ATRC

Advanced Digital Television

System Description

SS-WP1 Certification

January 30, 1992

Outline

- Introduction
- Video and Audio Compression
- Transport and Transmission
- Coverage Area
- Summary

Key Elements of ADTV

- MPEG++ video compression
  - ATRC adaptation of ISO-MPEG video compression standard
  - upgrades MPEG to HDTV performance levels
  - adds video format flexibility
  - performs video data prioritization for robustness
- MUSICAM audio compression
  - ISO-MPEG audio compression standard
- Prioritized Data Transport
  - cell-relay data transport layer provides robustness
  - prioritized delivery of data allows “graceful degradation”
  - provides service flexibility (video, audio, data)
- Spectrally Shaped QAM
  - ATRC adaptation of proven and widely-accepted QAM
  - two-tier physical transmission
  - increases immunity from co-channel NTSC interference
  - reduces interference into NTSC co-channels

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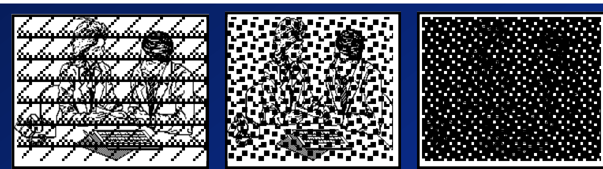
ADTV System Layers

Production Standard

Pictures



Motion Vectors

Low Order DCT Coeffs

High Order DCT Coeffs

Video Data Structures

MPEG++ Compression

Coding

1 2 3

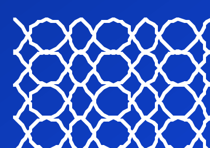
Ranking

Prioritized Data Transport

Cells

11010011101101001110100101010011

Spectrally-Shaped QAM Transmission



Symbols

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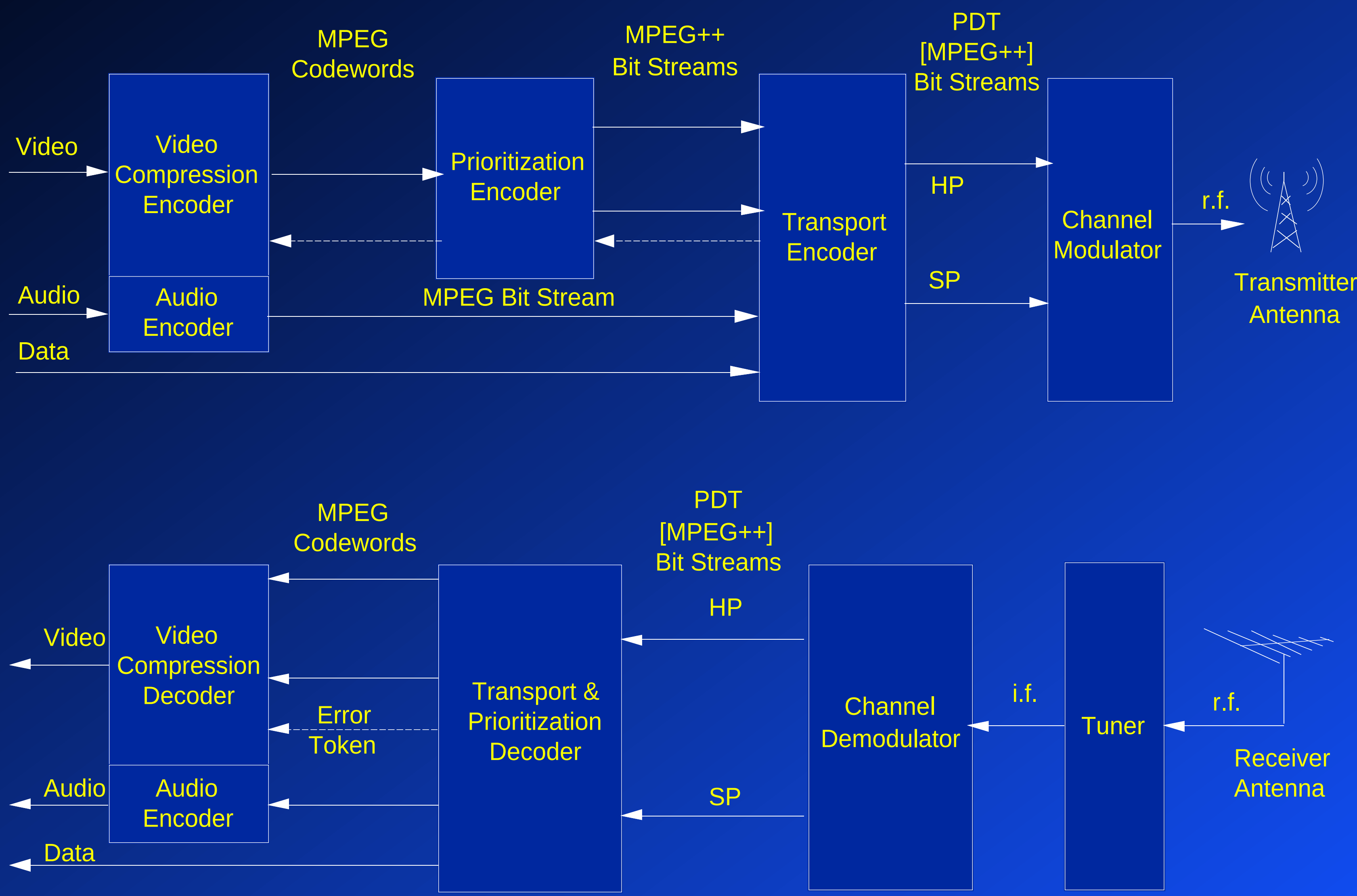
ADTV System Block Diagram



Video and Audio Compression

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Video Specifications

Raster Formats	* 1050/2:1/59.94 1050/1:1/29.97 1050/1:1/24
Pixel formats	1440 x 960 (720 x 480) 1440 x 810 (720 x 405) * 1500 x 960 (750 x 480)
Sampling rate	54.0 MHz (27.0 MHz chroma) * 56.64 MHz (28.32 MHz chroma)
Bandwidth	24.5 to 27 MHz * 23.6 MHz
Resolution	730 to 810 TVL/PH * 700 TVL/PH (1248 samples/PW)
Video bit rate	17.73 Mbps

* prototype hardware configuration

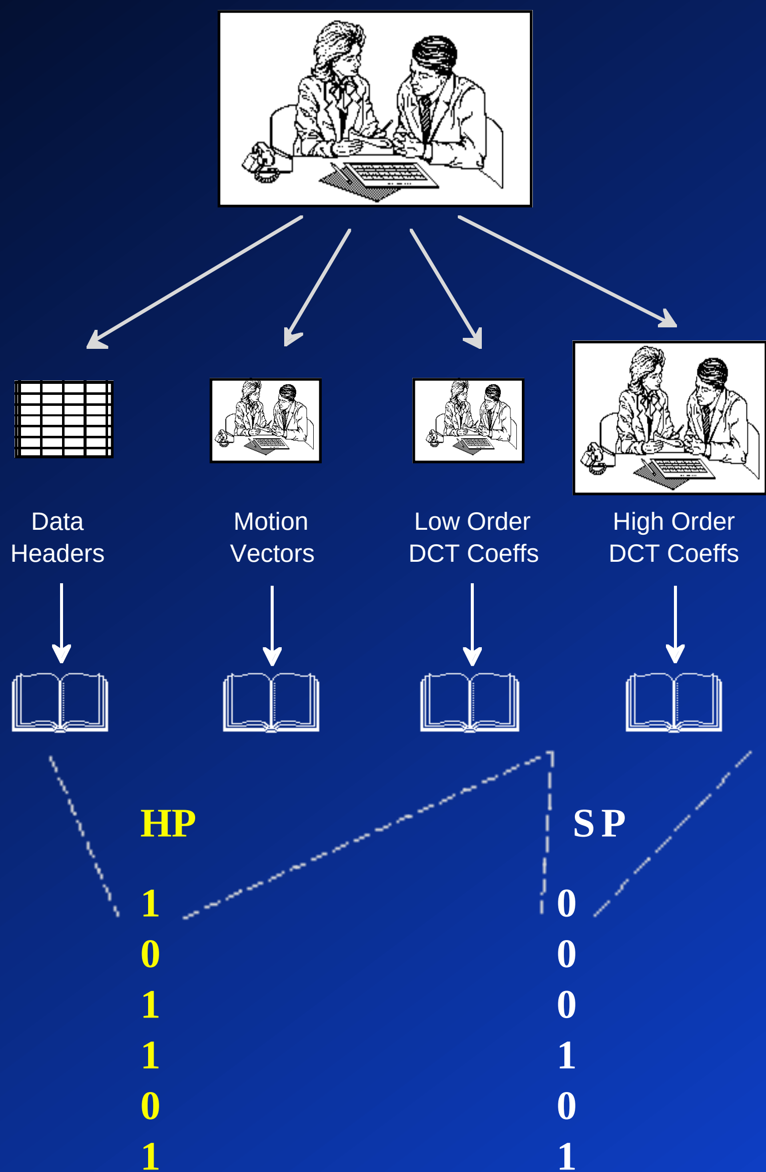
MPEG++

- **MPEG provides high-quality compression**
  - developed by a committee of worldwide compression experts
  - bi-directional motion compensation is a key attribute
  - solves occlusion/reveal problems of traditional approaches
  - preserves motion compensation performance on a scene cut

- **ATRC improvements**
  - scene analysis for perceptual optimization
  - frame-based coding provides HDTV and film modes and transparently handles interlaced and progressive scan

- ***Prioritization* produces High-Priority data that constitutes a "viewable picture" -- and Standard-Priority data that carries the additional information for "full HDTV quality"**
  - viewable pictures provide service during occassional periods when full-quality pictures cannot be received

MPEG++ Concept



Pictures,
Pixels and Lines

Video Data
Structures

Coding

Prioritization

MPEG++ Data Streams

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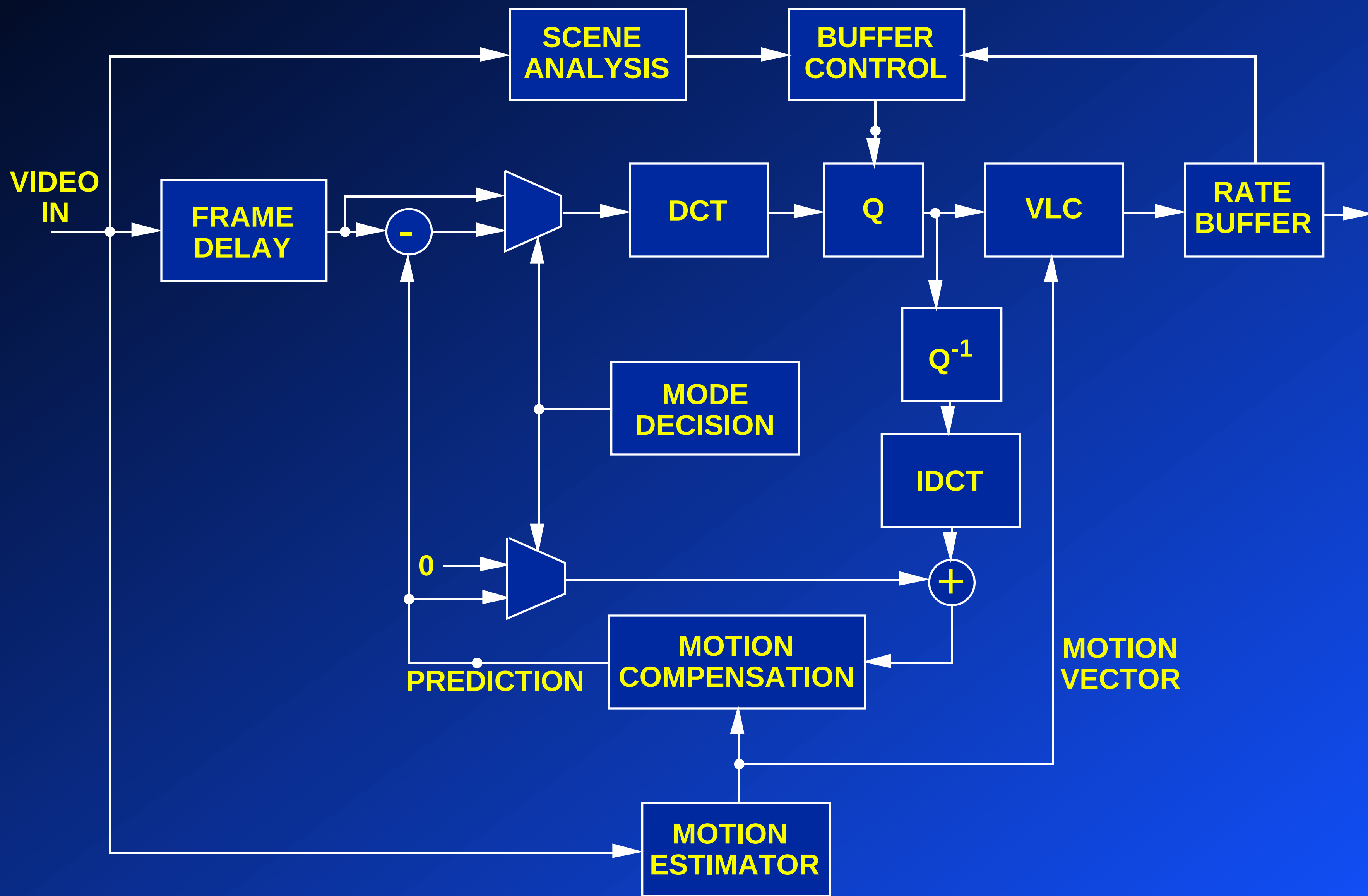
MPEG Video Encoder



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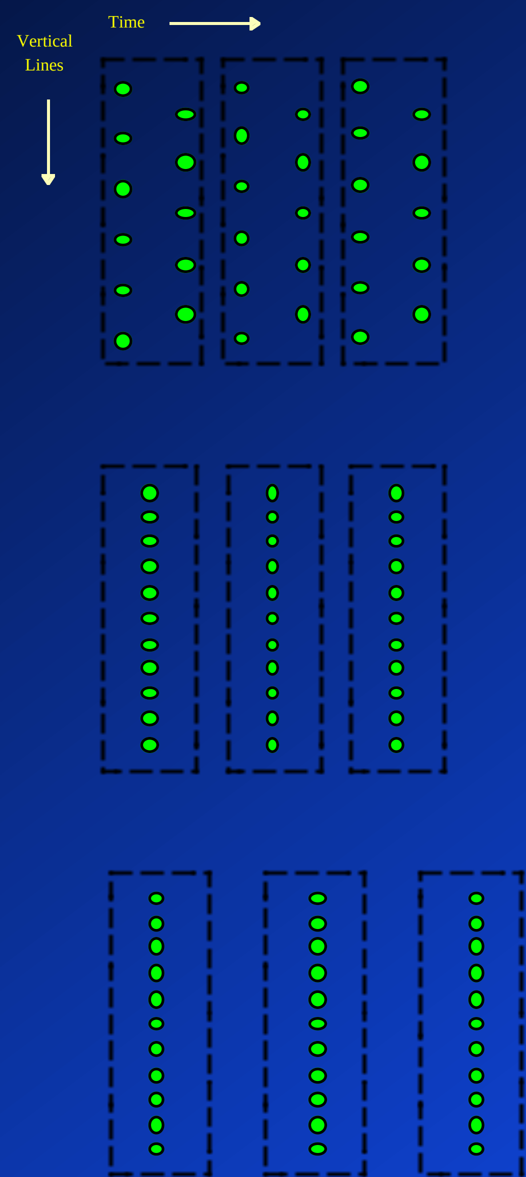
Frame-based Coding



HDTV Production

1050 Lines
2:1 Interlaced
59.94 fields per second

Mixed-Media Production

1050 Lines
Progressive Scan
29.97 frames per second

Film Production

1050 Lines
Progressive Scan
24 frames per second

Frame-based Coding and Interlace

- Constant velocity motion is accurately predicted by motion vectors and removed by motion compensation
- Residual motion energy is treated as vertical resolution
  - high contrast (perceptually visible) information is preserved
  - after decompression, re-interlacing reconstitutes the temporal information

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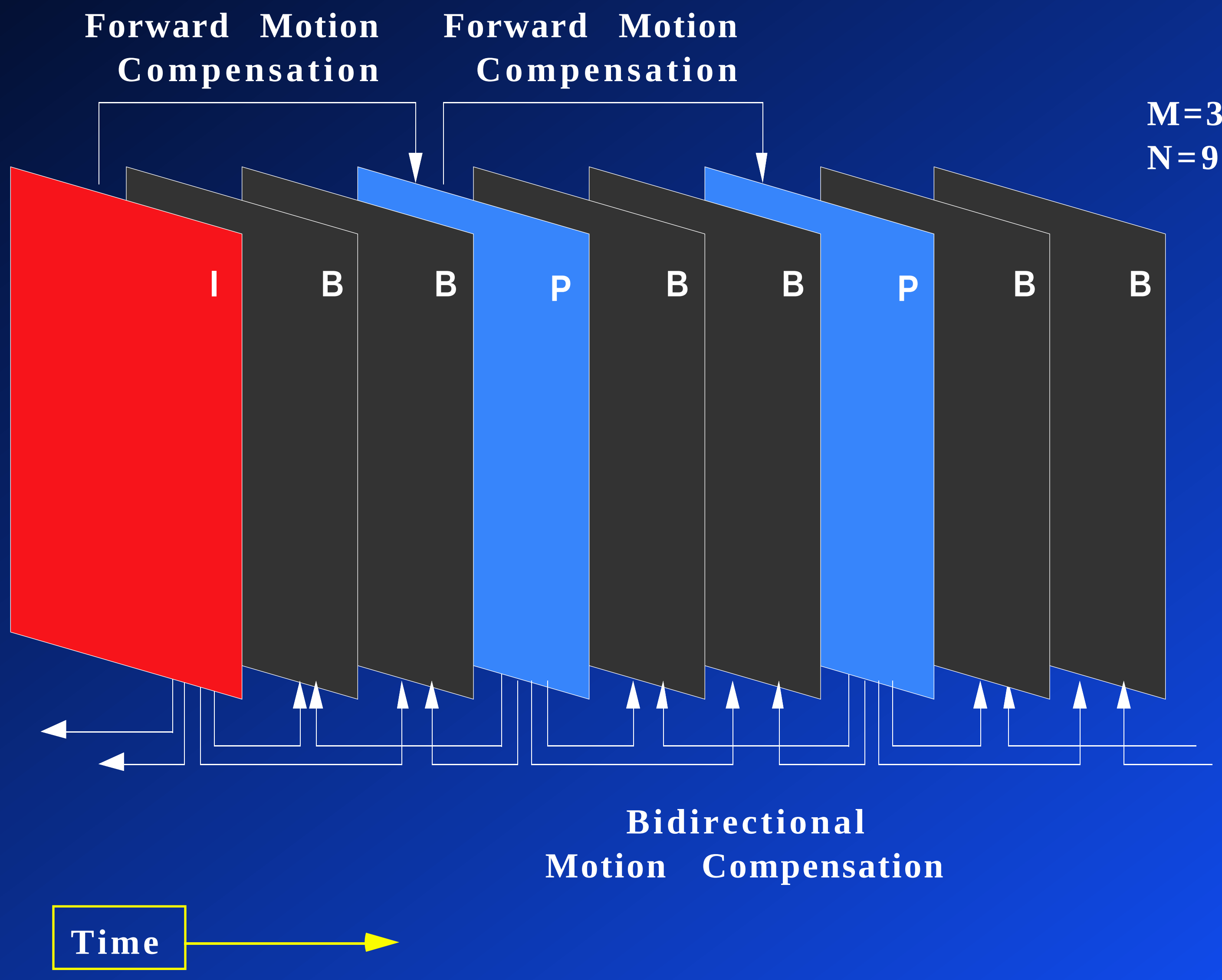
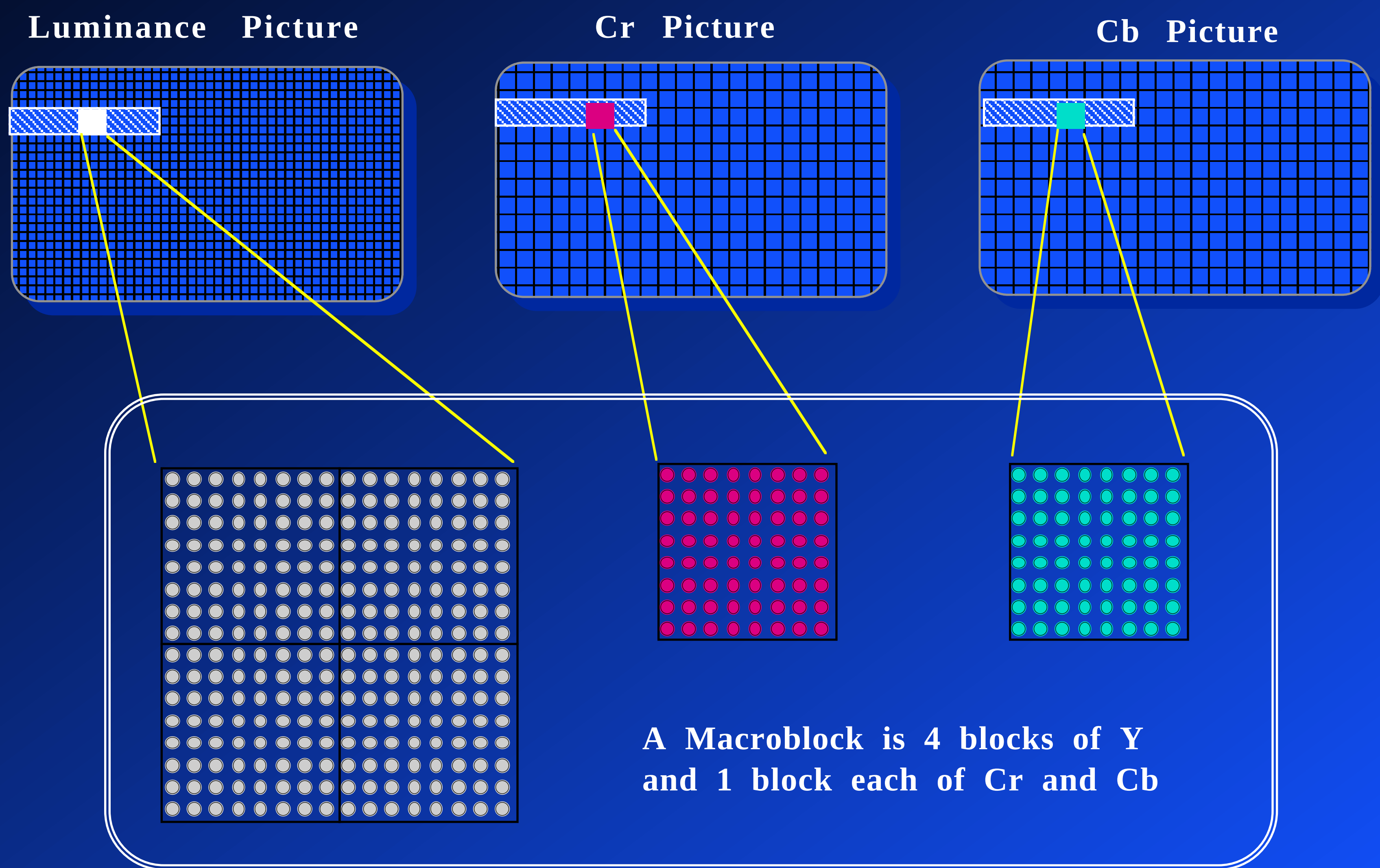
Group of Pictures



Slices, Macroblocks and Blocks

A slice is a collection of adjacent Macroblocks



Motion Compensation

- Motion Vectors are derived from luminance
- Motion estimation utilizes full-search block matching performed on macroblocks
- Motion vectors have 1/2 pixel accuracy
- Maximum motion vector range is [-1024,+1023] (motion range is an encoder manufacturer's cost/performance tradeoff — prototype hardware implements a [-32,+31] range)

Coding Modes

FRAME TYPE	INTRAFRAME MODE	INTERFRAME MODES		
		FORWARD MOTION	BACKWARD MOTION	BIDIRECTIONAL MOTION
I (INTRAFRAME)	√	N/A	N/A	N/A
P (PREDICTED)	√	√	N/A	N/A
B (BIDIRECTIONAL)	√	√	√	√

- **Coding mode selection is performed for each macroblock**
  - performance is optimized to picture content
  - example: on a scene cut, B-frame MBs will be coded as intra

Compression Techniques

- Lossy techniques
  - adaptive quantization matrix

- Lossless techniques
  - DPCM on MV and DC coefficients of intra-coded MBs
  - run-length coding and zig-zag scanning
  - variable length coding using Huffman tables

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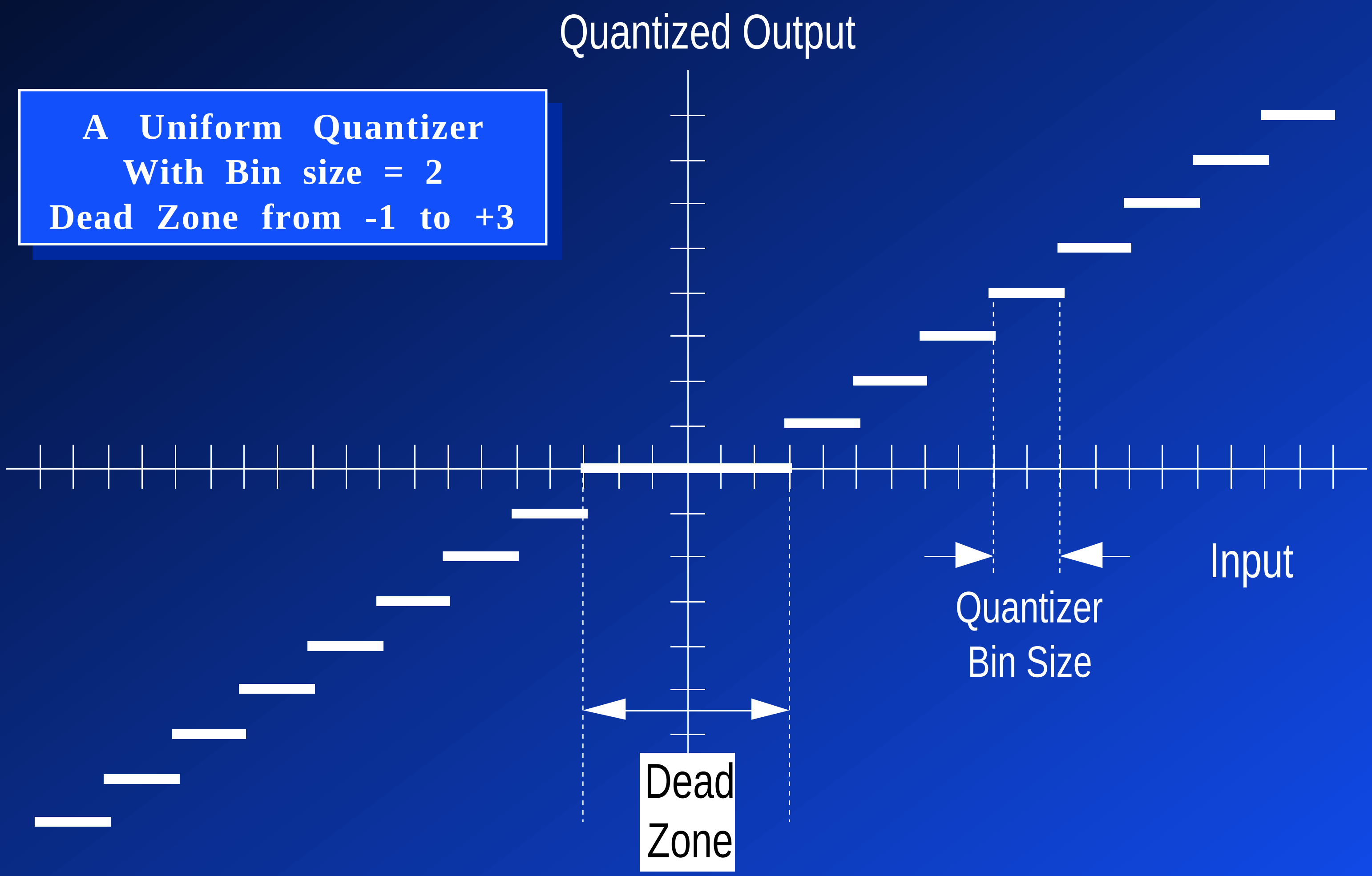
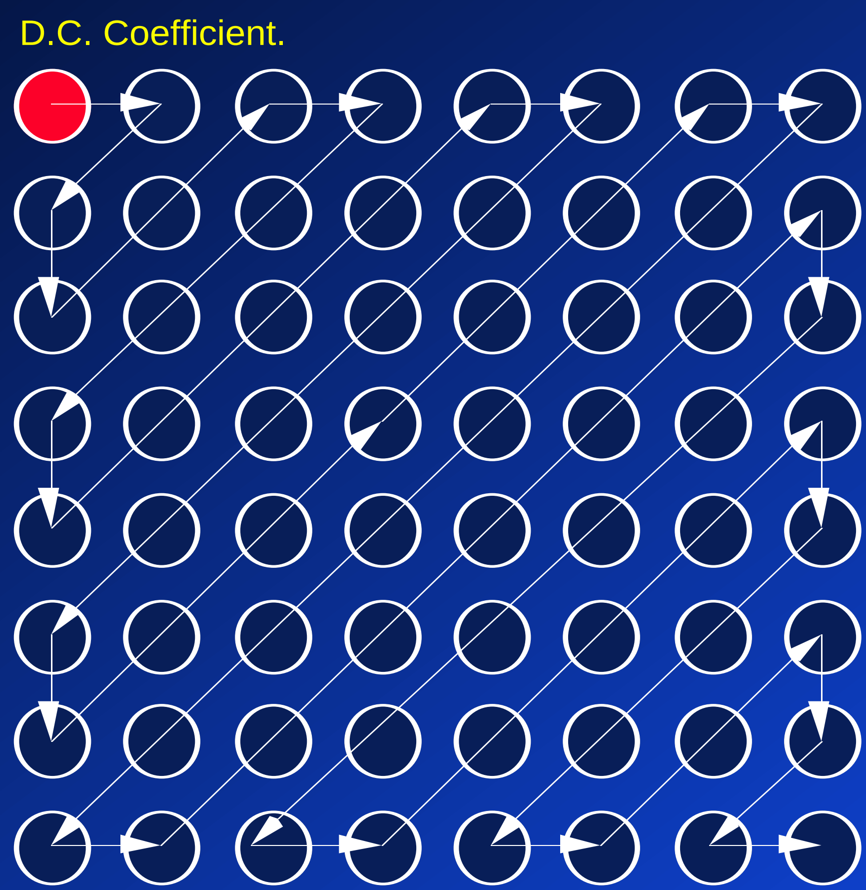
Quantization

A Uniform Quantizer
With Bin size = 2
Dead Zone from -1 to +3



Zig-Zag DCT Scanning



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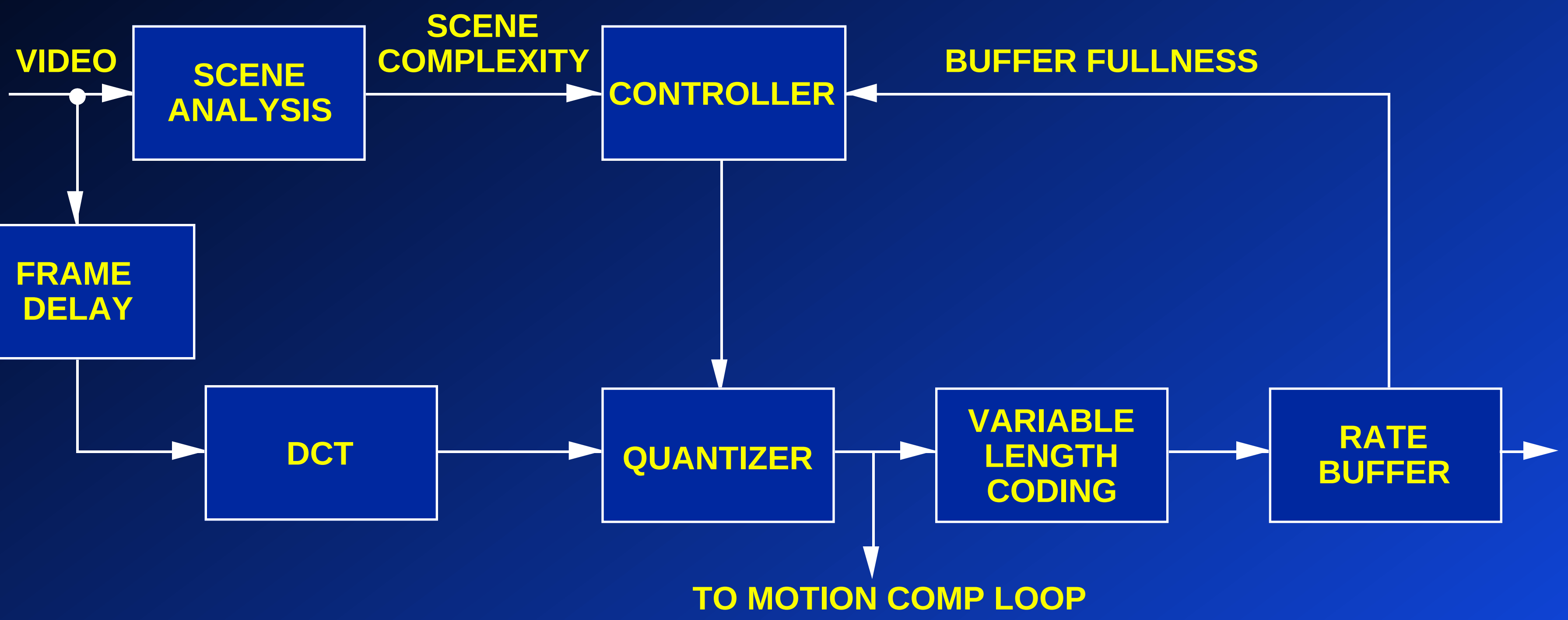
Scene Analysis and Buffer Control



Scene Analysis

- DCT + RLC + Fixed Q/Frame
- Update at Macroblock rate
- Allows perceptually optimized coding

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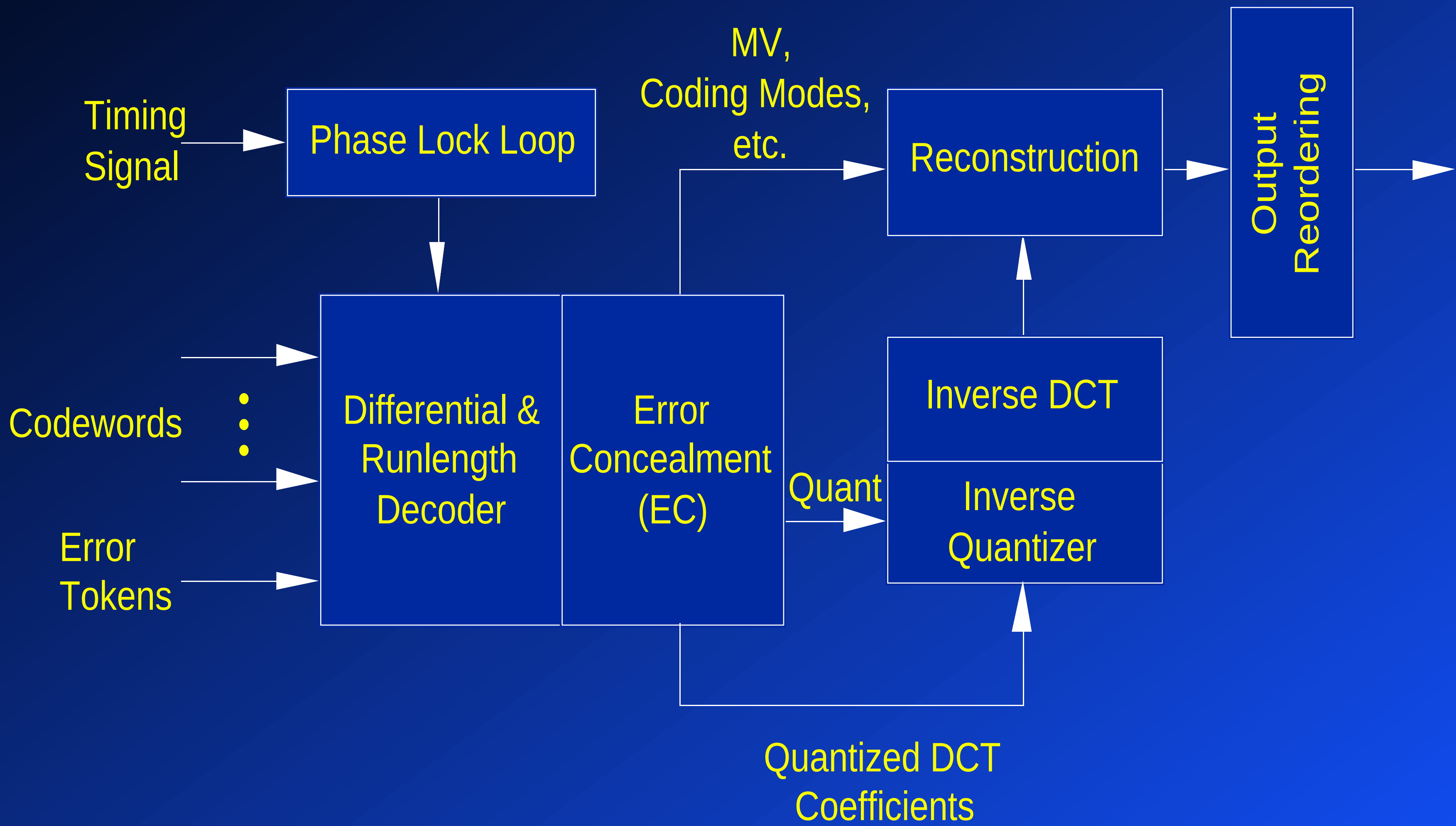
Video Decoder



ADTV Audio Specifications

MUSICAM — (Masking-Pattern Adapted Universal Subband Integrated Coding and Multiplexing)

- ISO-MPEG Layer II
- Subband Coding
- Bit allocation of each subband is determined by use of a psychoacoustic model

Nominal Audio configuration	2 stereo pairs of audio
Sampling rate	48 kHz, (8008/5 x 29.97)
Bandwidth	23 kHz
Dynamic range	16 bits/sample
Compressed audio bit rate	256 kbps per stereo pair
Auxiliary Data	256 kbps

Data Compression Summary

- ADTV's MPEG++ video and MUSICAM audio are based on ISO-MPEG compression standards
  - proven techniques developed as winners of side-by-side expert evaluations
  - bi-directional motion compensation provides high performance

- MPEG++ improves standard MPEG performance and adapts it for simulcasting
  - flexible video formats
  - picture quality
  - prioritization

- MPEG was designed for digital storage media
  - preserves search and random access capabilities
  - a good basis for VCR

Transport and Transmission

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Transport Specifications

SERVICE DATA (video, audio, etc.)	120 bytes
forward error correction	20 bytes
frame check sequence (error detect)	2 bytes
adaptation header	4 bytes
service type	1 byte
cell synchronization	1 byte
total cell size	148 bytes

Prioritized Data Transport

- Packages and synchronizes data for two-tier (High-Priority and Standard-Priority) transmission

- Transport is a communications layer that encapsulates the MPEG++ bit stream in fixed-size transport cells (standard practice in data communications)

- Provides many layers of “safety nets”
  - error correction
  - error detection
  - decoder reentry

- Provides flexibility and extensibility
  - there is no predetermined mix of video, audio, or data
  - service type mix can change dynamically
  - cells with unrecognized service types are disregarded
  - accepted practice in data communications

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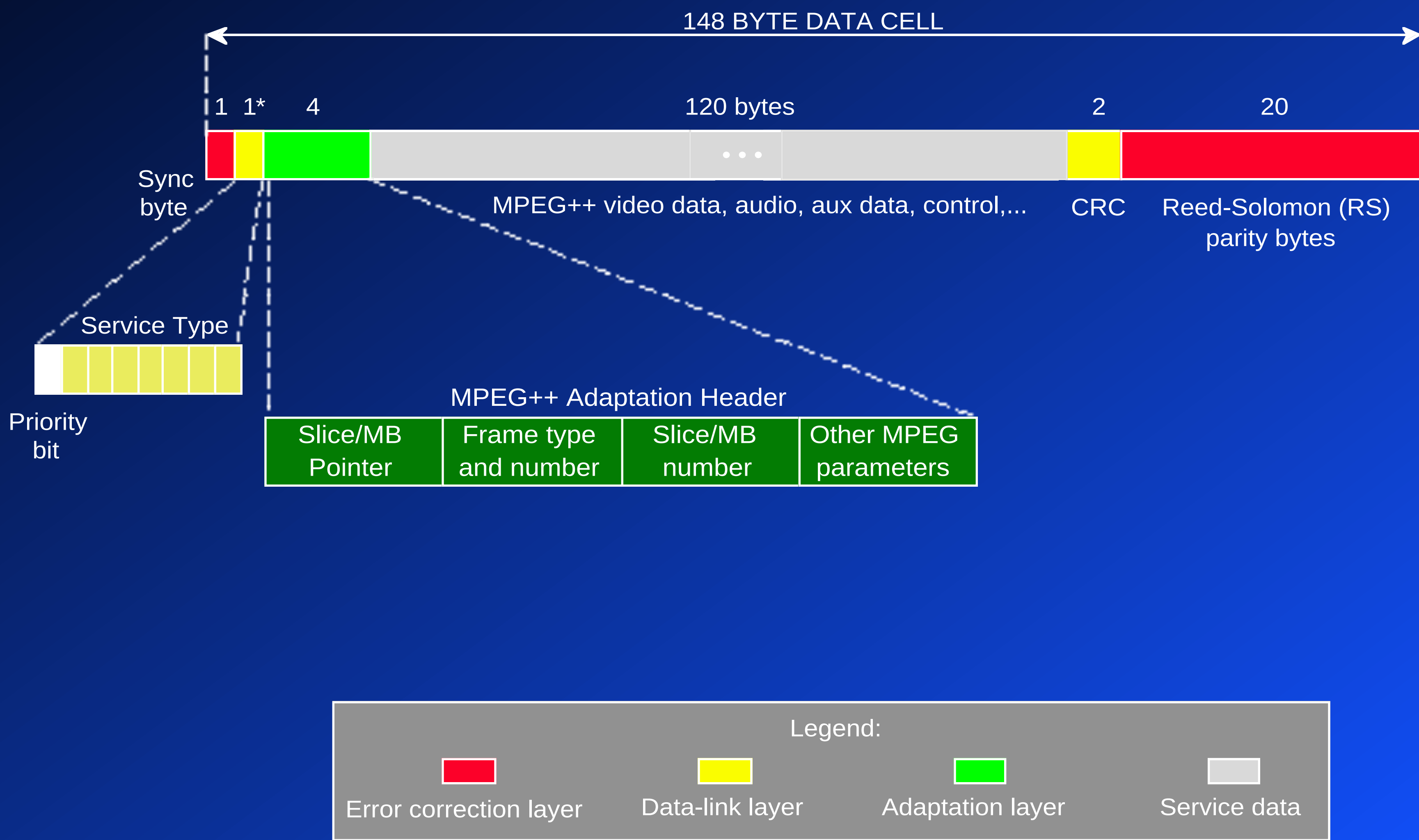
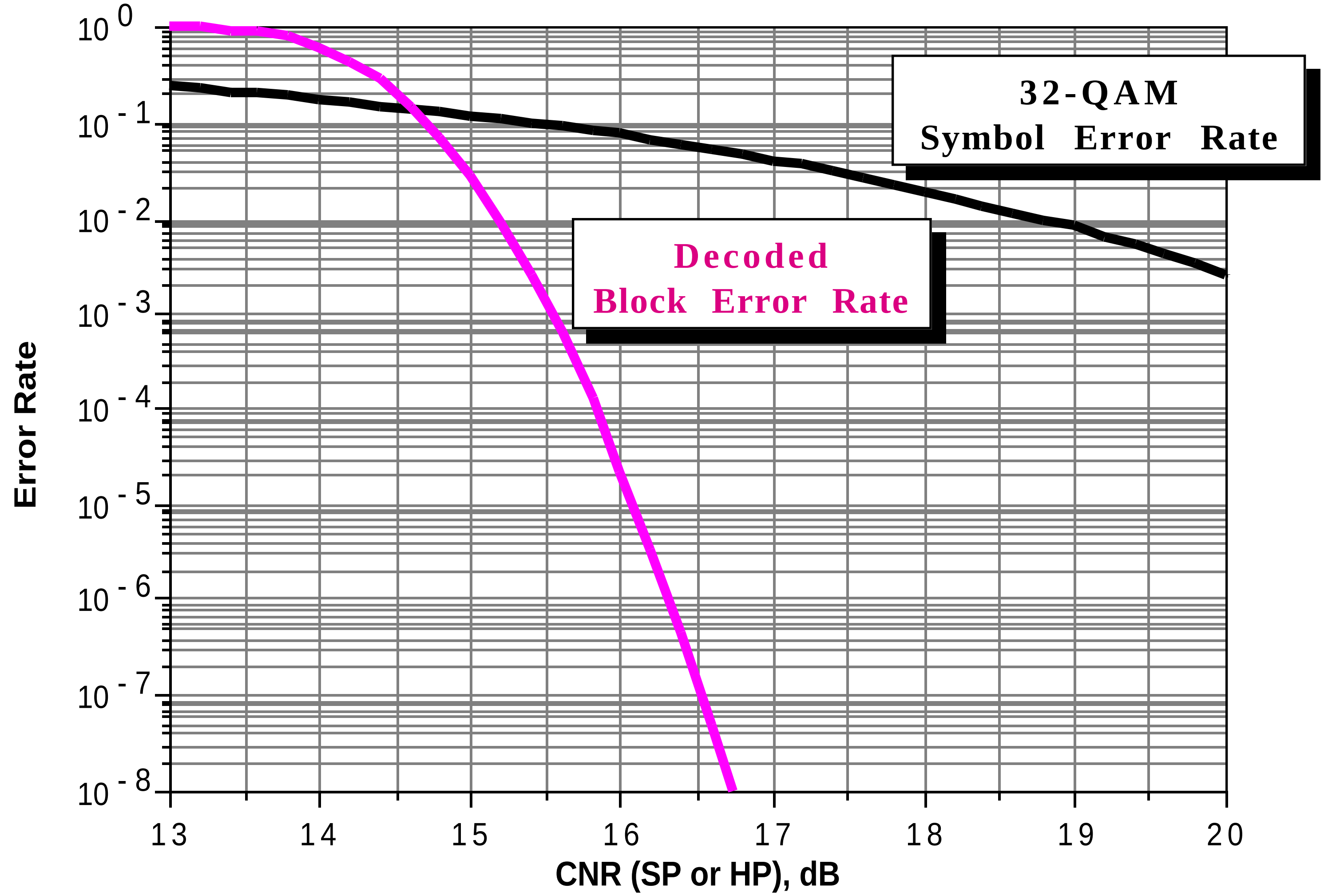
Prioritized Data Transport Format

ADTV separately packages video, audio and auxiliary data in fixed-length cells.



Reed-Solomon Code



Data Transport Robustness

- Reed-Solomon FEC corrects up to 10 Byte errors per cell
- Data interleaving protects against burst errors
- Cyclic Redundancy Check FCS detects uncorrectable errors
- MPEG++ adaptation header provides a reentry pointer that allows the video decoder to smoothly resume processing good video data after a cell loss
- Erroneously received cells are discarded
- Cell sync and sequence number allow synchronization even under extremely poor transmission conditions

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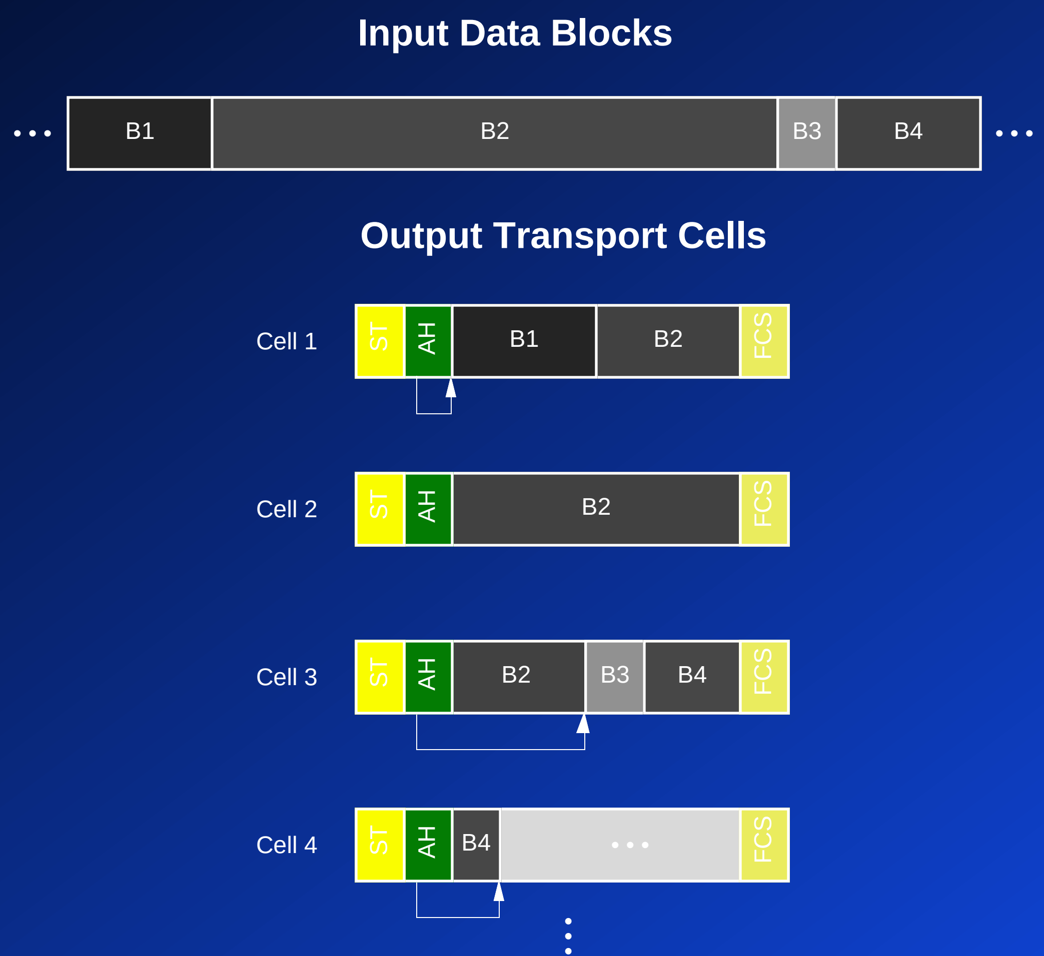
Reentry Pointer Example



Four variable-length data records (B1, B2, B3, and B4) are to be formatted according to the PDT format specification into four transport cells. Cells 1,3 and 4 each have an entry points corresponding to the start of the first new video record, while cell 2 (which contains video data segmented from within record B2) has no entry point. In the event that an error leads to a loss of cell 2, the entry pointer in cell 3 enables the receiver to decode B1, reject B2 and restart video decoding at record # B3.

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ADTV Data Stream

VIDEO	VIDEO	AUX DAT 2	AUDIO 1	VIDEO	AUX DAT 1	AUDIO 2	VIDEO	AUX DAT 1

- **An ADTV data stream consists of a flow of cells**
  - **each cell contains a single type of data**
  - **there is no predetermined mix of video, audio, or aux data**
  - **service type mix can change *dynamically***
  - **cells with unrecognized service types are disregarded**

- **This allows flexibility in the services that can be provided**
  - **“second video program” in a user-selectable window**
  - **download program-related software to “smart receivers”**
  - **rapid enabling of pay-per-view decoders on cable**
  - **future enhancements such as compatible 3-D HDTV**

Important Signal Characteristics

- Ability to continuously deliver a high data rate
- Ability to provide coverage area comparable to NTSC, even with relatively low power transmission
- An NTSC-friendly signal that minimizes interference with existing NTSC service
- Ability to withstand very high levels of NTSC co-channel interference

Spectrally-Shaped QAM

- SS-QAM uses two separate 32-QAM carriers
  - a wideband Standard-Priority carrier
  - a narrowband, higher-power High-Priority carrier
- The HP carrier has "viewable picture" and sound
- The SP carrier has the rest of the HDTV data
- Spectral structure *avoids* NTSC co-channel interference
  - NTSC picture and sound carriers miss ADTV spectrum
  - reliable ADTV reception up to -2 dB D/U ratio
- NTSC-friendly operation
  - low ADTV power
  - ADTV spectrum misses NTSC sound carrier
  - HP carrier is attenuated by NTSC VSB filter

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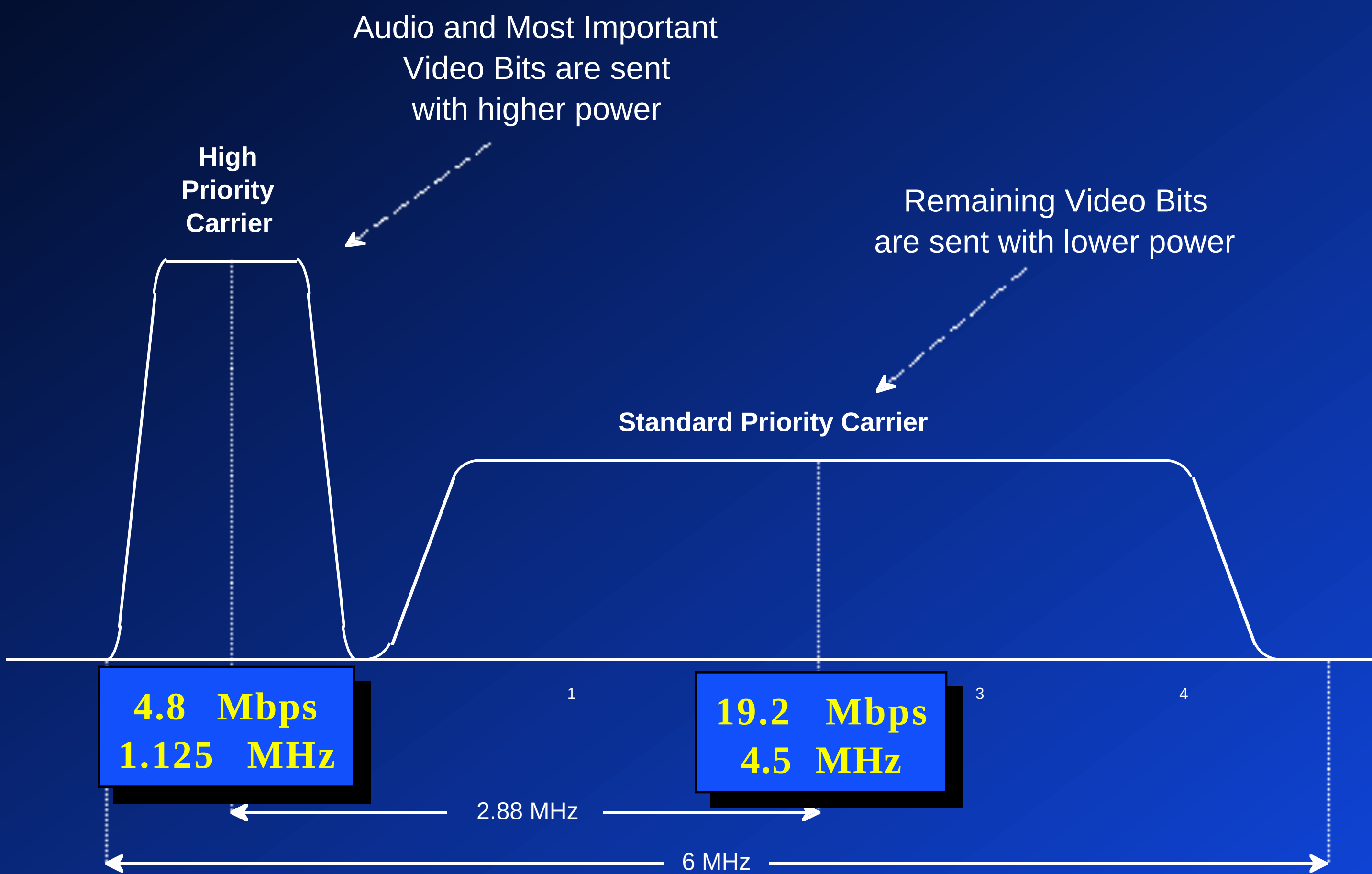
Spectrally-Shaped QAM Concept



- **Total data rate 24 Mbps**
- **Net data rate 18.5 Mbps**

Transmission Specifications

Spectrally Shaped QAM — two trellis coded 32-QAM carriers

High Priority Carrier

Symbol rate	0.96 MHz
Bandwidth	1.125 MHz
Data rate	4.8 Mbps (3.7 net)
Threshold CNR	11.1 dB

Standard Priority Carrier

Symbol rate	3.84 MHz
Bandwidth	4.5 MHz
Data rate	19.2 Mbps (14.8 net)
Threshold CNR	16.1 dB

Overall SS-QAM signal

Channel Bandwidth	6 MHz
Data rate	24 Mbps (18.5 Mbps net)
HP:SP power ratio	5 dB

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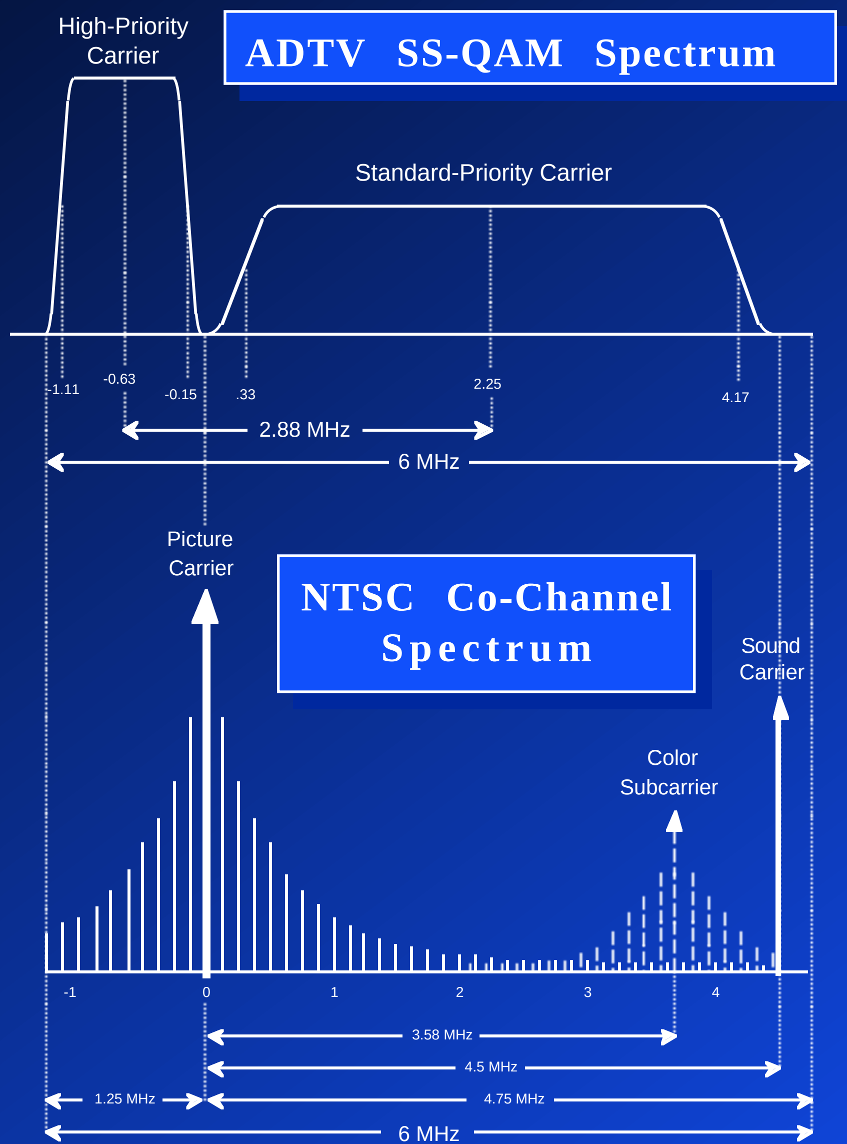
SS-QAM and NTSC Spectra



Noise Equivalent Factor

- NTSC VSB filter attenuates interfering signals in the first 1.25 MHz portion of the 6 MHz channel
- Noise or interference power in the lower sideband can be 12 dB higher than in other spectral areas, and produce subjectively equivalent impairment
- This allows average power of ADTV to be 1.4 dB higher than an equivalent 6 MHz random noise source

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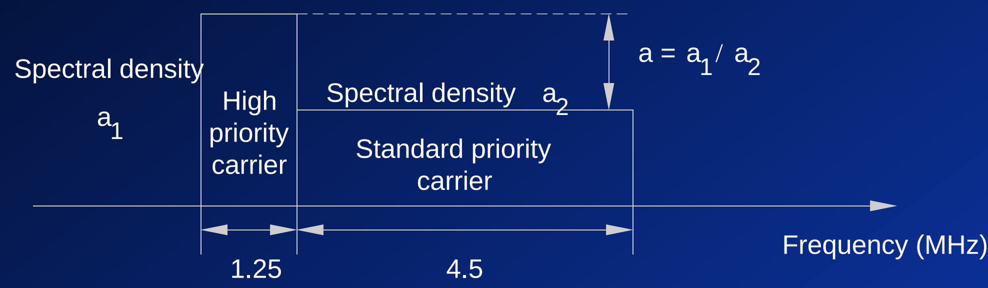
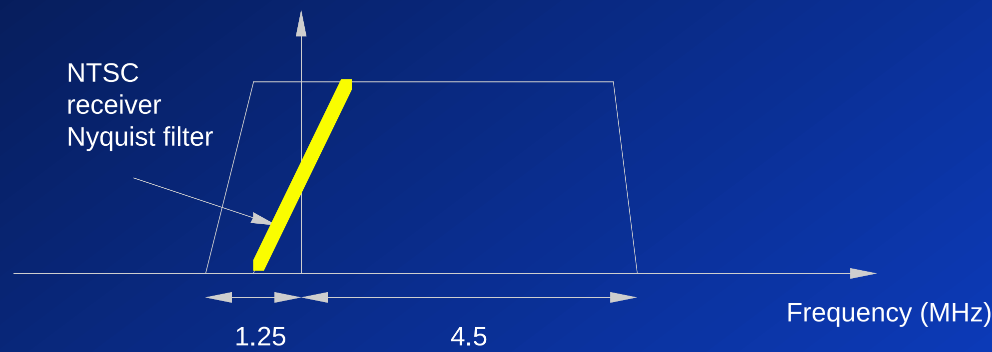
Effect of NTSC VSB Filter



(a) SS-QAM spectrum



(b) Cochannel NTSC spectrum

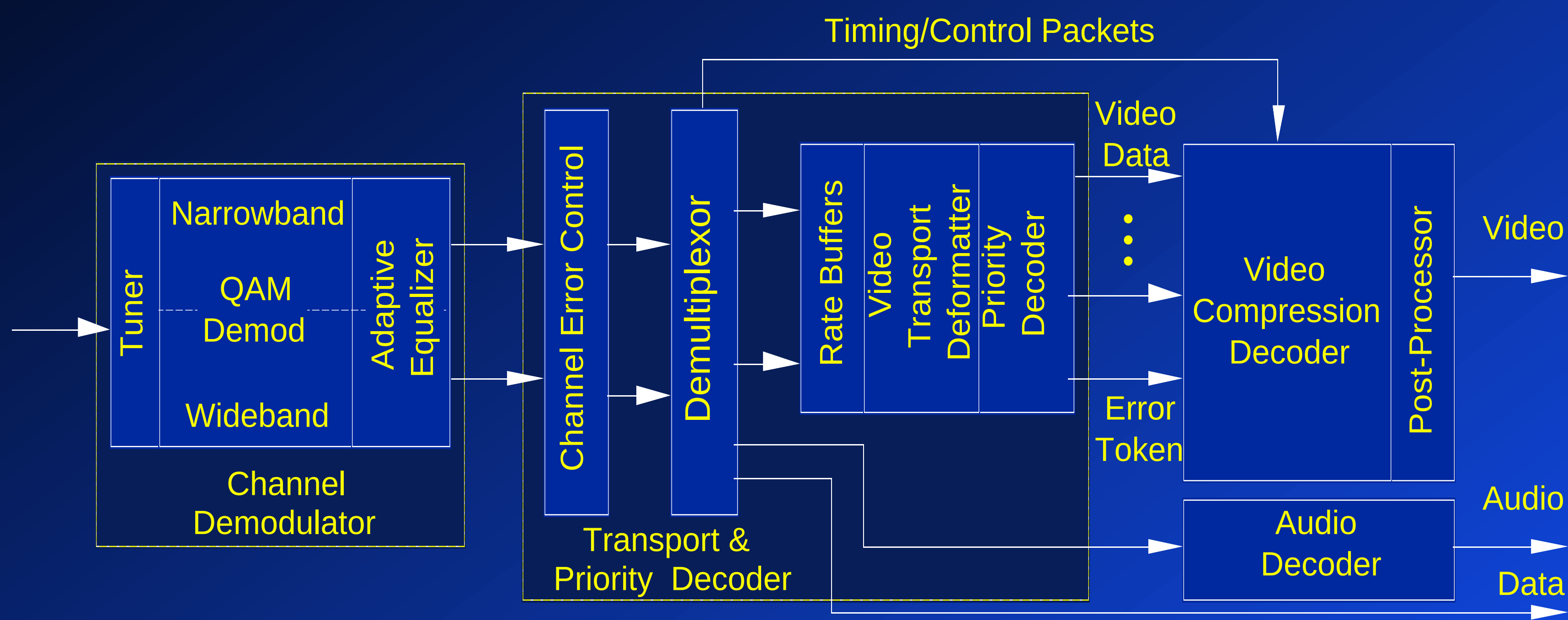
(c) High Priority carrier contribution to the NTSC baseband noise

(d) Standard Priority carrier contribution to the NTSC baseband noise

Transmission Robustness Summary

- MPEG++ prioritization produces a viewable picture in its High Priority data
- Program audio is always High Priority data
- High Priority video and audio data is delivered by the High Priority carrier in SS-QAM. This ensures that a viewable picture and high-quality sound remain available even under poor transmission conditions.
- Trellis coding provides an additional 3 db of coding gain, increasing the robustness of both HP and SP signals.

ADTV Receiver

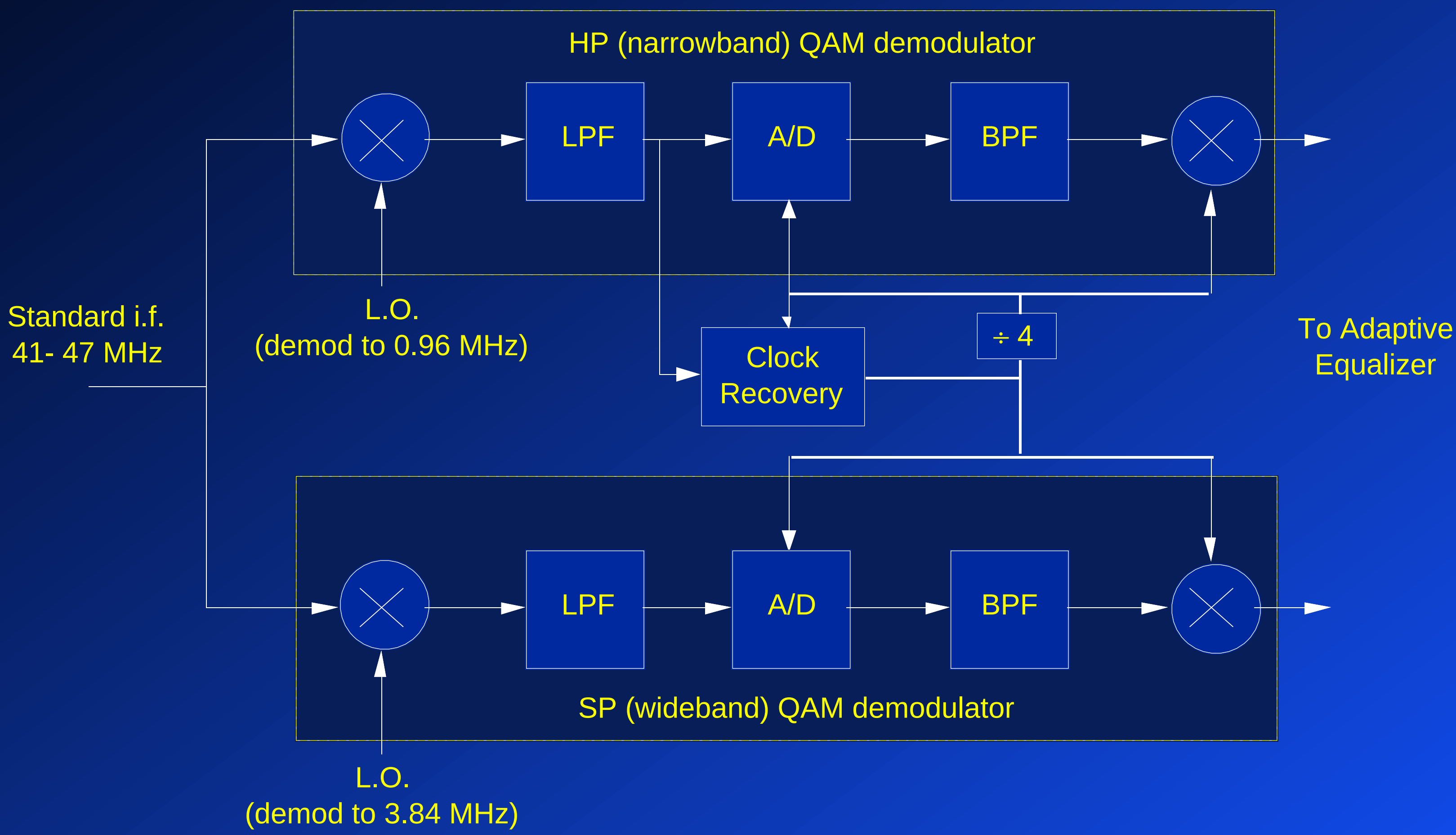


ADTV Receiver Robustness

Additional robustness is provided by the ADTV receiver:

- Carrier and clock recovery is derived from the higher power High Priority signal
- Cells with uncorrectable errors are discarded in order to ensure the integrity of all bits that are decoded by the receiver, protecting against gross artifacts
- ADTV receivers may implement error concealment approaches that will further hide the effects of losing the video data during transmission

SS-QAM Front End



Coverage Area

Coverage Area Introduction

- Precise specification of coverage area for a simulcast system requires tradeoffs to be made among simulcast coverage area, accommodation percentage, and the limits of acceptable interference into existing NTSC service

- These decisions are beyond the scope of a proponent

- Such tradeoffs are most appropriately made for the public good by the FCC and its Advisory Committee, in cooperation with the broadcasting industry

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Coverage Definition for Simulcast

- Applying NTSC coverage area rules (90% time availability at the fringe of the defined coverage area) without some additional condition on robustness is inappropriate for a digital system

- 90% time availability for full-quality HDTV service should be acceptable, IF...

- Sound and a viewable picture have very high (97-98%) time availability

- Increasing a signal's time availability from 90 to 97.7% requires 5 dB additional power density -- ADTV provides this margin by design

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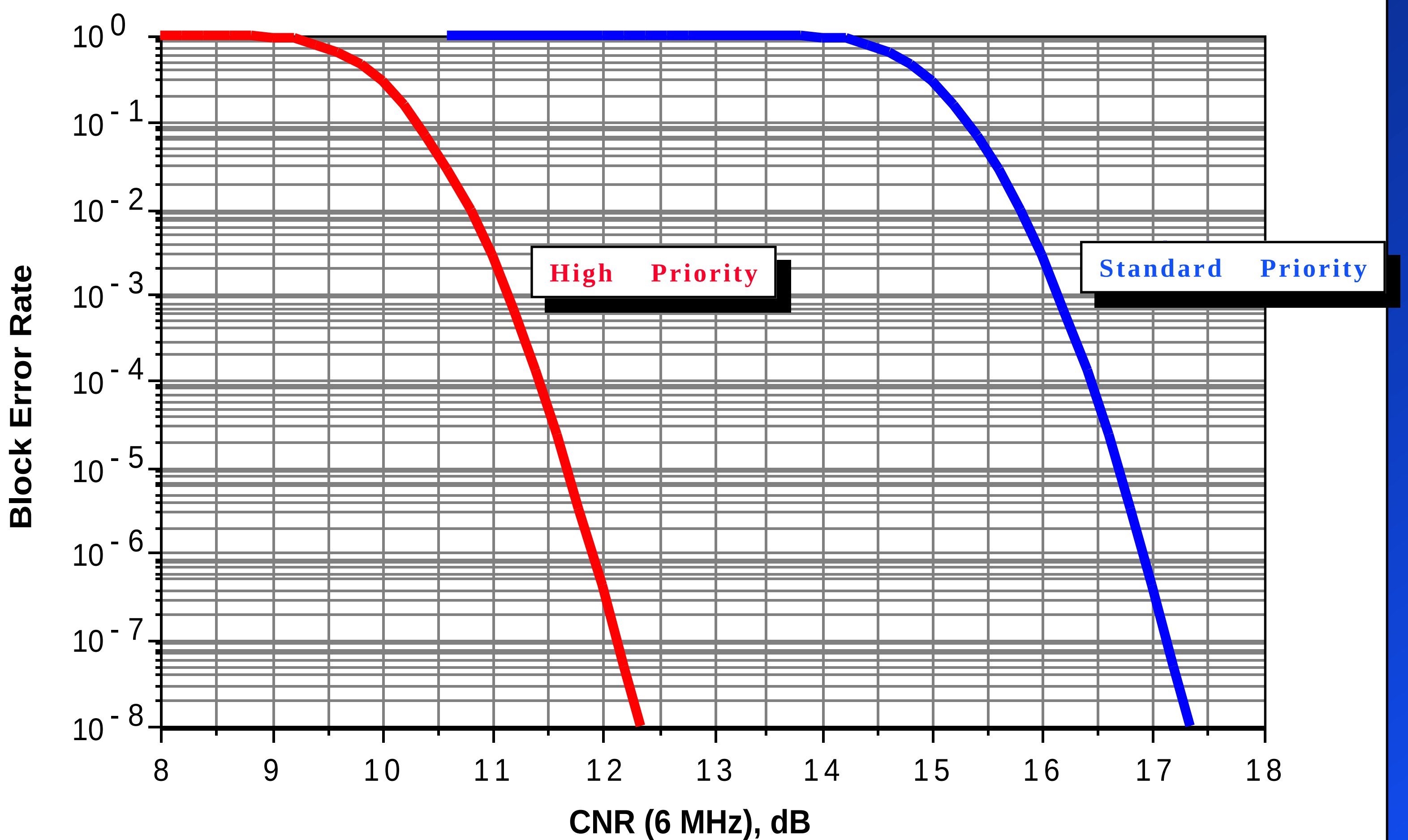
BER vs. CNR Performance



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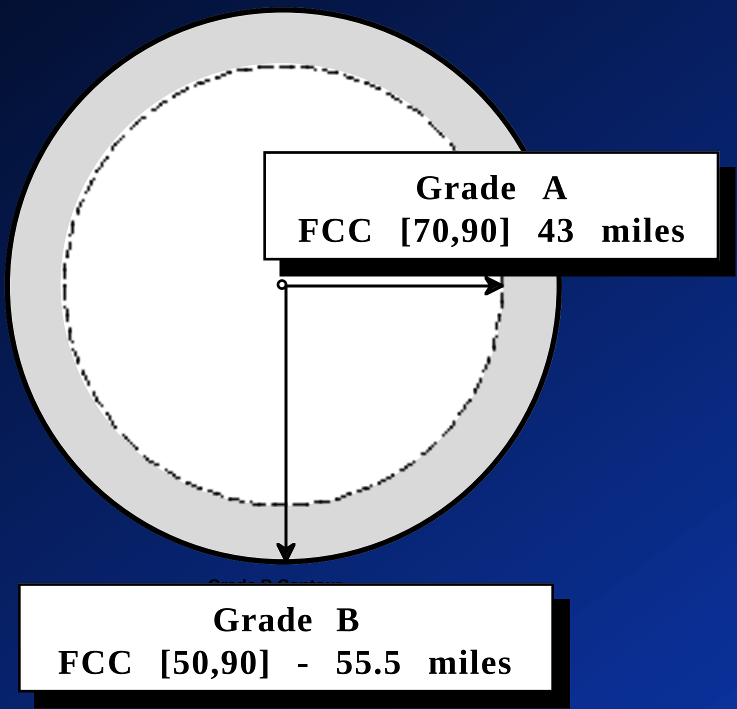
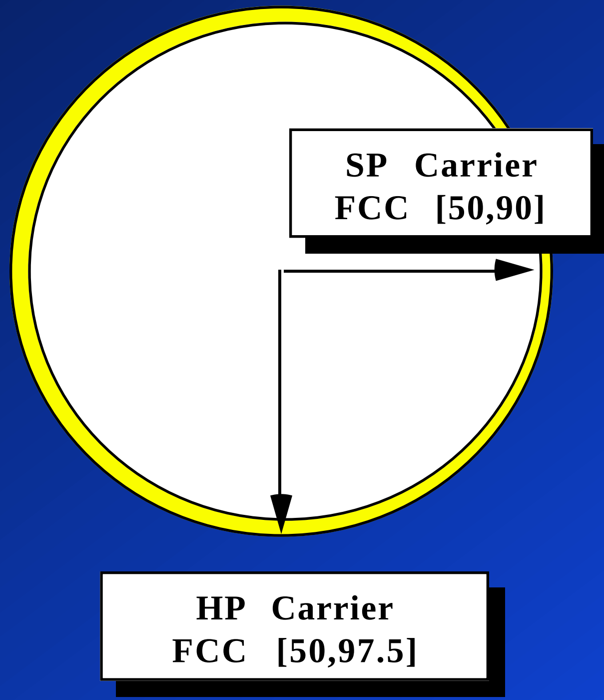
Coverage Area Strategy





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.

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.

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Coverage Area Parameters

- CNR required for full HDTV quality (16.1 dB)
- CNR required for viewable pictures and sound (11.1 dB)
- D/U ratio required to receive full-quality ADTV when interfered with by an NTSC co-channel station (-2 dB)
- D/U ratio required to receive full-quality ADTV when interfered with by an ADTV co-channel station (16.1 dB)
- Noise Equivalence factor - ratio of interfering signal power to random noise that results in an identical subjective impairment to NTSC (1.4 dB)

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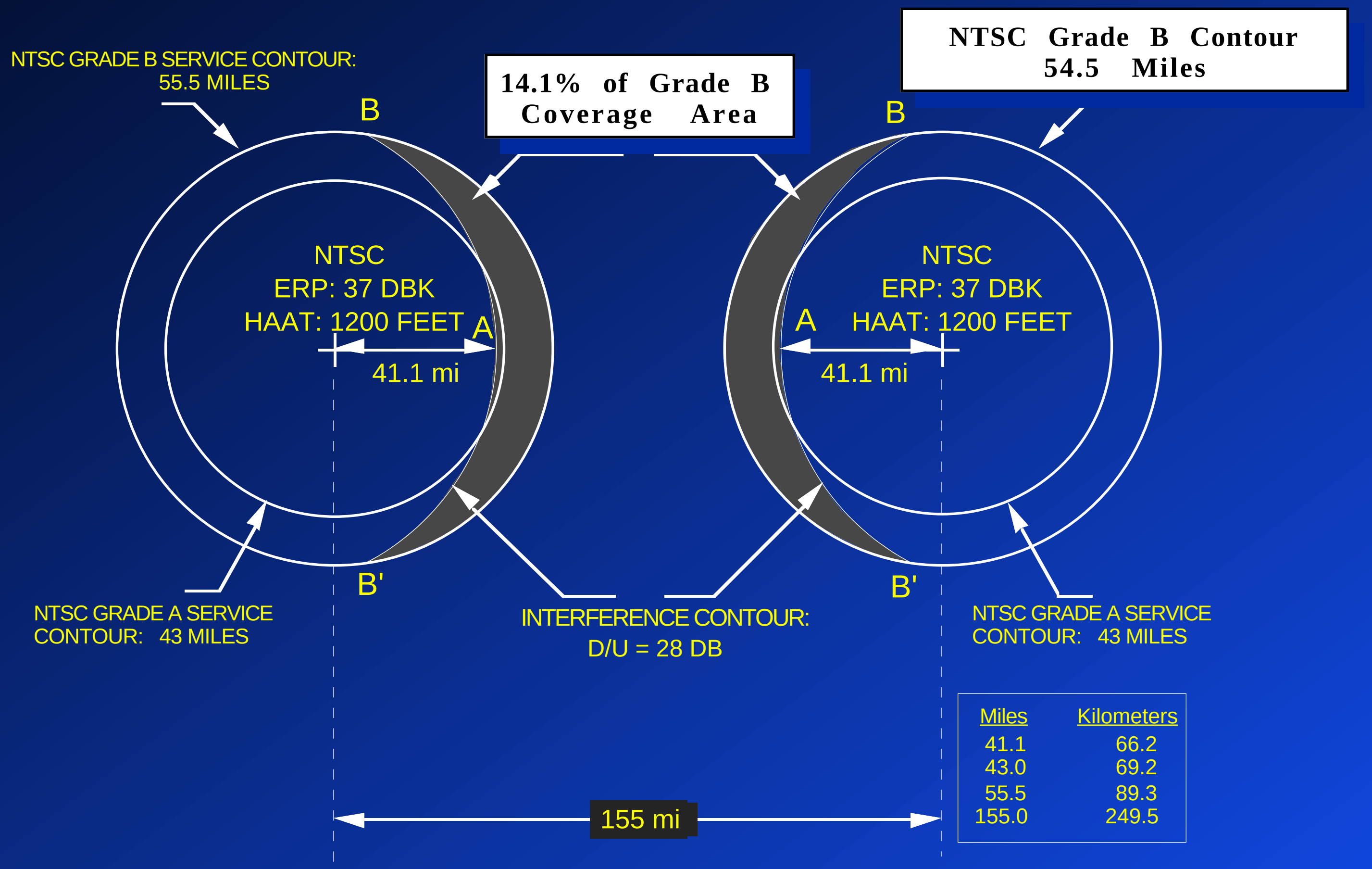
NTSC Coverage Area



Miles	Kilometers
41.1	66.2
43.0	69.2
55.5	89.3
155.0	249.5

Co-Channel NTSC Transmission with 155 Miles Station Separation.

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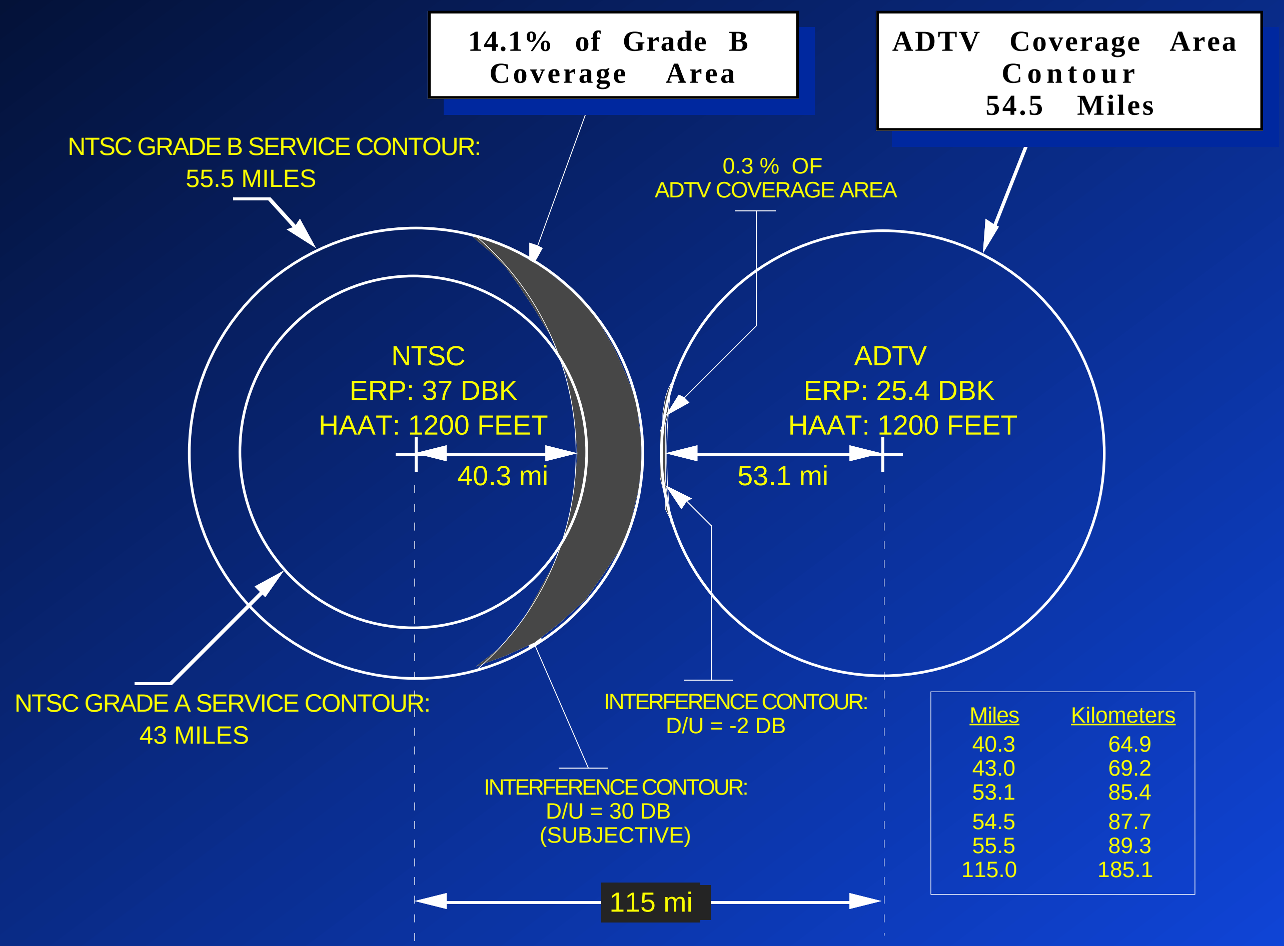
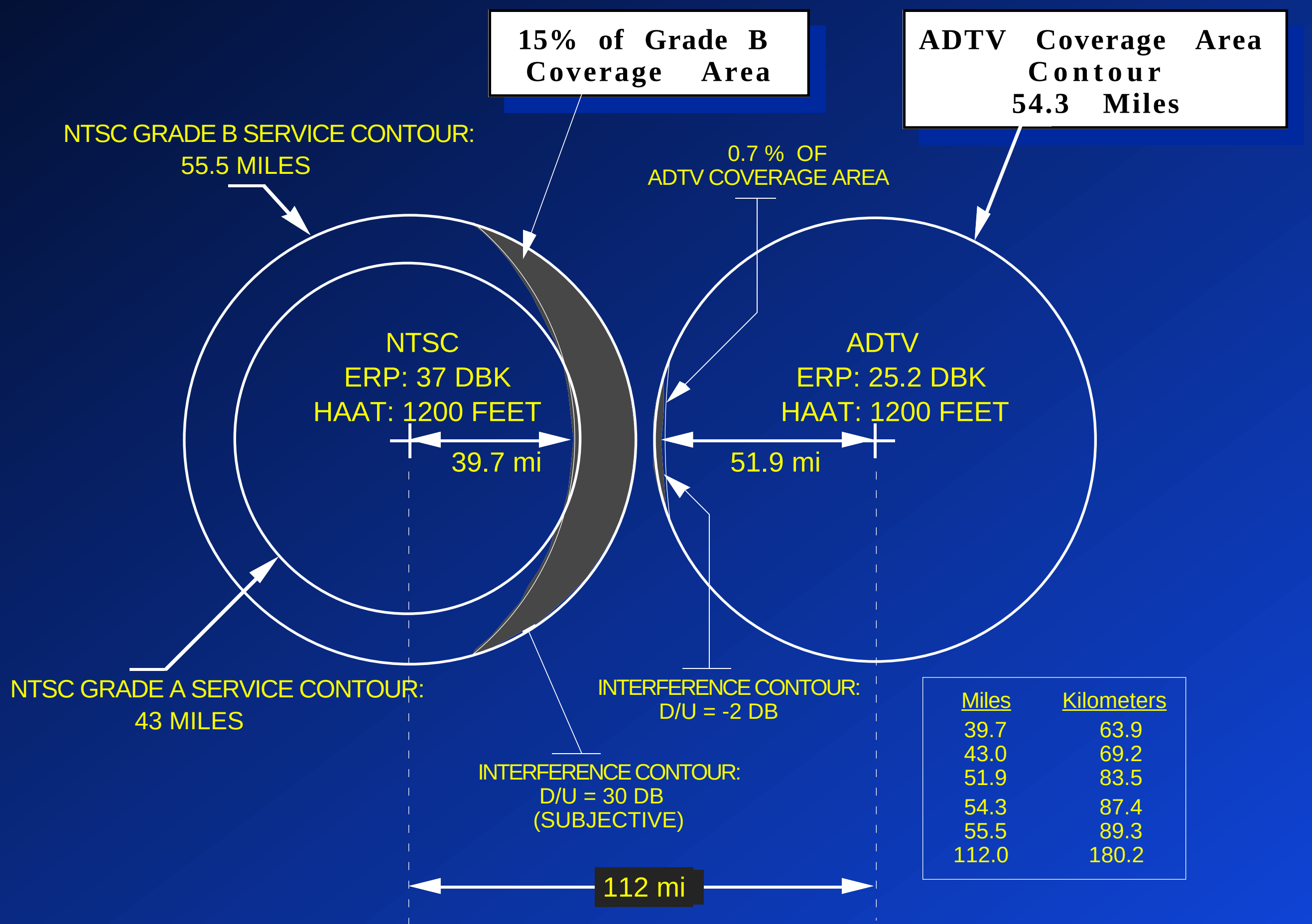
ADTV Coverage Area Example #1



Miles	Kilometers
40.3	64.9
43.0	69.2
53.1	85.4
54.5	87.7
55.5	89.3
115.0	185.1

NTSC and ADTV Co-Channel Transmission with 115-Mile Station Separation.

ADTV Coverage Area Example #2



Miles	Kilometers
39.7	63.9
43.0	69.2
51.9	83.5
54.3	87.4
55.5	89.3
112.0	180.2

NTSC and ADTV Co-Channel Transmission with 112-Mile Station Separation.

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Summary of Average Coverage Results

NTSC transmitter is assumed to have an ERP of either 37 dBK or 27 dBK, and the ADTV noise-limited contour distances have been computed for both of these cases, and then used to compute an average.

Minimum Separation	Accommodation Percentage	Coverage Radius (with 15% NTSC coverage area loss)	Coverage Radius (with 10% NTSC coverage area loss)	Coverage Radius (with 5% NTSC coverage area loss)
160 km (99.4 mi)	99.7 %	81.5 ± 0.5 (50.7 ± 0.3)	75.8 ± 1.2 (47.1 ± 0.8)	68.8 ± 1.9 km (42.8 ± 1.2 mi)
170 km (105.6mi)	98.8 %	84.7 ± 0.4 (52.6 ± 0.3)	78.9 ± 1.1 (49.0 ± 0.7)	71.9 ± 2.0 km (44.7 ± 1.3 mi)
180 km (111.9mi)	98.4 %	87.7 ± 0.5 (54.5 ± 0.3)	81.8 ± 1.0 (50.8 ± 0.6)	74.9 ± 1.8 km (46.5 ± 1.1 mi)
190 km (118.1mi)	96.6 %	90.9 ± 0.6 (56.8 ± 0.4)	84.7 ± 1.2 (52.6 ± 0.7)	77.6 ± 1.7 km (48.2 ± 1.1 mi)
200 km (124.3mi)	95.8 %	94.3 ± 0.6 (58.6 ± 0.4)	87.8 ± 1.4 (54.6 ± 0.9)	80.5 ± 1.9 km (50.0 ± 1.2 mi)
210 km (130.5mi)	93.1 %	97.5 ± 0.4 (60.6 ± 0.3)	90.9 ± 1.2 (56.5 ± 0.8)	83.5 ± 2.0 km (51.9 ± 1.2 mi)

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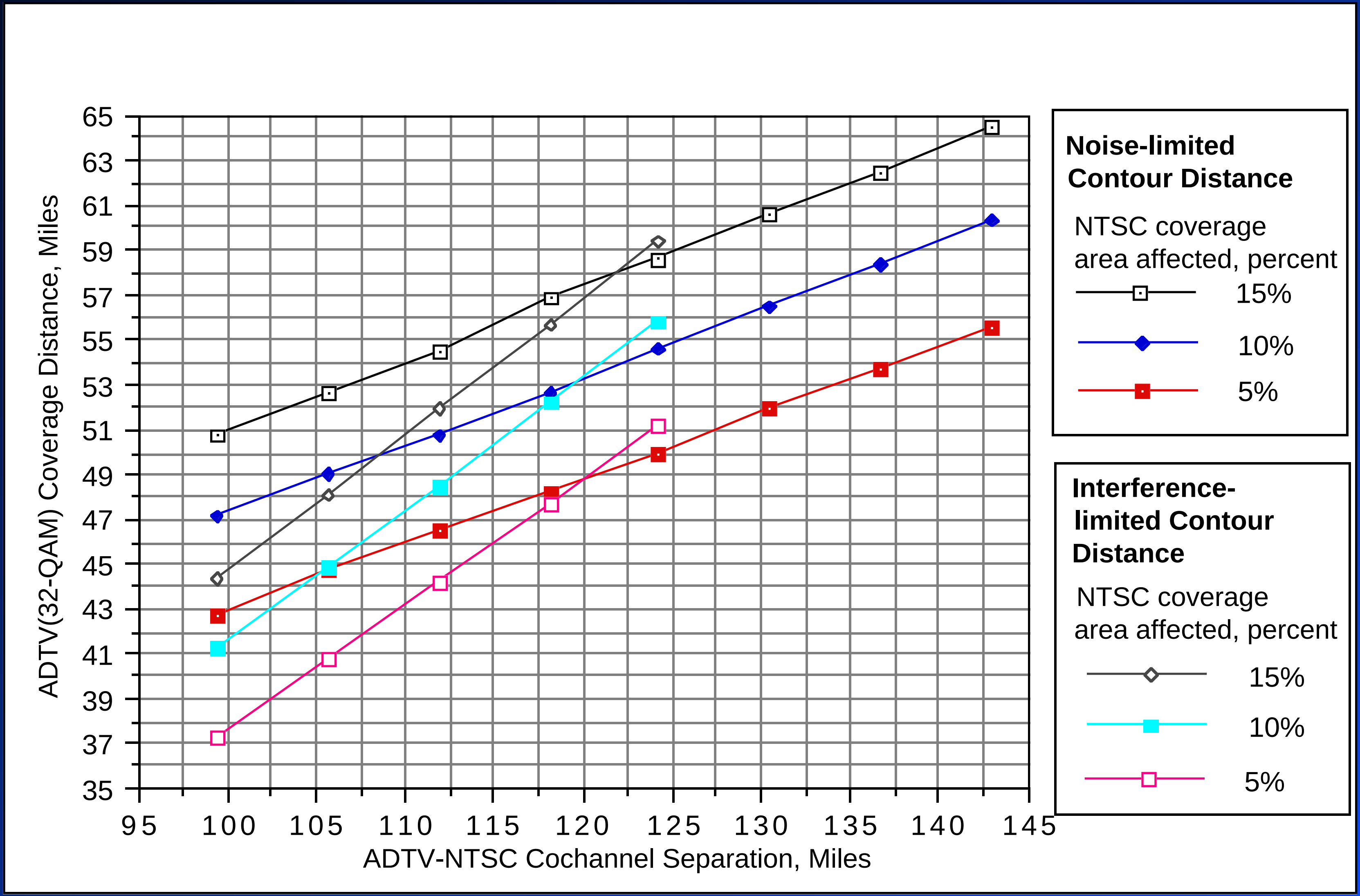
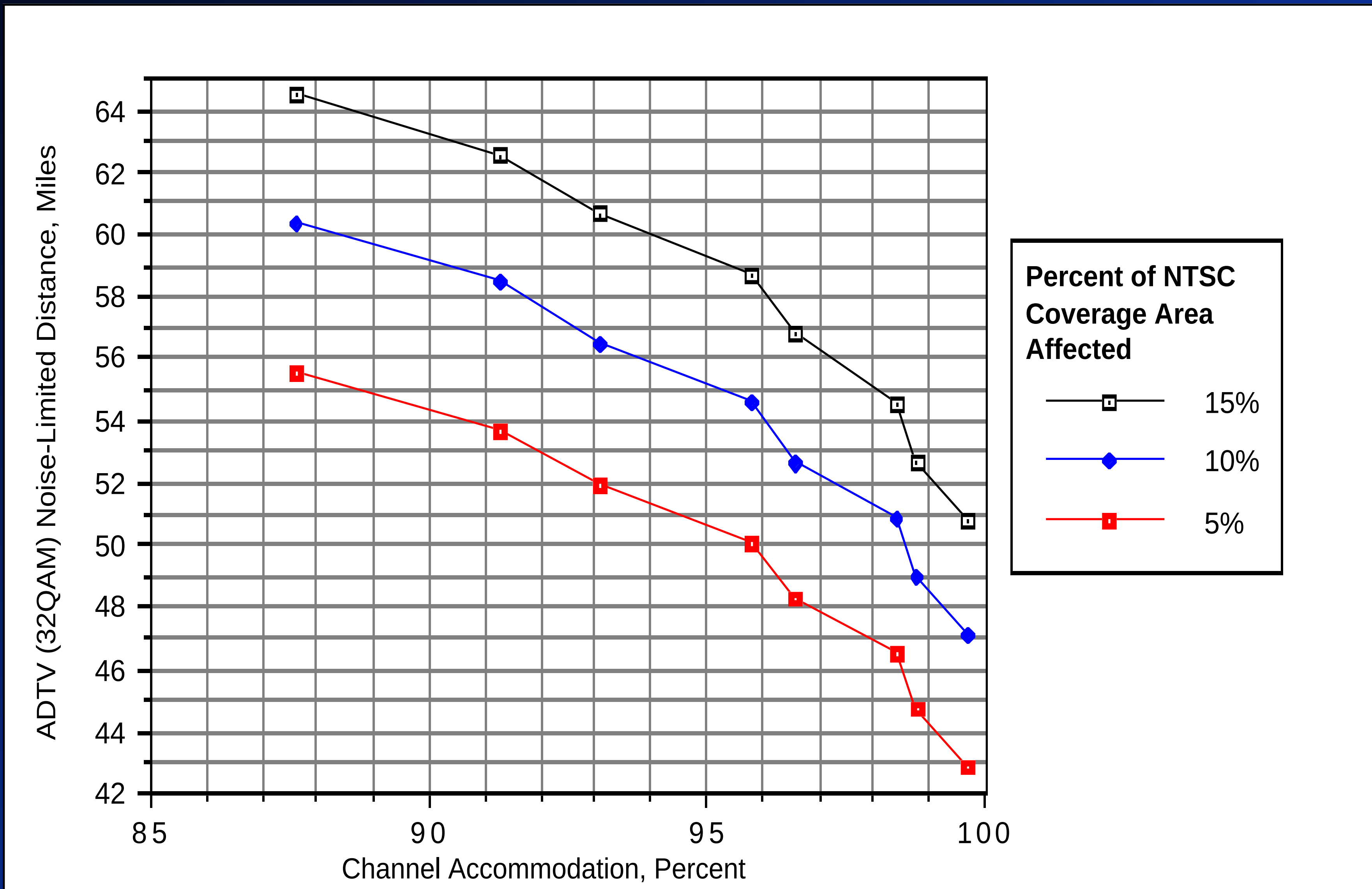
Coverage vs. Co-Channel Spacing



Coverage vs. Accommodation



16-QAM Option

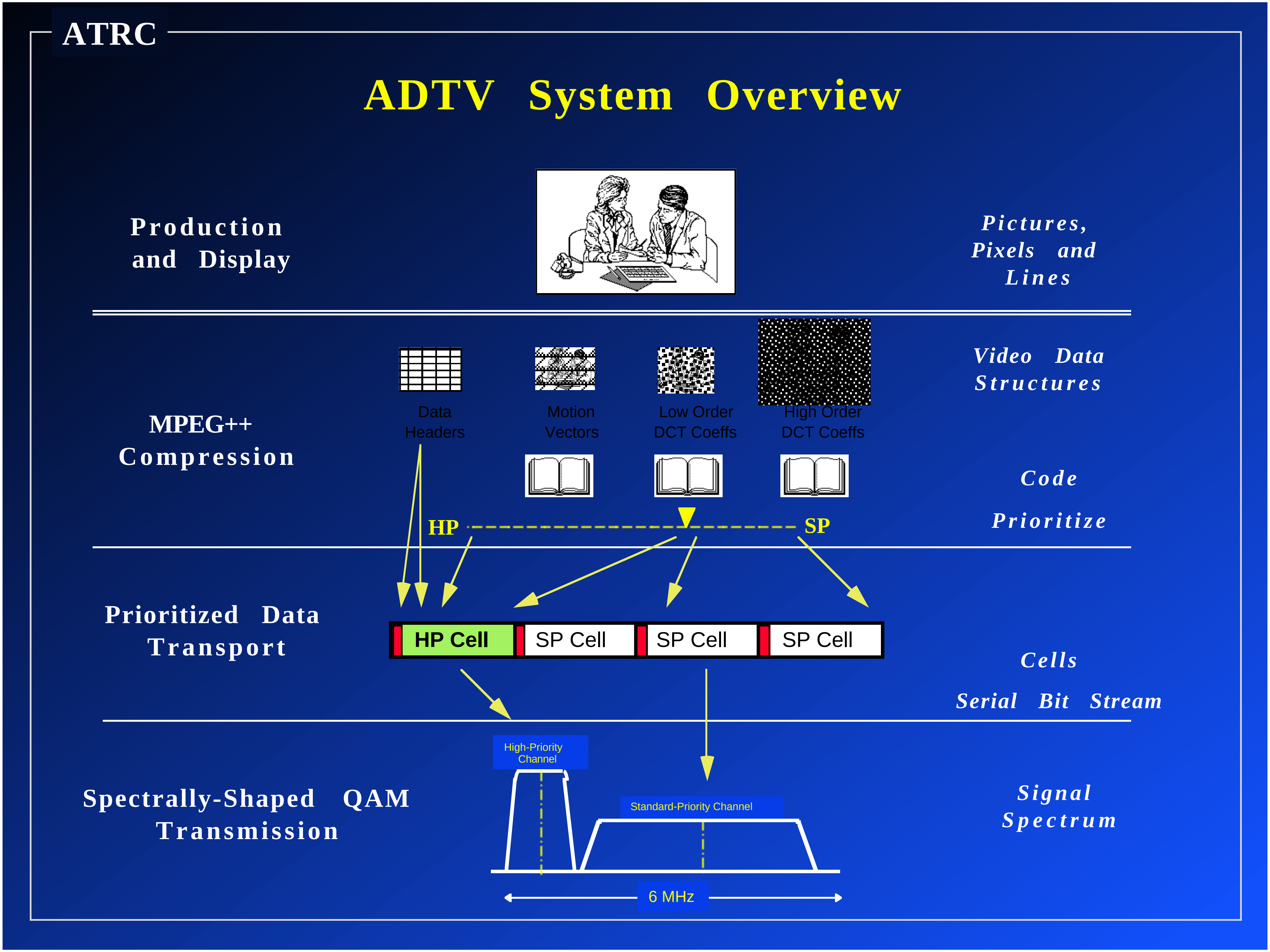
Broadcasters in especially difficult co-channel situations can reduce their coverage area, or they can slightly reduce their picture quality and select ADTV's 16-QAM option.

- Threshold CNR of the Standard Priority carrier is reduced from 16.1 dB to 13.6 dB (2.5 dB improvement).
- Threshold CNR of the High Priority carrier is reduced from 11.1 dB to 8.6 dB (2.5 dB improvement).
- D/U ratio required for SP reception (with an NTSC co-channel interferor) is improved from -2 dB to -4 dB. D/U ratio required for HP reception is improved from about -6 dB to about -8 dB.
- D/U ratio required for SP reception (with an ADTV co-channel interferor) is improved from 16.1 dB to 13.6 dB.
- There is no change in the Noise Equivalent advantage factor of 1.4 dB.

Coverage Area Conclusions

- Average coverage area results indicate that a noise limited range of 55.5 miles can be provided with a co-channel spacing of 115 miles (97.5% accommodation)
- Broadcasters in especially difficult co-channel situations can reduce coverage area, or they can slightly reduce their picture quality and use ADTV's 16-QAM option. Average coverage area results indicate that this provides a noise limited range of 55.5 miles with a co-channel spacing of 105.6 miles (98.8% accommodation)
- 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 provides coverage area that is superior to NTSC in situations where co-channel constraints are not present.

Summary



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ADTV System Overview
Production and Display
Pictures, Pixels and Lines
MPEG++ Compression
Data Headers
Motion Vectors
Low Order DCT Coeffs
High Order DCT Coeffs
Video Data Structures
Code
HP
SP
Prioritize
Prioritized Data Transport
HP Cell
SP Cell
SP Cell
SP Cell
Cells
Serial Bit Stream
Spectrally-Shaped QAM Transmission
High-Priority Channel
Standard-Priority Channel
6 MHz
Signal Spectrum

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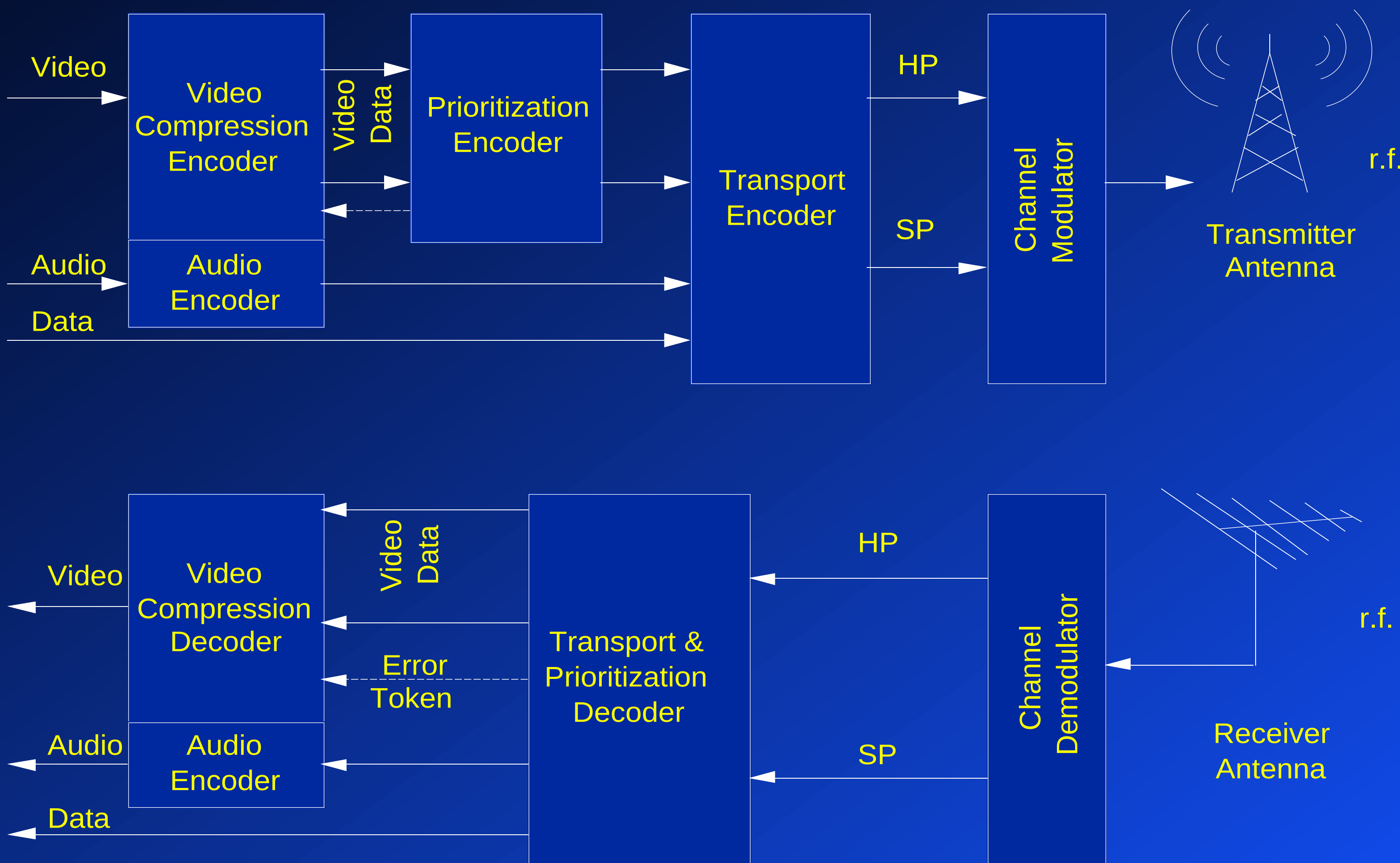
ADTV System Block Diagram



Interoperability

- Two video formats (and additional MPEG flexibility)
  - 1440 x 960 perceptually square display pixels
  - 1440 x 810 provides logically square image pixels
- Interlaced & progressive scan - frame based coding
  - 1050/2:1/59.94 HDTV
  - 1050/1:1/24 film
  - 1050/1:1/29.97 "mixed-production"
- MPEG-based compression provides the possibility of direct interchange of compressed data among HDTV and multimedia applications
- ADTV provides interoperability at any of its layers

Extensibility

- Flexibility in the mix of video, audio and data
  - there are no predetermined data rates
- The service mix can be dynamically allocated
  - well-suited to multimedia applications
  - can fundamentally change the nature of TV programming
- Open-ended extensibility
  - receivers disregard cells of inappropriate service types
  - no backward-compatibility burden for new applications
  - can compatibly introduce new features and services

Low Cost

- Standards are the most important factor in reducing cost
  - single decoder for the consumer
  - production volumes and economy of scale
- Memory is already commodity-priced. ADTV's format allows a frame to be stored in a 16 Mbit DRAM
  - these are predicted to cost about $13 each in 1996
- MPEG was designed for digital storage media -- it is a good basis for VCR
  - periodic I-frames allow search modes and random access
- Prioritized Data Transport format is similar to B-ISDN
  - opportunity to use B-ISDN interface ICs

ADTV Features

- **Multiple video formats that:**
  - support both film and HDTV production
  - support both television and computer applications (both interlaced scan and progressive scan/square pixels)
- **Data compression that:**
  - achieves outstanding picture and sound quality
  - is compatible with international standards
  - is practical for broadcasting (survives uncorrectable bit errors)
- **Digital transmission that:**
  - provides a high 24 Mbps data rate
  - is immune to NTSC interference and friendly to existing stations
  - provides a large coverage area (comparable to NTSC)
  - provides reliable fringe area service
- **A system that:**
  - has a broad scope of services
  - has interoperability with film and computers
  - has extensibility for future growth