats, at related temporal (field/frame) rates (59.94, 29.97 and 24) that are matched to HDTV and film production.
- ADTV's use of MPEG-based video and audio compression provides the possibility of interoperability with MPEG-based computer multimedia applications directly in the compressed bit stream format.

- ADTV is a “layered” system that provides interoperability at any of its layers. This allows interoperability among various transmission media, data formats, compressed video and audio bit streams, and the uncompressed pictures and sound.

Future growth will also require extensibility, to ensure that new products and services can be provided within the framework of an established standard. ADTV provides *open-ended extensibility* through its Prioritized Data Transport format:

- An ADTV receiver will *disregard* any cell with a service type that it does not recognize or cannot process. This will eliminate future “backward-compatibility” problems in the installed base of receivers, removing a crucial constraint from the introduction of new services.

These capabilities pave the way for delivering many new features or services using the ADTV standard, ranging from compatible HDTV stereo (3-D) television, to new interactive entertainment forms, to compatible ultra-high definition television. With future improvements to its compression, ADTV’s higher-power, narrow bandwidth High-Priority carrier even provides the opportunity to provide service to “personal video” receivers that are small, economical and mobile.

LOW COST FOR BROADCASTERS, ALTERNATE MEDIA AND CONSUMERS

ADTV leverages the ISO-MPEG standard to achieve the most powerful economy of all — a single video compression standard for all consumer and computer delivery media, which will eliminate the need for multiple decoder types and create important synergies and economies of scale. ADTV provides this opportunity:

- ADTV’s MPEG video and MUSICAM audio are based on the International Standards Organization MPEG compression standards. MPEG has achieved a great degree of worldwide consensus, and it will be used in many new computer and consumer electronics applications.
- ADTV’s transmission is based on QAM transmission, a standard technique that is used in microwave communications as well as at lower speeds in computer modems.

Leveraging standards also creates important cost-reducing economies of scale. The largest factor in reducing cost is high production volume and associated commodity pricing of essential integrated circuits. ADTV’s standards-based approach is advantageous in two ways:

- At the time of its introduction, ADTV will benefit from the established momentum of the MPEG video and audio standards. High-volume production of MPEG video and audio

decoder ICs will help to cost-reduce the most complex electronic portions of an ADTV receiver, resulting in accelerated receiver penetration.

- Over the long term, a standards-based approach will result in the use of common (or at least similar) devices in both the consumer and computer industries. The resulting high-volume production and commonality will benefit both industries, as well as the consumer.

ADTV also has attributes that contribute to low cost for program producers, broadcasters, and alternative delivery media:

- ADTV's 59.94 field rate is identical to NTSC — this eliminates temporal artifacts and the need for frame synchronization in mixed ADTV-NTSC production environments.
- ADTV's 1440 x 960, 1050-line scanning format is cost effective in the production studio. Its 2:1 vertical ratio with 525-line (NTSC) video and 2:1 horizontal ratio with the CCIR Rec. 601 sampling standard used in 525-line D1 tape recorders offers economical transcoding in mixed ADTV-NTSC production environments.

Other aspects of ADTV that contribute to low cost for consumers are:

- ADTV's 1050-line scan format is cost-effective in the receiver. The 2:1 vertical ratio with 525-line NTSC allows economical combination (ADTV-NTSC) receivers. In addition, the required 2H deflection system is practical and economical.
- ADTV's 1440 x 960 format is well-matched to low-cost memory devices. The 16 Mbit DRAM frame memories in an ADTV receiver are predicted to cost about \$13 each in 1996.
- ADTV's data format is similar to broadband data network formats. This creates potential economy of scale for interface ICs that are common to HDTV and telecommunications.
- MPEG compression was designed for digital storage media and provides important capabilities for a viewable picture in fast-forward and reverse in VCRs, as well as random access capabilities for disks.

CONCLUSIONS

ADTV has the outstanding HDTV picture and sound quality, transmission reliability and robustness, low-interference characteristics, and large coverage area required to be an effective HDTV simulcast system. ADTV also has flexible operating characteristics that allow it to provide a broad scope of services, as well as the interoperability and extensibility needed to form the basis for new and innovative applications of HDTV in many industries. And ADTV ensures low cost by its approach of leveraging other widely accepted standards.

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1. ADTV INTRODUCTION

Advanced Digital Television (ADTV) is the digital high-definition television (HDTV) system developed by the Advanced Television Research Consortium (ATRC). This chapter provides an introduction to the ADTV system by discussing the challenges that it was designed to overcome and the fundamental principles of its approach.

1.1 DESIGN CHALLENGES FOR A U.S. HDTV SYSTEM

The criteria for selecting an American HDTV standard can generally be categorized into three challenges that ADTV has been designed to solve.

The first challenge is *performance* — an HDTV standard must compress high-quality pictures and sound to fit into a standard television channel, and reliably deliver them in a *simulcast* environment. A simulcast system must be robust enough to survive both noise and high levels of interference from NTSC co-channel stations. ADTV tightly integrates efficient digital compression, reliable data transport and high data rate digital transmission to reliably deliver high-quality HDTV service to a coverage area comparable to NTSC, even with the reduced co-channel spacing needed to accommodate most broadcasters with a simulcast channel.

The second challenge is *flexibility* — an HDTV standard should provide a broad scope of services and be useful in many applications. Innovative uses of video, audio and data in new products and services will require interoperability among different types of delivery media, as well as among a wide variety of consumer electronics, telecommunications, and computing equipment in the home and office. Future growth will also require extensibility, to ensure that new products and services can be provided within the framework of an established standard. ADTV has been designed with an emphasis on its scope of services, extensibility and interoperability.

The third challenge is *cost* — in order to become a reality, an HDTV standard must be economical for broadcasters, alternate media and consumers. ADTV is a practical system that leverages other standards and their associated production volumes to provide cost advantages.

1.2 KEY ELEMENTS OF ADTV

Digital video compression and digital transmission technologies provide the basic building blocks for an effective HDTV system. Digital video compression uses computational techniques to efficiently and adaptively remove the spatial and temporal redundancy in a television picture. For example, a digital HDTV production signal (with a data rate on the order of 1.2 Gigabits per

second) can be compressed by a factor of 60 times (producing this serial bit stream on the order of 20 Megabits per second). Digital transmission techniques can translate this serial bit stream into a signal that will occupy a 6 MHz broadcast television channel, and survive in a noisy transmission environment. Digital systems are generally transparent with respect to various delivery media. They are also cost-effective, due to the rapidly increasing density and speed of digital integrated circuits. However, the unique combination of performance, flexibility and cost required by an effective solution for HDTV simulcasting can only be achieved by an innovative system design.

ADTV consists of major subsystems that perform video and audio compression, data transport and digital transmission. The ATRC has made unique contributions to the performance and flexibility of each of these subsystems, as well as to their cohesive integration, so that they operate in unison as an effective simulcast system. ADTV consists of:

- MPEG++ video compression
- MUSICAM audio compression
- Prioritized Data Transport format
- Spectrally-Shaped Quadrature Amplitude Modulation

Each of ADTV's subsystems is based on existing standards and/or widely used technology, in order to ensure that low *cost* is achieved. The following sections provide a high-level technical overview of ADTV by explaining how it provides performance, flexibility and cost through each of its key elements, and their integration into a complete simulcast HDTV system.

1.3 PERFORMANCE ASPECTS OF ADTV

The requirements for a U.S. HDTV system demand that special attention be paid to those *performance* aspects of a system that provide a solution to the unique problems of simulcasting. First and foremost, the compression used in a digital HDTV system must provide outstanding picture quality. But a simulcast system must provide continued service even when many bit errors occur due to poor transmission conditions. The circumstances that produce bit errors can occasionally happen anywhere in the coverage area, and can be a frequent occurrence with the weaker signal that is received near the fringe areas of coverage. Conventional digital video compression techniques are generally fragile to bit errors, and conventional digital transmission techniques exhibit an extremely rapid failure as their noise or interference threshold is approached. Without innovative approaches to mitigate such characteristics, digital systems may fail to deliver the robustness and graceful degradation that are required to provide broadcast television service that is reliably available to its audience, especially at the fringe areas of coverage. Furthermore,

while conventional digital modulation techniques are robust to moderate levels of noise, they do not address the unique problems of NTSC co-channel interference that are associated with simulcast transmission. Each of the major subsystems in ADTV, and their integration as a total system, contributes to the solution of these key simulcast performance challenges.

1.3.1 MPEG++ Compression

ADTV's MPEG++ compression simultaneously provides high-quality HDTV pictures and forms the basis of ADTV's reliable and robust performance as a simulcast system. MPEG is an ISO standard¹ for compressed video on digital storage media. It was developed by selecting and refining the best approaches for video data compression, based on side-by-side picture quality comparisons by video compression experts around the world. MPEG video compression achieves outstanding picture quality through several approaches:

- MPEG compression uses an adaptive motion-compensated Discrete Cosine Transform (DCT). Each block of the picture is individually evaluated to determine its best spatial or motion-compensated encoding mode from among several alternatives. The result is that picture quality is perceptually optimized on a block-by-block basis.
- MPEG motion compensation uses bidirectional prediction (both forward and backward in time) to efficiently remove the frame-to-frame correlation from moving video. This accurate motion compensation approach dramatically improves picture quality, since bits can be used to represent fine picture details, rather than being wastefully spent to correct the prediction errors that result from poor motion compensation.
- MPEG has periodically occurring frames that are entirely spatially coded. This preserves the ability to reconstruct pictures in fast-forward and reverse scanning modes from digital storage media.

MPEG has achieved a great degree of worldwide consensus and it is an important standard for many emerging computer and consumer electronics applications. Based on its outstanding picture quality and wide acceptance, the ATRC selected an MPEG-based approach for ADTV. ADTV's MPEG++ is the result of ATRC performance and robustness improvements to the basic MPEG approach. MPEG++ performance improvements are:

- MPEG++ compression uses frame based coding. This is transparent to interlaced HDTV sources, and provides for *higher quality progressively scanned* film sources, with virtually no additional cost at the receiver (this will be explained in more detail later).

¹ "MPEG Video Committee Draft", ISO/IEC JTC1/SC2/WG11 document, December 18, 1990.

- MPEG++ picture quality benefits from a two-pass encoding scheme. This approach allows bit allocation to be performed with perceptual weighting that significantly reduces compression artifacts and improves picture quality. (However, two-pass encoding is not an MPEG++ requirement — single-pass encoding can be performed in low-cost encoders).

The excellent compression performance of MPEG++ and the high 24 Mbps data rate provided by ADTV's SS-QAM modulation operate in conjunction to produce outstanding picture quality.

ADTV's MPEG++ also incorporates important robustness approaches that are essential to survive transmission bit errors that will inevitably occur during simulcasting. In general, compressed video data is highly vulnerable to bit errors that result from transmission impairments. The reason for this is that in a compressed video bit stream, a few bits can affect a large spatial and/or temporal region of the image sequence. Some bits in a compressed video stream are more important than others. For example, certain control bits encode the address of many blocks of pixels, that is, they determine the location of those blocks within the received picture². An error in one of these bits would cause an erroneous reconstruction of many pixels, resulting in a large and persistent picture distortion. Such control bits are considerably more important than bits that represent fine picture detail within a small block of pixels.³

To overcome the serious effects of errors occurring in critical bits, MPEG++ *prioritizes* an MPEG codeword stream, dividing it into two separate video data streams:

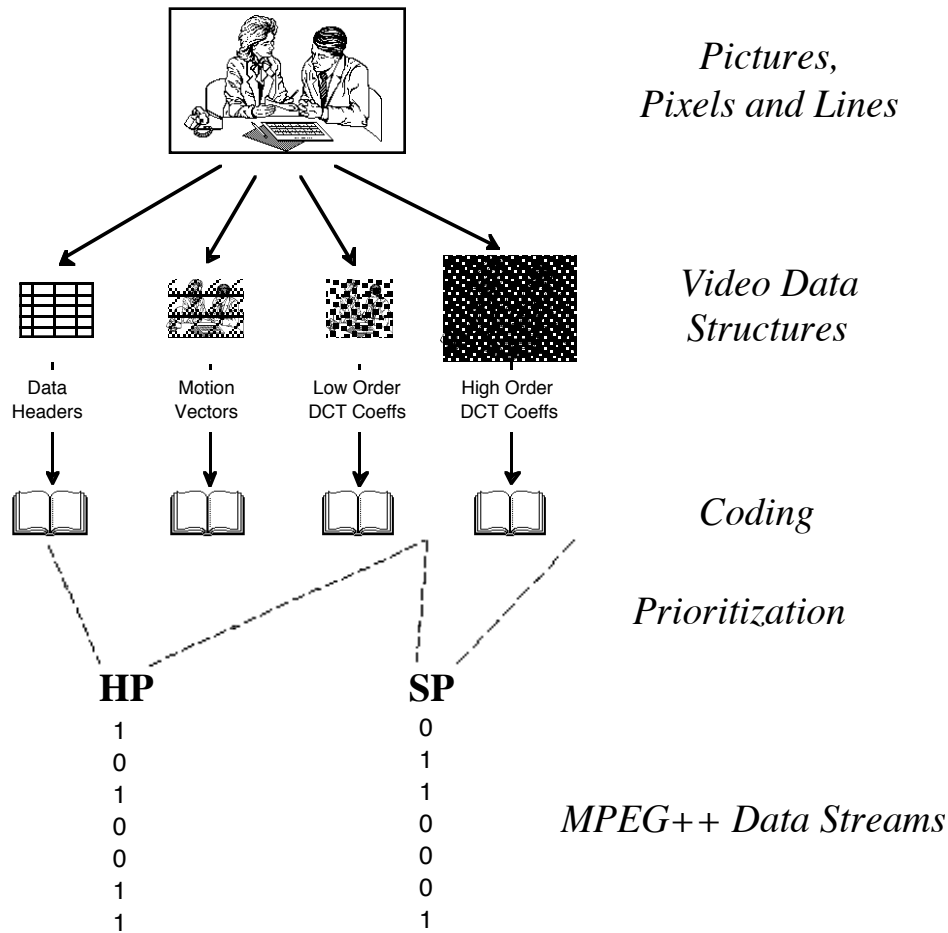
- 1) *high-priority* data that is essential to make viewable pictures
- 2) *standard-priority* data that is additionally required for high-quality HDTV pictures.

ADTV delivers high quality HDTV service to its coverage area, which is defined by the reception of its Standard-Priority data. Additional reliability and robustness is provided by transmitting the MPEG++ High-Priority video data at a higher *power level* — ensuring the reception of viewable pictures under virtually all conditions, even at the fringe areas of coverage. (This is explained in greater detail in following sections.) Codeword prioritization is a key improvement needed to make a practical compression system for terrestrial broadcasting. ATRC's MPEG++ development was driven by the desire to maintain MPEG data compatibility within the ADTV system, while also making strong provisions for robustness in terrestrial broadcasting. Specifically, MPEG++ encapsulates an MPEG-compatible video representation within additional media-specific levels that

² Specifically, this is the *slice header*, as explained in Chapter 3.

³ Namely, bits that encode higher-order DCT coefficients.

provide robust delivery over the terrestrial channel. The MPEG++ video compression technique is more fully described in Chapters 2 and 3. Figure 1.1 shows a conceptual diagram.



In MPEG compression, blocks of pixels from one or more frames are transformed into a set of video data structures, including control bits (headers), motion vectors and DCT coefficients. These data structures are coded to achieve a compressed representation of the video. MPEG++ prioritization identifies the important data needed to make viewable pictures, which are transmitted as a high-priority bit stream. The remaining data that is additionally required to make a full-quality HDTV picture is transmitted as a standard-priority bit stream.

Figure 1.1 - ADTV’s MPEG++ video data compression

1.3.2 Prioritized Data Transport

ADTV’s Prioritized Data Transport format is specifically designed to carry, synchronize and protect MPEG++ high-priority and standard-priority data through a two-tier (prioritized) transmission system that has two separate data channels. It provides several layers of “safety nets” that allow ADTV receivers to continue decoding useful video data even under very high bit error rate conditions.

Especially with the low transmitter power needed for simulcasting, fluctuating transmission conditions and interference can temporarily result in uncorrectable bit errors occurring at any receiver site within the simulcast coverage area. This becomes a more frequent occurrence near the fringe of coverage, where time and location variations in signal strength and interference can cause sudden increases in the bit-error rate (BER) of the received signal. Given this situation, it is extremely important that a simulcast HDTV system be able to continue useful operation during brief periods of high bit error rate, avoiding the sudden catastrophic failure traditionally associated with digital systems. This performance goal motivated the design of ADTV's Prioritized Data Transport subsystem, which provides several layers of protection against channel impairments in the form of error correction, error detection, and error recovery capabilities. (Additional protection is provided by ADTV's SS-QAM modulation, which will be discussed in the following section.).

ADTV's Prioritized Data Transport format separately packages MPEG++ high-priority and standard-priority data streams into separate (but related) sequences of fixed-size *cells*. Each cell is a self-contained data unit of 148 bytes (1184 bits) that consists of a header, data and a trailer, as shown below in Figure 1.2.

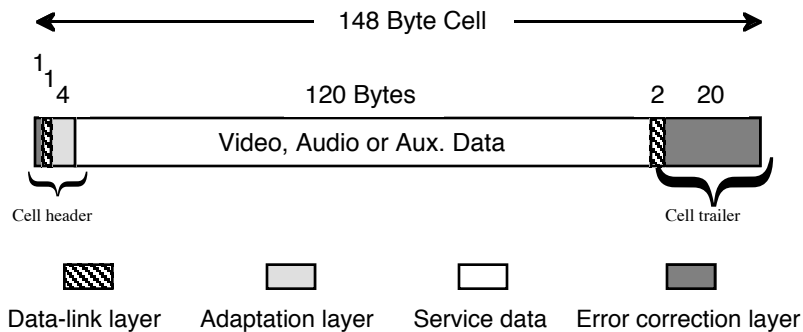


Figure 1.2 - ADTV's Prioritized Data Transport format.

The transport header provides the functionality necessary for efficiently packing several variable length coded video data units into a single cell, as well as for segmenting longer video units over multiple cells. The transport cell provides several layers of "safety nets" that ensure reliable transport across a wide range of bit error rate conditions that can occur during transmission:

- The first layer of protection is provided in the trailer by a Forward Error Correction (FEC) code⁴ that will fully correct up to 10 byte errors in each cell. The Prioritized Data Transport format also protects against long burst errors that typically result from impulse noise, by

⁴ A Reed-Solomon (RS) block code.

interleaving its payload data across several cells, resulting in shorter errors that can be corrected by the FEC code.

- The second layer of protection comes into play under more severe bit error rates. The trailer has a two-byte Frame Check Sequence (FCS) code⁵ that reliably detects cell errors that could not be corrected by the FEC code. Erroneous cells are discarded, in order to prevent the gross picture distortions that would result from decompressing erroneous data.
- The third layer of protection comes into play during extremely poor transmission conditions. Cell headers include MPEG-specific logical resynchronization information (i.e., a “reentry pointer”). This allows the MPEG++ video compression decoder to smoothly reenter the high-priority and/or the standard-priority compressed data stream at a known point. The video compression decoder can then immediately resume producing useful video after the loss of one or more cells in the received data stream.
- The fourth layer of protection also comes into play during extremely poor transmission conditions. A unique sync byte in each cell header ensures robust cell synchronization even under conditions where many entire cells are lost due to errors. Cell synchronization is an essential condition required to receive picture or sound.

1.3.3 Spectrally Shaped Quadrature Amplitude Modulation

ADTV’s Spectrally Shaped Quadrature Amplitude Modulation (SS-QAM) provides two-tier simulcast transmission for prioritized MPEG++ data. The SS-QAM signal is the key to simultaneously providing good coverage area, reliable and robust service, immunity to NTSC interference and NTSC-friendly simulcast signals. *SS-QAM consists of two separate QAM carriers – a High-Priority carrier and a Standard-Priority carrier.* Both carriers provide the high data rate and excellent performance of QAM transmission, and the High-Priority carrier is transmitted at an increased power level. *This ensures that the High-Priority carrier will be reliably received over the entire ADTV coverage area, even under severely impaired transmission conditions that might momentarily incapacitate the Standard-priority carrier.*

Quadrature amplitude modulation (QAM) was selected as the basis for the ADTV transmission system because it is a proven approach which provides efficient data transmission, produces a noise-like spectrum, and can be implemented in economical transmitters and receivers. But the demands of simulcasting require improving upon conventional QAM practice. Minimal

⁵ A Cyclic Redundancy Check (CRC) code.

interference into NTSC co-channels requires operating at relatively low power levels. A low-power simulcast signal needs an especially high degree of robustness against noise and interference, and SS-QAM provides this robustness with its High-Priority carrier. The robustness provided by this approach will continue to benefit broadcasters even after the demise of NTSC broadcasting.

As long as NTSC co-channels continue to operate, a low-power simulcast signal must also have high immunity from a higher-power NTSC interfering signal. SS-QAM provides high immunity from NTSC interference by using the simple and effective approach of avoiding the high-power spectral components of a co-channel NTSC signal, namely, its picture and sound carriers. ADTV's SS-QAM frequency spectrum and its relationship to an NTSC co-channel frequency spectrum are shown in Figure 1.3.

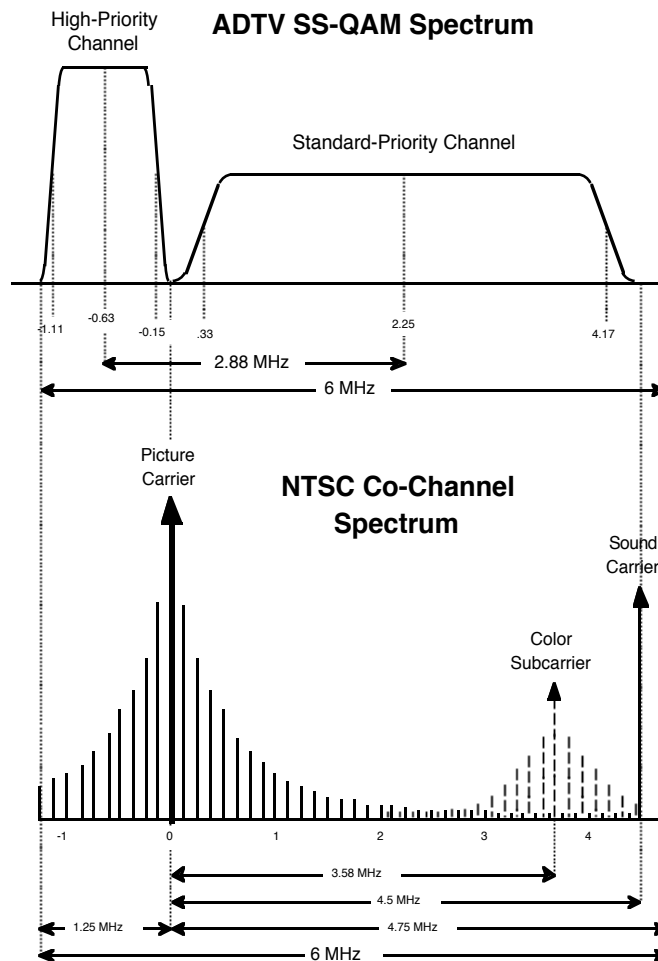


Figure 1.3 - ADTV's SS-QAM Spectrum and its relationship to an NTSC co-channel spectrum

SS-QAM's High-Priority (HP) carrier is a narrowband (1.125 MHz) signal that is located in the lower vestigial sideband region of an NTSC co-channel, below the NTSC picture carrier. The Standard-Priority (SP) carrier is a wideband (4.5 MHz) signal that is located in the upper sideband region of an NTSC co-channel, between the NTSC picture carrier and the NTSC sound carrier. SS-QAM provides many performance advantages for ADTV:

- Due to the location of its carriers, the SS-QAM signal *avoids* interference from the highest power components of an NTSC co-channel. This approach has significantly greater NTSC immunity than single-channel systems, which are interfered with by NTSC's high-power picture and sound carriers. This results in improved simulcast coverage area.
- The High-Priority channel achieves high transmission reliability by operating at a higher power spectral density (5 dB) than the Standard-Priority channel. This can be achieved without causing additional co-channel interference on NTSC receivers by virtue of the Vestigial Sideband filter used in all NTSC receivers (see Chapter 5). This is the means for providing ADTV's reliability and robustness.
- The SS-QAM signal is NTSC-friendly, due to the location of its standard-priority channel prevents interference *into* an NTSC co-channel's sound carrier.
- SS-QAM provides rugged performance that results in improved coverage area. Each of the QAM channels is trellis coded, which provides approximately 3 dB of additional coding gain against the onset of failure.
- SS-QAM provides high data rate. The nominal operating mode of each channel is 32-QAM, which provides a data rate of 4.8 Mbps for the high-priority carrier and 19.2 Mbps for the standard-priority carrier, with a total data rate of 24 Mbps. This high data rate, used in conjunction with Prioritized Data Transport to deliver compressed MPEG++ video data, provides outstanding HDTV pictures.

ADTV's unique SS-QAM transmission approach solves many practical simulcasting problems, and its two-tier transmission with separate trellis-coded QAM carriers will continue to provide reliable and robust broadcast performance even after NTSC broadcasting has ceased.

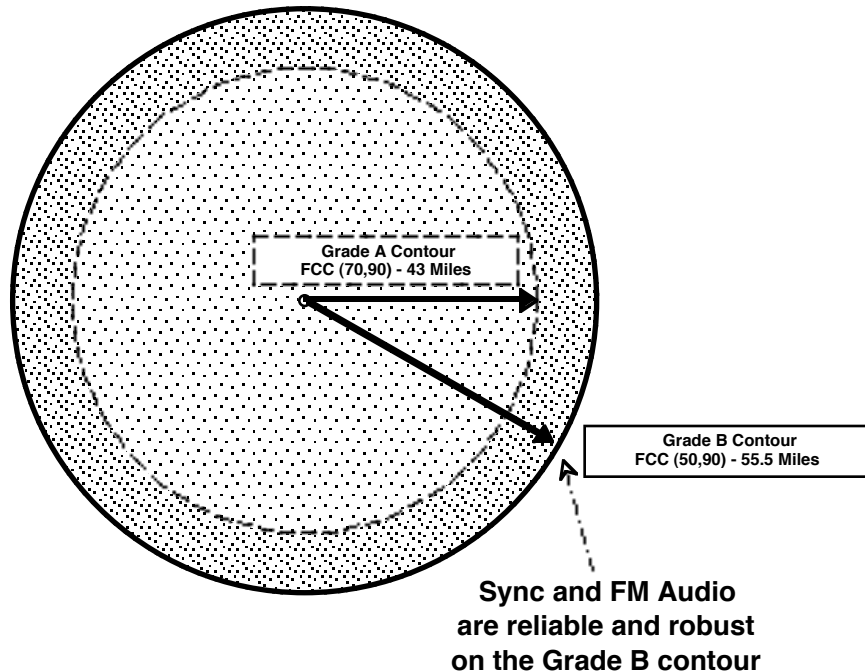
1.3.4 ADTV as a Simulcast System

ADTV's subsystems operate in unison to provide the performance characteristics required in an effective simulcast HDTV system. To accomplish this, ADTV uniquely combines the advantages of digital systems with important television reliability and robustness principles.

The design of a simulcast HDTV system for terrestrial broadcasting involves many issues, including picture and sound quality, power, coverage area, interference, and transmission robustness. Its successful deployment also depends upon the selection of appropriate planning factors to ensure that a reliable service is always available to the public within the defined coverage area of the system. Although a digital approach inherently overcomes certain problems of analog transmission, there are important problems that must be solved in the design of a digital simulcast system. For instance, while conventional digital communications systems are virtually perfect when they work, they fail rapidly — exhibiting an extremely sharp increase in bit error rate (BER) below their threshold carrier-to-noise ratio (CNR). The combined effects of sudden catastrophic failure in conventional digital transmission and the fragility to bit errors of conventional compressed video systems would not allow reliable television service under difficult transmission conditions, especially near the fringes of coverage. ADTV overcomes these problems by applying three important television reliability and robustness principles in the context of a digital system:

- 1) Rugged synchronization is essential. It is a basic requirement for reception.
- 2) Robust sound performance is extremely important. Noise and distortion in audio are subjectively more annoying than the same level of impairment in video.
- 3) Picture impairments in fine detail are more tolerable than other impairments. Subjective assessments of picture quality are relatively less sensitive to noise and distortion in fine picture detail (high-frequency information).

NTSC implements these same principles with analog techniques, including the overall allocation of power, the use of periodic signal structure for synchronization (sync) and the use of Frequency Modulation (FM) for audio. As shown in Figure 1.4, sync and sound technically have greater range than the picture — but this extended range is not important as such. Rather, it is the reliability and robustness of sync and sound on the Grade B contour that are important, rather than their extended range.



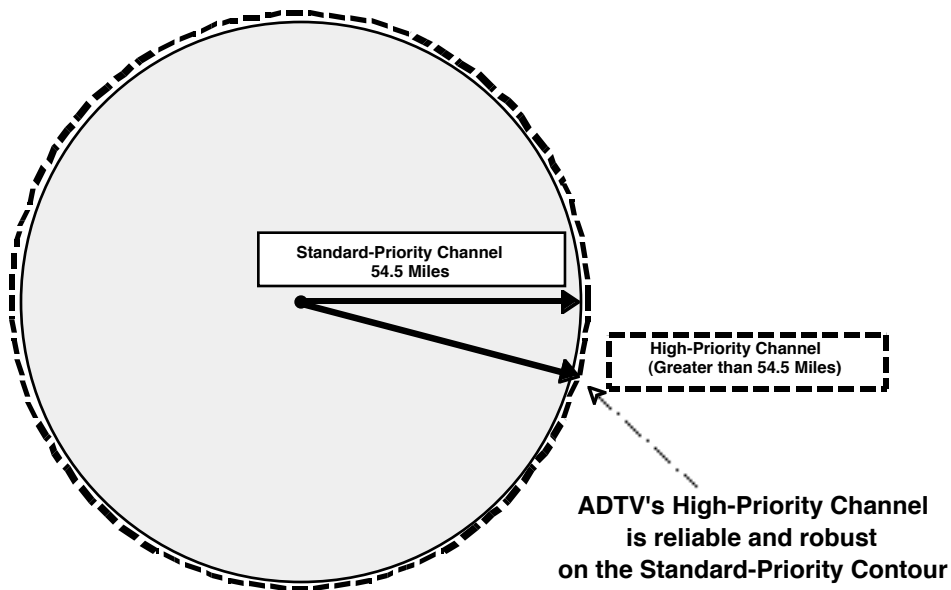
The defined coverage area of an NTSC station is based on 90% time availability of “acceptable quality” video at the Grade B contour. The more rugged performance of sync and sound are essential elements of NTSC’s overall reliability and robustness.

Figure 1.4 - NTSC Coverage Area Definition.

NTSC relies upon its higher sync and sound performance to achieve *availability*. NTSC’s Grade B contour is defined by “acceptable” picture performance (better than about 28 dB signal-to-noise ratio) in 50% of the locations 90% of the time [this is referred to as FCC(50,90)]. But NTSC does not exhibit catastrophic failure, so that even when its video quality is “less than acceptable,” the audio service is maintained and the picture never breaks up or disappears from the screen. Significantly higher availability factors for sync and sound ensure that NTSC service is always available within its defined coverage area, even under transmission conditions that occasionally produce less than desirable picture quality.

ADTV’s compression, transport and transmission subsystems operate in unison to apply these important television system principles in the context of a digital system. Most importantly, SS-QAM’s High-Priority carrier is transmitted with a higher power spectral density than its Standard-Priority carrier, providing a higher level of transmission robustness for synchronization, sound and the subjectively important video data contained in the MPEG++ High-Priority data stream. As shown in Figure 1.5, ADTV’s High-Priority carrier provides very high (about 97.7%) time availability over the entire ADTV coverage area (defined by 90% time availability of the

Standard-Priority carrier). This ensures that sync, sound and a viewable picture are virtually always available over the entire ADTV coverage area, including the fringes. (Note that without the reliable High-Priority carrier, a time availability factor of 90% would not be an acceptable basis for determining the coverage area of a digital simulcast system — see Chapter 5 for further details.)



The coverage area of an ADTV station is based on 90% time availability of its standard-priority carrier. The higher power high-priority carrier ensures reliability and robustness.

Figure 1.5 - ADTV Coverage Area Definition.

In addition, the spacing of SS-QAM's carriers, which avoid the high-energy components of an NTSC co-channel signal, makes ADTV highly immune to NTSC co-channel interference. This significantly increases useful coverage in the geographic region that is penetrated by the higher-power NTSC co-channel signal. The net effect of ADTV's combined strategies is to increase the coverage area that can be obtained at a given level of transmitter power (the technical details of this topic are covered in Chapter 5).

To summarize, ADTV's MPEG++, Prioritized Data Transport and SS-QAM subsystems operate in unison, as shown in Figure 1.6. ADTV combines the advantages of digital systems with important television reliability and robustness principles. Critical sync and control information, sound, and the important MPEG++ data constituting a viewable picture is packaged in cells and transmitted with additional power in SS-QAM's high-priority carrier. This signal is reliably available over the entire ADTV coverage area, including the fringes, under virtually all transmission conditions. This approach allows ADTV's coverage area to be based on the 90%

time availability of full-quality service (based on standard-priority carrier reception) at the fringe. The result of this is that ADTV has the superior performance needed to provide a reliable and robust television service to its audience, over a large coverage area.

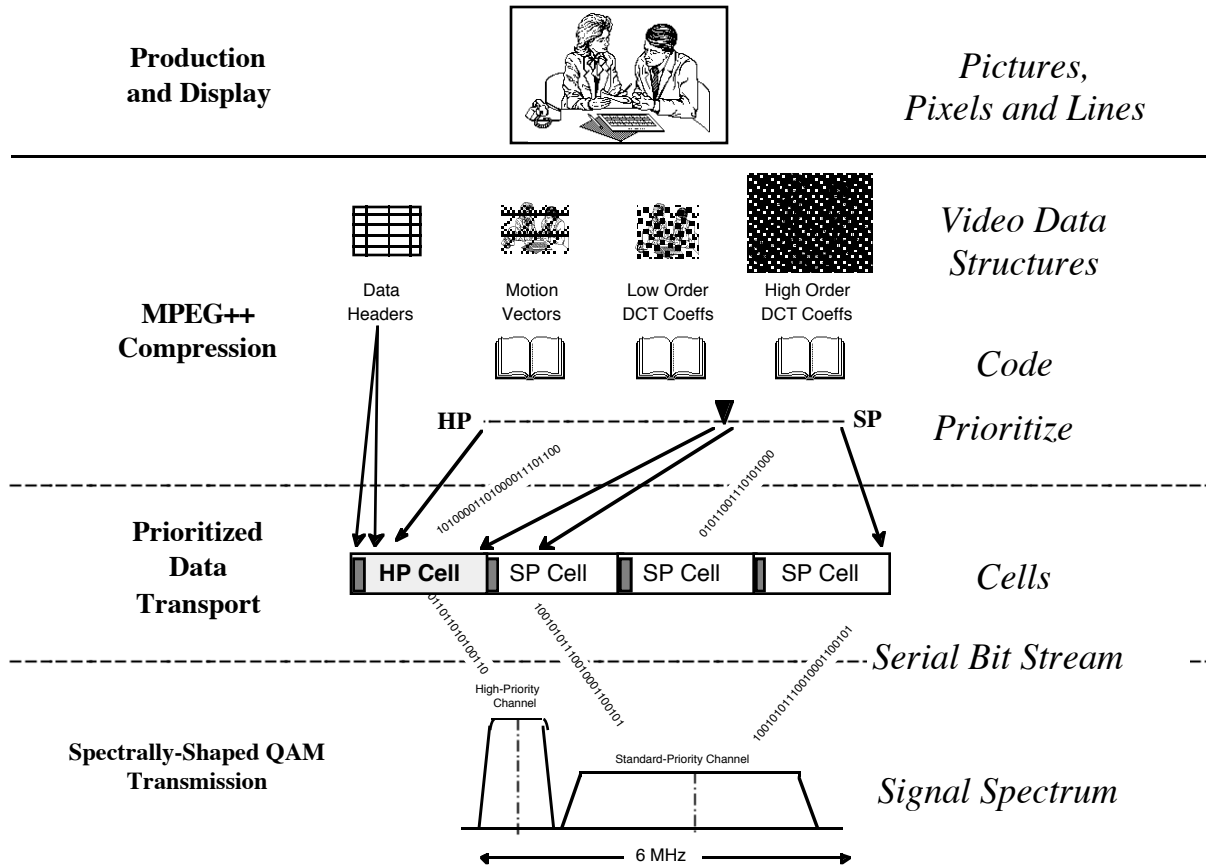


Figure 1.6 - A conceptual overview of the ADTV system.

1.4 FLEXIBILITY ASPECTS OF ADTV

The *flexibility* of an American HDTV system will determine its usefulness across many different industries, ranging from entertainment television to multimedia computer applications. While digital systems are generally flexible, ADTV has several unique and important capabilities that will benefit both the public and a diverse set of industries, all provided within the scope of a single standard. Such flexibility will be extremely important to the evolution of HDTV.

1.4.1 MPEG++ Video Format Flexibility

ADTV's MPEG++ compression delivers several related video formats over the simulcast channel, in order to promote interoperability and extensibility. ADTV's family of video formats has been selected to provide the best characteristics for typical television viewing, to accommodate

both high-definition video and film production standards, and to accommodate uses beyond entertainment television, in areas such as multimedia computing applications.

ADTV's nominal raster format is a 1050 line, 2:1 interlaced, 59.94 fields per second HDTV production standard. This format uses interlaced scanning to simultaneously provide 960 vertical lines of resolution on still scenes and 59.94 fields per second of temporal resolution on moving scenes. Interlacing is well matched to human psychovisual characteristics (e.g., the diminished visual acuity on rapidly moving objects) and it has consistently been found to be a good choice for entertainment applications. This raster format is also well matched to the capabilities of available technology in high-definition cameras, tape recorders and displays. ADTV's nominal pixel format is 1440 x 960 (i.e., 1440 pixels per line and 960 lines), which is exactly four times the 720 x 480 pixel format of CCIR Rec. 601. The choice of 1440 pixels also results in a display with equivalent perceptual resolution in the horizontal and vertical dimensions, after accounting for the Kell factor⁶ of an HDTV display (assumed to be about 0.8). This results in "perceptually square" pixels on an HDTV display, which are desirable for typical television applications.

Film is an extremely important and widespread production medium, and ADTV directly supports an "electronic film" format. Film has a slower (24 frames per second) temporal rate, so ADTV uses a 1050 line progressively scanned raster at 24 frames per second, with the same 1440 x 960 pixel format that is used in its nominal format. This allows ADTV to efficiently compress film sources in a way that is inherently matched to their characteristics. However, in film productions where computer graphics are used extensively, square pixels may be more desirable in the image representation rather than as perceived on the display. To accommodate these situations, ADTV also provides a progressively scanned 1440 x 810 square pixel format.

ADTV also provides a 1050 line, progressively scanned, 29.97 frames per second raster with both 1440 x 960 and 1440 x 810 formats. This is useful for mixed-media productions that employ both 29.97 frames per second film and 59.94 fields per second video, intermixing production on both media. It will also be useful for computer animation and graphics applications that benefit from progressive scan and square pixels, and are required to interface to video equipment rather than film recorders and/or cameras.

ADTV provides this flexibility at essentially no additional cost by using *frame-based coding* in its MPEG++ compression. Frame-based coding identically handles a pair of interlaced fields (at 59.94 fields per second) and a single progressively scanned frame (at either 29.97 or 24 frames per second) as a frame entity, as shown in Figure 1.7. This allows both interlaced and progressively

⁶ A display factor that accounts for the perceptual effects of discrete scanning lines.

scanned formats to be completely transparent to the video compression and decompression, and to have the same processing and memory requirements in both the encoder and the receiver.

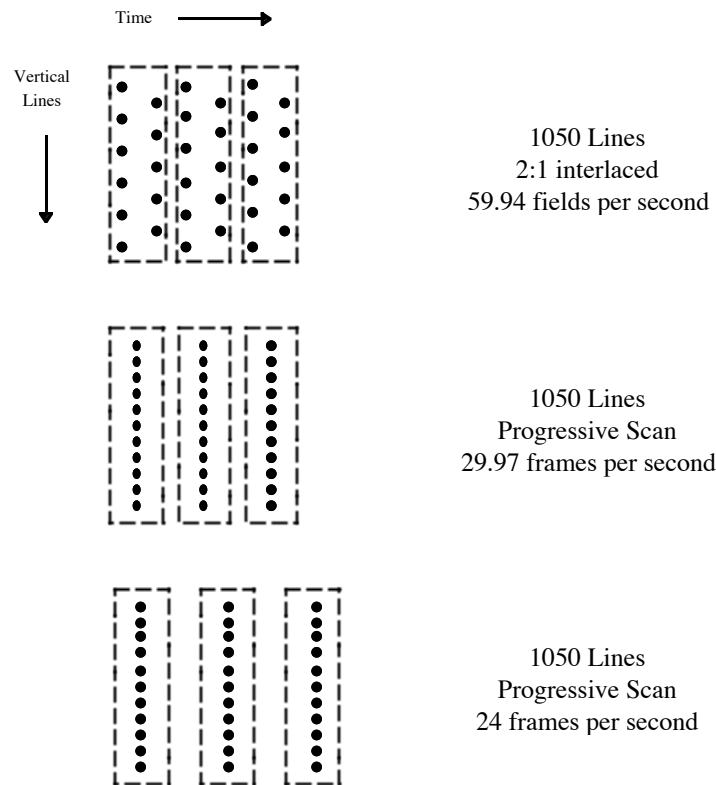


Figure 1.7 - Frame-based coding is transparent to interlaced and progressive scanning

An ADTV receiver can process and display each of these formats with essentially no additional cost. The presence of frame store memory for decompression allows temporal frame rate conversion between 24 (or 29.97) frames per second and a 59.94 Hz display to be performed in the receiver by appropriately repeating frames⁷. Likewise, conversion between 960 and 810 active scan lines can be performed in the receiver by simple memory addressing and vertical deflection changes. Other techniques such as electronic zoom can be used at the discretion of receiver manufacturers.

To summarize, for broadcast and consumer electronics use, ADTV provides a family of related video formats that accommodate HDTV and film production. It accommodates both interlaced and progressive scan, and provides square pixels either on the display or in the image. Non-entertainment applications using computers or special receivers can benefit from even greater format flexibility and use different resolutions and frame rates that are provided by ADTV's

⁷ Historically, this function is performed in the television studio by "3:2 pull-down" in a telecine camera.

MPEG-based compression. A discussion of other formats and applications can be found in the section on Interoperability in Chapter 6.

1.4.2 Prioritized Data Transport - Dynamic Allocation of Capacity

Although digital systems are generally described as flexible, many of them use a fixed format that carries different types of data (e.g., video, audio and auxiliary data) with a pre-determined capacity. ADTV offers *complete flexibility* to allocate its capacity among video, audio and auxiliary data services, which is accomplished entirely within the scope of its system definition. ADTV's Prioritized Data Transport format includes a special *service type* byte in each cell header. This service type indicates whether the cell's data are video, audio channel 1, audio channel 2, auxiliary data, or other service types. Thus, an ADTV data stream simply consists of a sequence of cells, as shown in Figure 1.8, and it allows many different types of data to be delivered asynchronously.



An ADTV data stream consists of a flow of cells, each containing a single type of data. The order and type of cells is arbitrary, allowing complete flexibility in the mix of services that can be provided.

Figure 1.8 - An ADTV data stream.

The use of a service type in the cell header means that the mix of video, audio and auxiliary data is completely flexible and need not be specified in advance. ADTV enables broadcasters to alter their mix of video, audio and data services to address special market needs or to innovate new service opportunities. For example, if a market were found to exist for eight stereo sound channels, ADTV could provide this capability, with a modest reduction in picture quality taken to provide the capacity for the additional audio channels. Likewise, the mix of data could easily be altered to provide additional auxiliary data capacity for closed-captioning or other community services.

An important capability that both meets established needs and creates opportunities for innovative new video production in the future is that ADTV allows its mix of data types to be altered *dynamically*. Some examples of applications requiring this capability are:

- The entire channel capacity can be reallocated in bursts for data delivery. This capability can be used on cable systems to distribute decryption keys to a large audience of receivers during the seconds preceding a popular pay-per-view program.

- New, more interactive video programming could allow a sports viewer to select an alternate view of the game in a small pop-up window, or a game show viewer to access an additional audio channel that contains helpful hints, or a news viewer to get tomorrow's weather forecast at any time during the newscast.
- The use of burst data capacity could be used to download computer software to "smart receivers." In conjunction with the video program, the software in the receiver would be used to complement or augment the pictures. This capability could potentially change the nature of video production, creating entirely new possibilities that range from educational television programming to games.

Because there will be possibilities for future services that we cannot anticipate today, ADTV's extensibility is an extremely important attribute that will serve the needs of all video service providers. ADTV provides *open-ended extensibility*, since an ADTV receiver will *disregard* any cell with a service type that it does not recognize or cannot process. This means that new service types can be easily introduced without having to overcome the constraints of maintaining "backward-compatibility" with the installed base of receivers. In the future, this capability could be used to:

- Introduce compatible ultra-high definition television by sending augmentation data along with the normal ADTV data.
- Introduce compatible "HDTV stereo (3-D) television" by sending stereo image data along with the normal ADTV data.
- Deliver many new features and services using the ADTV standard.

Although the new services will not be delivered to older ADTV receivers, the freedom from restrictive backward-compatibility constraints ensures that innovative new features and services can be frequently introduced.

1.4.3 SS-QAM Transmission Modes and Media Interoperability

ADTV has been designed with interoperability in mind. In order to achieve interoperability over many delivery media, ADTV is architected as a "layered" system, whose media-specific communications requirements are met at its lowest layer. This approach achieves both flexibility and economy, which are recognized benefits of using layered approaches in data communications.

For the broadcaster, each of SS-QAM's channels is intended to operate with a trellis-code 32-QAM signal. However, SS-QAM also has a trellis-coded 16-QAM mode that provides broadcasters with an option to extend their coverage area or to operate with additional signal robustness in areas where this may be either advantageous or necessary. ADTV receivers, which

use digital signal processing to perform SS-QAM demodulation, can easily detect and adapt to these two transmission modes. This capability is discussed in Chapters 4.

Recognizing the unique relationship between broadcasting and cable, ADTV provides two important options for the cable operator. For cable channels that carry broadcast signals, ADTV's SS-QAM signal may be frequency translated directly to the appropriate cable channel. However, since cable transmission eliminates the unique difficulties imposed by the simulcast environment, a single conventional QAM signal⁸ can be used for programming that is not originated as a terrestrial broadcast source (e.g., from satellite or video tape). ADTV receivers can be designed to detect and adapt to this kind of cable transmission by simply operating their wideband QAM demodulator over a slightly wider bandwidth. This will have little cost impact on receivers, yet provides important interoperability between terrestrial and cable transmission.

For digital data transmission on satellites, Quadrature Phase Shift Keying (QPSK) modulation is in nearly universal use and is supported by commercially-available transmitting and receiving equipment. ADTV's layered architecture, and the ease of transcoding between QAM and QPSK support economical interoperability at the bit stream level. All other aspects of ADTV are completely transparent to the satellite and its QPSK link.

Interoperability with video cassette recorders can be achieved by demodulating ADTV from its broadcast channel, and repackaging the digital bit stream to an appropriate format and recording channel code (typically a phase code) for tape. It is notable that MPEG video compression was designed for digital storage media — its unique approach of periodically encoding frames entirely using spatial compression (I-frames, as explained in Chapter 3) ensures that features such as a viewable picture in fast forward and reverse play can be preserved in digital VCRs.

ADTV also accommodates interoperability with computer applications and advanced digital communications networks by interfacing at the transport level of its architecture. ADTV's cell format and synchronization mechanisms are similar to the cell methodology used in the Asynchronous Transfer Mode (ATM) of the Broadband Integrated Services Digital Network (B-ISDN). This approach gives ADTV a high degree of interoperability with B-ISDN and other future data networks, and supports the integration of computer and data communications technology that will result in new multimedia applications.

⁸ Note that this mode of cable transmission is not implemented in ADTV prototype hardware.

1.5 COST ASPECTS OF ADTV

ADTV achieves low cost for broadcasters, alternative media and consumers by leveraging established standards, and by the many pragmatic aspects of its design.

1.5.1 Leveraging Standards

For the consumer, the greatest way to achieve economy is to have a single receiver that decodes compressed video signals delivered by any media, such as broadcast, cable, satellite, VCR, or consumer multimedia disks. The most practical and cost-effective way that a receiver can meet this requirement is to have a single compression approach for all of these media. ADTV's compression, based on the ISO-MPEG standard for compressed video on digital storage media, provides this opportunity. The alternative of different proprietary approaches leaves the consumer with a variety of expensive set-top receivers/converters, each requiring its own decompression decoder. Different proprietary approaches also hurts both broadcasters and alternate media service providers by leaving them with a fragmented, confused audience, and by prohibiting them from benefiting from new product and service opportunities that will inevitably occur if a single compression standard is adopted, and rapidly accepted by consumers.

Leveraging standards also creates important cost-reducing economies of scale. The largest single factor in cost reducing a consumer product is to achieve high production volumes (and their associated commodity prices) for essential integrated circuits. At the time of its introduction, ADTV will benefit from the established momentum of the MPEG video and audio standards. High-volume production of MPEG video and audio decoder ICs will effectively cost-reduce the most complex electronic portions of an ADTV receiver. It is notable that several companies have already announced MPEG video encoding and decoding integrated circuits (albeit for much lower than HDTV resolution), which will likely hasten MPEG's adoption in new multimedia computer products. With the momentum of the semiconductor industry established behind MPEG, it is reasonable to expect that rapid increases in performance and reductions in cost will take place for MPEG decoders, including those in ADTV products, consistent with the trends in computer and memory devices. MPEG audio components will follow the same trend.

Over the long term, ADTV's standards-based approach will result in the use of common (or at least similar) devices in the consumer electronics, computer, communications and broadcast equipment industries. In addition to its MPEG-based compression, ADTV can also benefit from its similarity to B-ISDN formats, which may result in certain interface ICs being used in ADTV receivers. Similarly, QAM demodulation is standardized in lower speed applications, requires relatively simple processing and is amenable to IC implementation. The resulting high-volume production and commonality of devices will benefit each of these industries, and the consumer.

1.5.2 Pragmatic Aspects of ADTV

ADTV has been designed as a practical system. Many aspects of its design are a result of pragmatic considerations.

ADTV uses video formats that significantly reduce the cost and artifacts of transcoding between HDTV and NTSC in both the production studio and in combination (ADTV and NTSC) receivers. ADTV's nominal 1440 x 960 format with a 1050 line 2:1 interlaced, 59.94 fields per second raster, has the following advantages:

- A field rate identical to NTSC eliminates temporal artifacts and the need for frame synchronization memory.
- A 2:1 vertical resolution relationship with NTSC allows conversion with simple line repetition or interpolation.
- A 2:1 horizontal relationship with the 720 active pixels used in D1 digital recorders⁹ allows conversion with simple pixel repetition or interpolation.
- The two frames of storage required for MPEG decoding are economically provided by two 16 Megabit memory devices.
- A 2:1 vertical relationship to NTSC allows cost-effective 2H scanning in the receiver.

ADTV's other formats preserve these advantages with essentially no additional cost. The presence of frame store memory for decompression allows frame rate conversion to be performed by appropriately repeating frames. Similarly, vertical scanning conversion can be performed in the receiver either by simple memory addressing and vertical deflection changes or by electronic zoom.

Memory, which is already commodity priced, is a significant component required in any HDTV receiver. An important virtue of ADTV's 1440 x 960 video format is that a single frame of luminance and chrominance pixels can be stored in 2 MegaBytes (one 16 Megabit memory chip). Since one of the ways that MPEG compression achieves its high picture quality is by using forward and backward motion compensation, at least two frames of storage are needed in an ADTV receiver. This capacity can be conveniently and economically provided by two 16 Megabit memory devices, which are projected to cost approximately \$13 each in 1996 (see Chapter 6).

ADTV's SS-QAM signal is designed with many practical considerations in mind. Its standard priority carrier is precisely four times the symbol rate (bandwidth) of its high priority carrier. This allows both carriers to be sampled with a clock that is reliably derived from the

⁹ This conforms to the CCIR Recommendation 601 component video sampling standard for 525-line systems.

higher-power HP carrier, as described in Chapter 4. It also allows cost-effective demodulator designs to be developed, including a single digital signal processor that is multiplexed to demodulate both carriers. SS-QAM's basic two-carrier structure also provides the framework for very low-cost receivers to decode only its narrowband high-priority carrier. Future improvements to ADTV compression encoding have the potential to make this a viable approach for receivers with some screen sizes and cost ranges.

1.6 SUMMARY

When integrated together to form ADTV, MPEG++, Prioritized Data Transport, and Spectrally-Shaped QAM operate in unison to meet the unique demands of simulcasting. ADTV creatively combines the advantages of digital systems with important television reliability and robustness principles. Its High-Priority carrier ensures that synchronization, audio and a viewable picture are reliably delivered over its entire coverage area, even under severe transmission conditions. This graceful degradation characteristic allows ADTV to provide reliable and robust service to a coverage area that is defined by 90% time availability of the full-quality service that is delivered by its Standard-Priority carrier. In addition, ADTV's high immunity to NTSC co-channel interference prevents its coverage area from being eroded by signal penetration from closely-spaced NTSC stations. The result is that even with the reduced co-channel spacing required to accommodate most broadcasters with a simulcast channel, ADTV reliably delivers high-quality HDTV pictures to a coverage area comparable to that of an NTSC station.

ADTV also provides a broad scope of features and services, allowing broadcasters to tailor services to specific markets. It has important interoperability capabilities that make it well-suited for broadcasters, alternative delivery media and applications beyond entertainment. ADTV also provides open-ended extensibility for introducing new features and services that are limited only by the imagination (and the data rate of the broadcast channel). With these characteristics, ADTV provides broadcasters with the ability to remain competitive in the 21st century.

ADTV is a cost-effective system that leverages standards and their associated production volumes to achieve low cost for broadcasters, alternative media and consumers. In the short term, ADTV benefits from the established production volume of components related to the standards that it leverages. In the long term, all users of the standards benefit from consumer production volumes of the components.

ADTV has many unique features that contribute to its performance, flexibility and cost attributes, as summarized in Table 1.1. The ATRC believes that these characteristics make Advanced Digital Television the best choice for an American HDTV simulcast system.

ADTV Subsystem	Performance	Flexibility	Cost
MPEG++ Video Compression	High compression Excellent picture quality Prioritization identifies the most important bits	Accommodates several video formats and frame rates Promotes interoperability at the MPEG bit stream level	MPEG is an ISO standard (standards reduce cost)
MUSICAM Audio Compression	High compression Excellent sound quality Program audio is high-priority data	promotes interoperability at the MPEG bit stream level	MUSICAM is based on the ISO-MPEG audio standard (standards reduce cost)
Prioritized Data Transport format	Supports two-tier transmission Performs error detection and correction Performs synchronization and error recovery	Total flexibility in the mix of video, audio and data Promotes interoperability with data networks at the cell/packet level	Fixed-size cells are an economical format Similarity to B-ISDN format provides cost-reduction opportunities
Spectrally-Shaped QAM Transmission	Two trellis-coded QAM carriers provide two-tier transmission High-Priority carrier reliably delivers the most important bits Signal structure is highly immune to NTSC interference Signal structure is friendly to NTSC	Optional 16-QAM mode for broadcasters SS-QAM <i>or</i> a single QAM for cable Layered system architecture allows other modulation for alternate media	QAM is widely-accepted and standardized in lower speed applications

Table 1.1 - ADTV Performance, Flexibility and Cost Attributes