ADVANCED DIGITAL HDTV — BASIC PRINCIPLES OF TRANSMISSION, COVERAGE AREA AND SERVICE FLEXIBILITY

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INTRODUCTION — UNIQUE PROBLEMS OF DIGITAL SIMULCASTING

A digital simulcast system requires many new technologies to compress and transmit HDTV in digital form. Unquestionably, the compression used in a digital HDTV system must provide outstanding picture quality. But a simulcast HDTV system involves much more than compression — its system design must be such that it will not be prone to catastrophic failure 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.

KEY ELEMENTS OF AD-HDTV

Each of the major subsystems in Advanced Digital High Definition Television (AD-HDTV), and their integration as a total system, contributes to the solution of these crucial simulcast problems. The key elements of AD-HDTV are:

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

This paper will explain how these elements operate in unison as an effective simulcast system.

MPEG++ Compression

AD-HDTV's MPEG++ compression simultaneously provides high-quality HDTV pictures and forms the basis of AD-HDTV's reliable and robust performance as a simulcast system. MPEG is an ISO standard[1] 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 capabilities to edit and search compressed video on 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 MPEG compression as the basis for AD-HDTV.

AD-HDTV's MPEG++ approach uses MPEG, but adds important robustness that is essential to survive the 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. To overcome the serious artifacts that typically result from 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.

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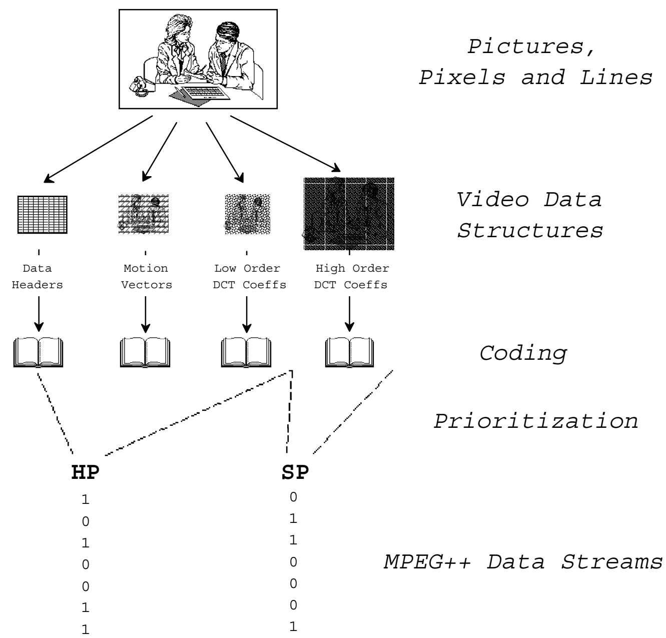
1 "MPEG Video Committee Draft", ISO/IEC JTC1/SC2/WG11 document, December 18, 1990.

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 use the MPEG standard within the AD-HDTV system, while also making strong provisions for robustness in terrestrial broadcasting. Specifically, MPEG++ transforms MPEG into two data streams that provide robust delivery over the terrestrial channel. Figure 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 - AD-HDTV's MPEG++ video data compression

AD-HDTV delivers high quality HDTV service to its coverage area, which is defined by the reception of both Standard-Priority and High-Priority data. With two separate data streams, 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.

Prioritized Data Transport

AD-HDTV's Prioritized Data Transport format is specifically designed to carry, synchronize and protect MPEG++ high-priority and standard-priority data through AD-HDTV's two-tier (prioritized) transmission system that has two separate data channels. AD-HDTV'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 in Figure 2.

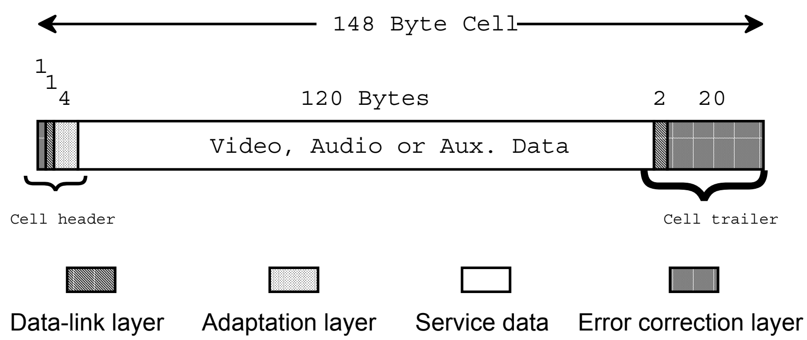


Figure 2 - AD-HDTV’s Prioritized Data Transport format.

The transport cell provides several layers of “safety nets” in the form of error correction, error detection, and error recovery capabilities that allow AD-HDTV receivers to continue decoding useful video data even under very high bit error rate conditions:

- A Reed-Solomon forward error correction (FEC) code fully corrects up to 10 byte errors in each cell. Long burst errors that typically result from impulse noise are protected against by interleaving data across several cells, resulting in shorter errors that can be corrected by the FEC code.

- A Cyclic Redundancy Check (CRC) code 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.

- 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.

Even more important is that Prioritized Data Transport forms the basis for AD-HDTV's service flexibility. 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. AD-HDTV 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. AD-HDTV's Prioritized Data Transport format includes a special *service type* 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 AD-HDTV data stream simply consists of a sequence of cells, as shown in Figure 3, and it allows many different types of data to be delivered asynchronously.

An AD-HDTV 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 3 - An AD-HDTV 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. AD-HDTV 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, AD-HDTV 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 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 AD-HDTV 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.
- 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.

It is important that AD-HDTV provides open-ended extensibility, since an AD-HDTV 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. Although the new services will not be delivered to older AD-HDTV receivers, the freedom from restrictive backward-compatibility constraints ensures that innovative new services can be frequently introduced.

Spectrally Shaped Quadrature Amplitude Modulation

AD-HDTV'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. The High-Priority carrier is transmitted at an increased power level, ensuring that the High-Priority carrier will be reliably received over the entire AD-HDTV coverage area, even under severely impaired transmission conditions that might momentarily incapacitate the Standard-Priority carrier.

A 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. AD-HDTV's SS-QAM frequency spectrum and its relationship to an NTSC co-channel frequency spectrum are shown in Figure 4.

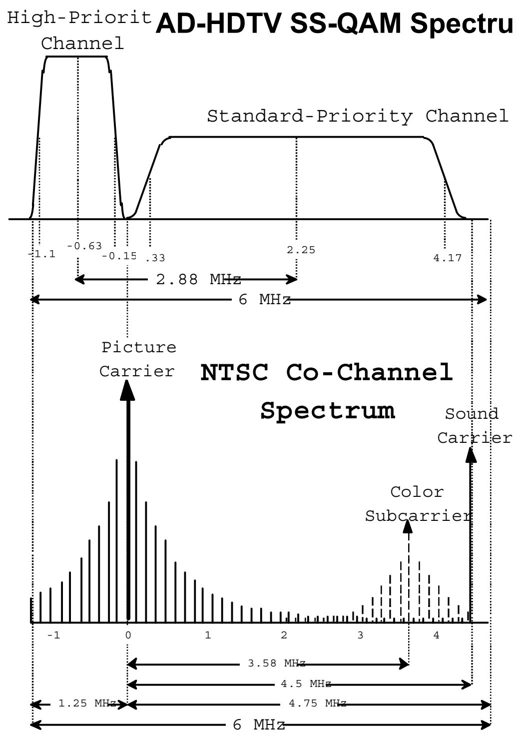


Figure 4 - AD-HDTV's SS-QAM Spectrum and its relationship to an NTSC co-channel spectrum

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 AD-HDTV:

- 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. This is the means for providing AD-HDTV'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.

AD-HDTV'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.

AD-HDTV as a Simulcast System

When integrated together to form AD-HDTV, MPEG++, Prioritized Data Transport, and Spectrally-Shaped QAM operate in unison to meet the unique demands of simulcasting, as shown in Figure 5. 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. This signal is reliably available over the entire AD-HDTV coverage area, including the fringes, even under poor transmission conditions. This approach allows AD-HDTV's coverage area to be based on the 90% time availability of full-quality service (provided by Standard-Priority carrier reception) at the fringe. AD-HDTV thus provides a reliable and robust television service to its audience, over a large coverage area. In addition, AD-HDTV'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, AD-HDTV reliably delivers high-quality HDTV pictures to a coverage area comparable to that of an NTSC station.

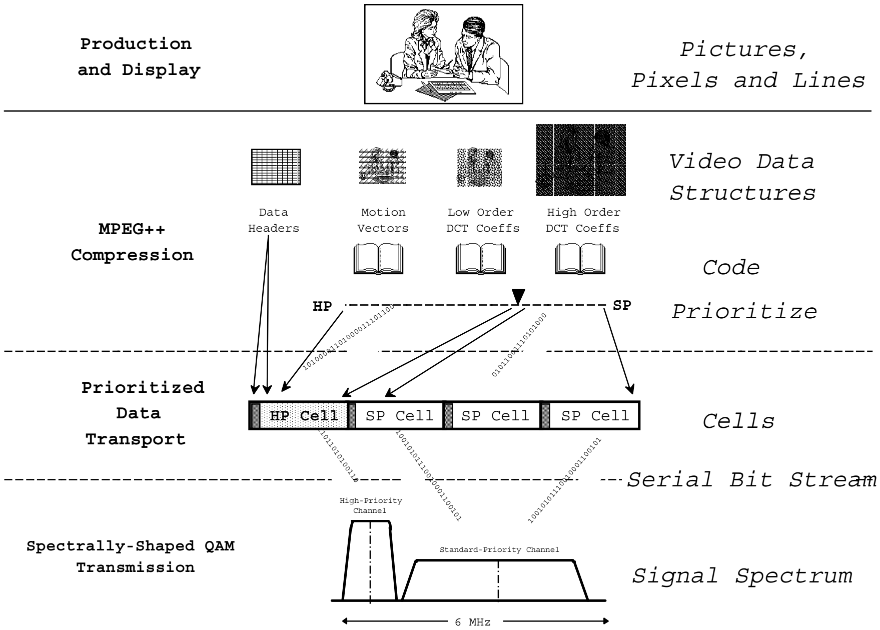


Figure 1.6 - A conceptual overview of the AD-HDTV system.

Over its coverage area, AD-HDTV provides a broad scope of features and services, allowing broadcasters to tailor services to specific markets. AD-HDTV 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, AD-HDTV provides broadcasters with the ability to remain competitive in the 21st century.