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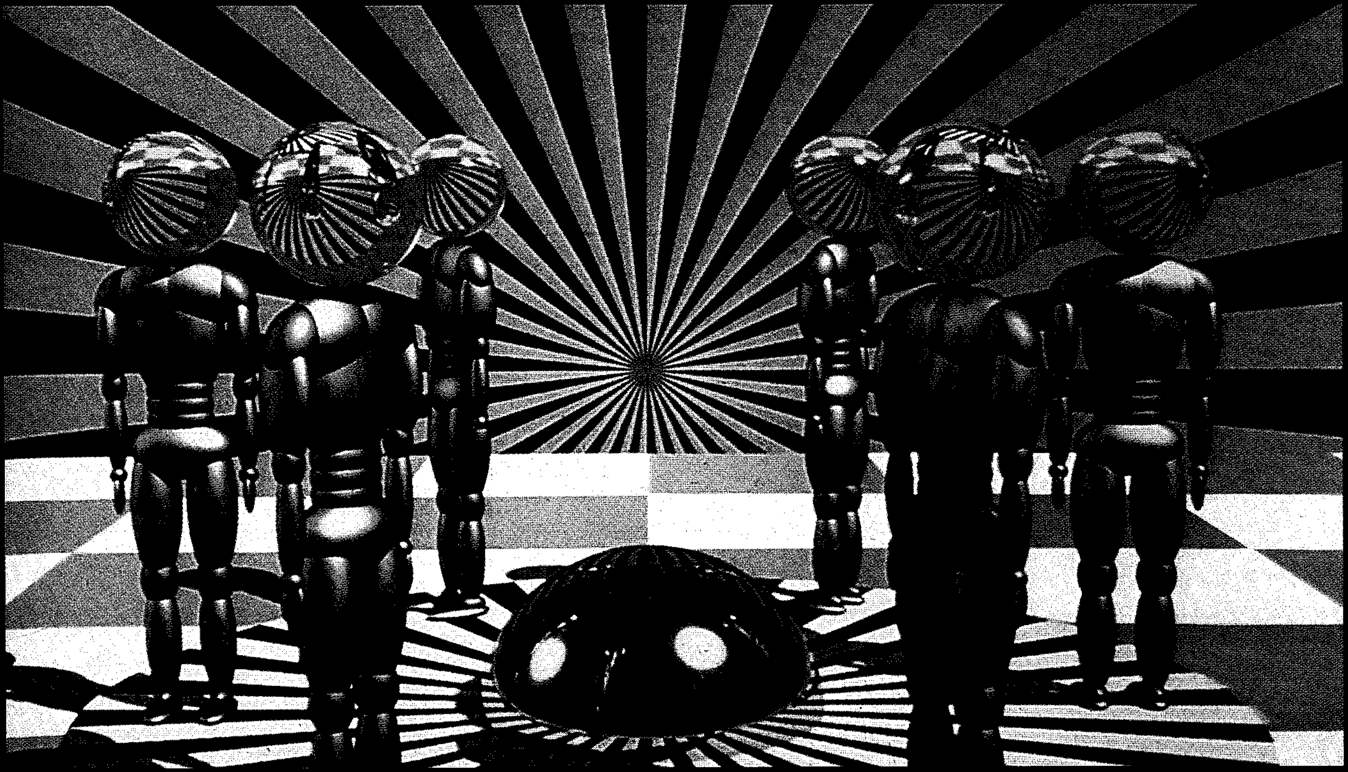

DIGITAL SPECTRUM COMPATIBLE

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TECHNICAL DESCRIPTION

DIGITAL SPECTRUM COMPATIBLE

Cover: "Carousel" by Don Mitchell of AT&T Bell Laboratories — computer-generated synthesized video images designed to challenge the Zenith-AT&T high-definition video compression system with very complex motion simulations.

February 22, 1991

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SECTION 1
GENERAL INTRODUCTION AND COMMONALITY WITH PREVIOUS ANALOG/DIGITAL SC-HDTV SYSTEM

1.1 Summary

The Digital Spectrum-Compatible HDTV System (DSC-HDTV) is very closely related to and is a natural extension of, the previous analog/digital (A/DSC-HDTV) system. A new effective system has been devised to reject NTSC cochannel interference into the DSC-HDTV channel which will result in an HDTV service area equal to that of an NTSC broadcast station while radiating at least 12 dB less power. The transmission signal now has a more noise-like character which has further reduced the visibility of interference into a NTSC channel. The simulcast feature in a 6 MHz band, the NTSC-like transmission signal timing and the low power are all retained.

It is foreseen, as before for A/DSC-HDTV, that the current Taboo channels can supply every current TV broadcast station with an extra channel for DSC-HDTV if certain interference conditions can be met (see Section 3).

The DSC-HDTV transmitter will not only operate with less power but also without aural transmitter, without notch diplexer and with a smaller antenna.

New algorithms have been developed to achieve the video compression needed for robust transmission without sacrificing image quality (see Section 2).

1.2 Why All-Digital?

The reason for conversion from partially digital to all-digital transmission is found in the improved displayed picture throughout a station's service area. Digital transmission renders a picture essentially free of thermal noise or "snow". Other picture impairments are avoided by forward error correction using a Reed-Solomon code and by automatic ghost canceling/channel equalization.

There are a number of other all-digital benefits:

- more flexible and better bandwidth compression;
- noise free tape recording in studio and home;

- no noise, interference, or ghost accumulation from cascaded processing and/or cascaded transmission segments;
- synergy with other communication and computer equipment

1.3 Why Spectrum-Compatible Digital?

1.3.1 Better Resolution.

Transmits 1,575 horizontal picture lines 30 times per second for more lifelike moving pictures than competing systems based on 1,125 or 1,050 lines in the same timeframe.

- Creates a completely new HDTV picture 60 times a second for more detail in fast-moving images (such as live sports action) than competing systems that transmit a complete picture 30 times a second.

- Uses progressive-scanning to eliminate jagged edges and other motion artifacts that degrade picture performance of interlace-scanned systems.

1.3.2 Square Pixels.

Uses square picture elements for easy graphical interfacing with computer workstations and improved performance in producing television special effects, such as rotating graphics.

1.3.3 Unique Compression Technology (See Section 2).

Uses a unique video compression system that squeezes 34 MHz of television picture information into a single 6 MHz channel. Unlike other approaches, this system offers:

- Full high-definition picture resolution even with live, 60-frame-per-second rapid motion scenes.
- No temporary loss of picture resolution when changing channels.

1.3.4 Unique Transmission Technology (See Sections 3-6).

Uses a unique transmission system that eliminates interference with conventional TV channels in the same service area and provides wide HDTV coverage of snow-free performance, even in fringe reception areas.

- Prevents interference <u>from</u> the relatively strong conventional signal by using unique digital filtering technology in the HDTV receiver.

- Prevents interference <u>into</u> conventional TV signals by using low-power transmission. Reduces transmission power by at least 12 dB and, at the same time, **provides HDTV signals to service areas equal to or greater than today's TV signals.**

1.3.5 Cost-Effective for Consumers.

Places more integrated circuit "intelligence" at the transmitter, which will result in more affordable HDTV receivers than other systems. HDTV sets based on the Spectrum-Compatible system are expected to sell for about $700 over prices for conventional TVs.

1.4 <u>Relation to A/DSC-HDTV.</u>

The system change is less radical than may be presumed and can be explained as follows:

Previously, the video portions transmitted in analog form by double-sideband suppressed-carrier amplitude modulation in quadrature were actually processed, before transmission, in digital form. The final stage in this process did, in fact, deliver a pulse-amplitude modulated (PAM) signal.

The current DSC-HDTV system transmission signal again uses a PAM signal except that the number of possible amplitudes is limited to four, thus constituting a four-level digital symbol.

Compared to continuous amplitude variation, a reduction to four levels provides immunity against thermal noise and other impairments.

1.5 <u>Scanning Standards.</u>

The source and display scanning standards of A/DSC-HDTV have been retained. They consist of progressively scanned 787.5 lines/frame, 59.94 frames/second video signals, corresponding to 1575 lines in 1/29.97th of a second. The aspect ratio is 16:9 and the horizontal line rate is 47.203 kHz, three times that of NTSC. The nominal video baseband signal bandwidth is still 34 MHz. (With a Kell factor of 0.9 for progressive scan and a sampling rate of 75.3 MHz the nominal video bandwidth equals 0.9 x 75.3/2 = 33.9 MHz.)

Transmitter and receiver signal processing are performed on square pixels in a 720 line by 1280 pixel array. In the studio, an additional guard band of pixels at all four edges is provided to allow for transient effects of processing, analog rise times, production related edge effects and timing tolerances.

Square pixels are chosen to facilitate computer interface and special effects processing. The particular numbers offer easy conversion to/from NTSC for simulcast purposes. Conversion to 525 line CCIR 601 requires only a 4:3 interpolation horizontally and 3:2 vertically. In addition, the simple relationship to NTSC provides economical means for designing dual purpose HDTV/NTSC receivers.

Progressive scanning has advantages in video compression and display of motion without line pairing or resolution loss. The 1280 by 720 format is simply related to the Common Image format by a linear factor of 2:3 and is easily extensible to higher-line-number progressive formats when they become practicable. The data rate generated by this format is within the range of commercial high definition tape recorder technology.

1.6 Colorimetry.

The initial test hardware will accept red, green and blue input signals with colorimetry according to SMPTE 240M and also will deliver R, G, B signals suitable for a display with SMPTE 240M colorimetry. Internally, the primary signals are linearized and converted to constant-luminance form before being coded for transmission by matrixing to Y, U and V. The U and V color difference components are bandlimited to 17 MHz, one half of the Y luminance component bandwidth of 34 MHz. Because the linearization is already present for constant-luminance reasons, it is relatively easy to include the matrixing required for any set of transmitter or receiver primaries; thus the system is designed to handle a possible wider color gamut with display-independent transmission. Future encoder hardware with sufficient A/D converter bit resolution will be able to accept linear R, G, B signals directly.

1.7 Constant Luminance.

The constant-luminance processing allows use of transfer curves which are optimized in terms of quantization error and/or coding artifact visibility. This makes the transfer curves ideal for use in studio recording. Similarly, the gamma correction for the display CRT occurs in the receiver and is optimized for the particular display. The digital circuits which will be developed to perform the dematrixing and gamma correction for consumer receivers will provide the economical solution to include this processing in all HDTV monitors and will provide the color conversion necessary for NTSC simulcast as well.

1.8 Alternate Delivery Means.

The DSC-HDTV system is adaptable to all the current alternate delivery means of Cable, Satellite, VTR, VCR, Video Disc and Fiber. The complete television signal, including video, chroma, audio, ancillary signals, decoder box address, and encryption information is encoded into one 6 MHz bandwidth signal. The alternate delivery means require only current technology, electrical as well as mechanical.

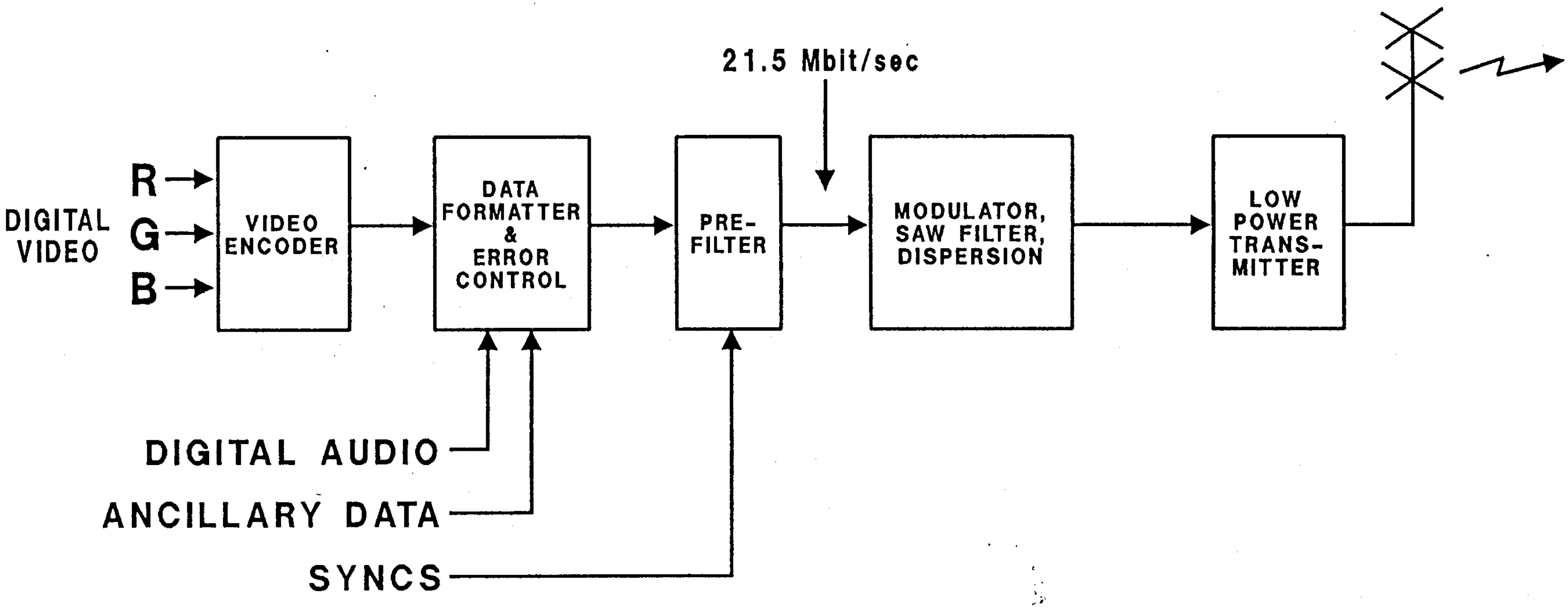
1.9 Transcoding.

The NTSC-related transmission signal timing and the progressive scan of DSC-HDTV facilitate transcoding to NTSC when required for simulcast broadcasts.

Because of the simple relationship between DSC-HDTV and NTSC, upconverting to the DSC-HDTV format requires line-tripling and video encoding and can be achieved without loss of NTSC quality.

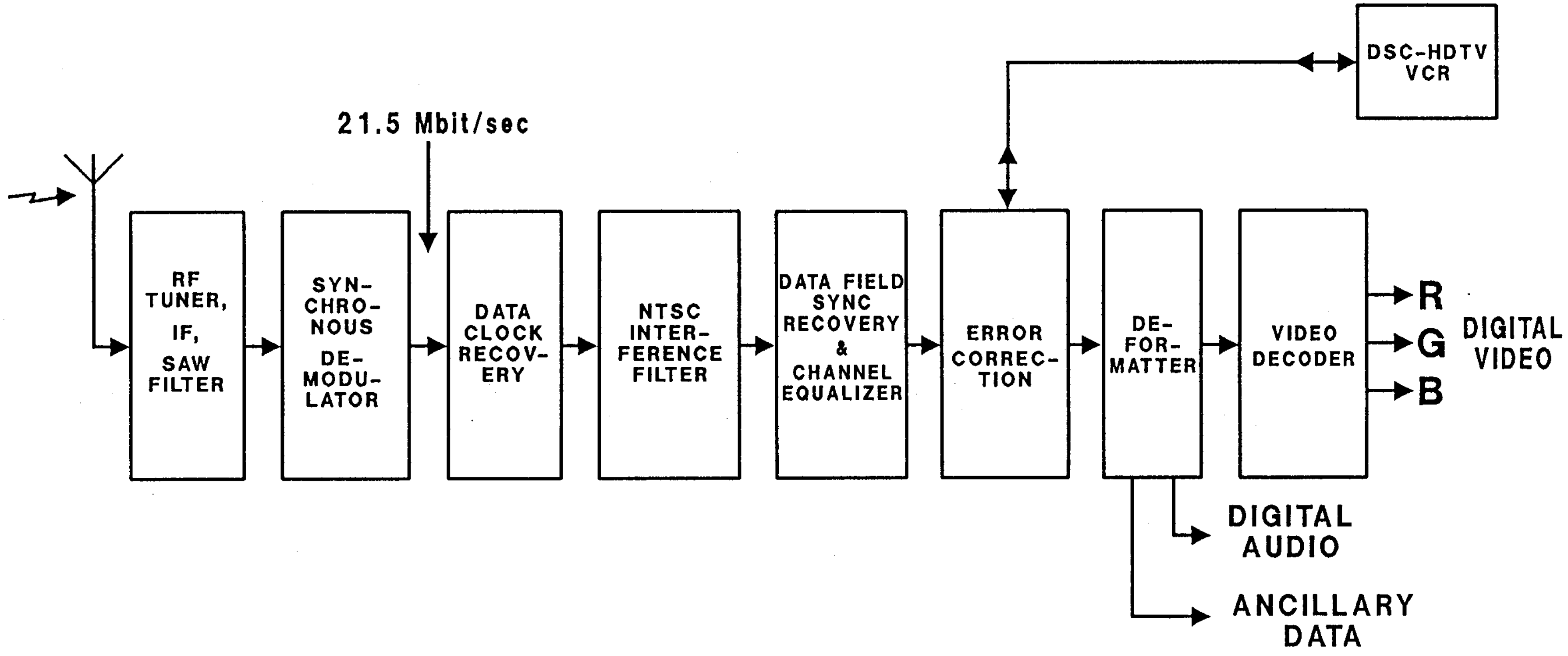
1.10 Block Diagrams.

The block diagrams of Figure 1-1 and Figure 1-2 show the main building blocks in transmitter and receiver, respectively, and will be discussed in later sections.



TRANSMITTER BLOCK DIAGRAM

FIGURE 1-1



RECEIVER BLOCK DIAGRAM

FIGURE 1-2

SECTION 2
VIDEO COMPRESSION

2.1 Introduction.

The video compression algorithm used in the DSC-HDTV system achieves the compression needed for robust transmission without sacrificing the image quality. The algorithm was designed for practical implementation and will result in a Decoder which is realizable in a small number of VLSI chips.

Motion compensated transform coding exploits both the temporal and spatial redundancy present in the HDTV signal. Temporal redundancy is removed by estimating the motion of objects from frame to frame using hierarchical block matching. Using the motion vectors, a displaced frame difference (DFD) is computed and transformed using a two dimensional transform to remove the spatial redundancy. Each new frame of DFD is analyzed prior to coding to determine its rate versus perceptual distortion characteristics and the dynamic range of each coefficient. Quantization of the transform coefficients is performed based on the perceptual importance of each coefficient, the precomputed dynamic range of the coefficients and the rate versus distortion characteristics. The perceptual criterion uses a model of the human visual system in order to determine the sensitivity to color, brightness, spatial frequency and spatial-temporal masking. This information is used to equalize and minimize the perception of coding artifacts throughout the picture. Parameters of the Coder are optimized to handle scene changes that occur frequently in entertainment/sports events and channel changes made by the viewer. The motion vectors, compressed transform coefficients and other coding overhead bits are packed into a format which is highly immune to transmission errors. In case of transmission errors, the Decoder uses a recovery technique which masks the errors. If loss of signal is detected or the channel is changed, the decoder switches to a special mode which quickly builds the picture to full quality.

In choosing the video compression algorithm the need for feasibility and low cost was considered. Particular attention has been given to minimizing the Decoder circuits that will be part of every HDTV receiver. Some elements of the encoding algorithms that affect picture quality can be altered without requiring modifications to the Decoder. This feature provides an opportunity for future improvement without affecting the installed base of equipment.

2.2 Encoder.

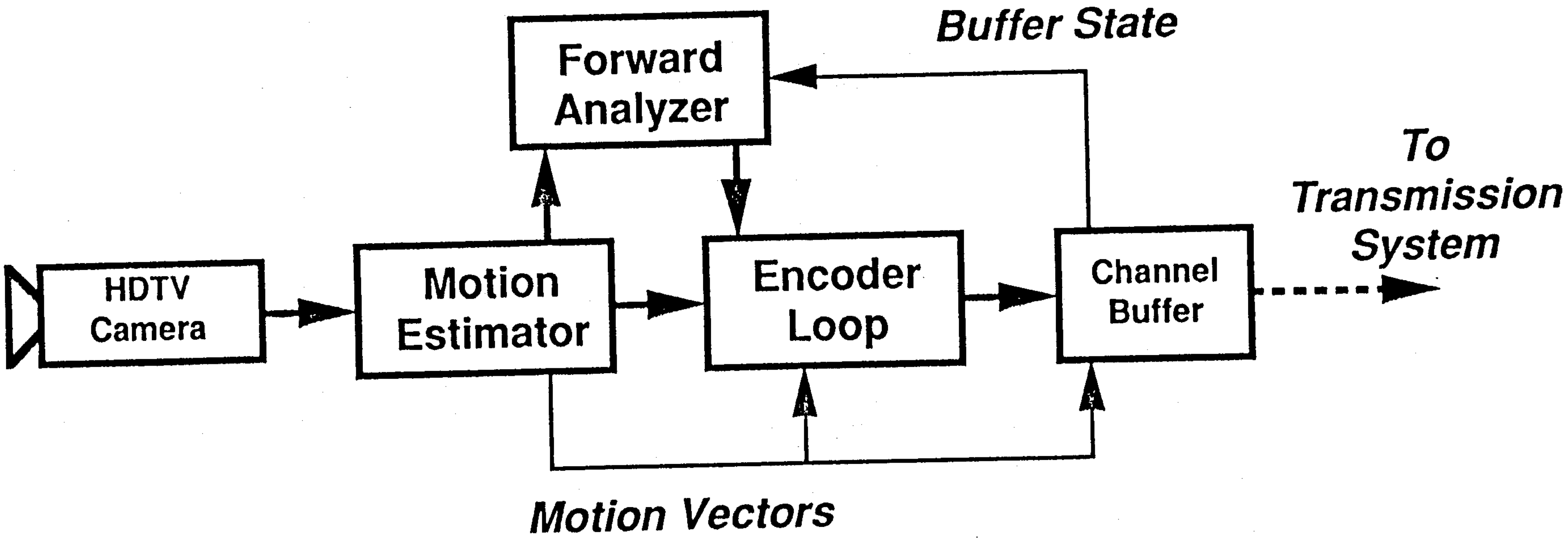
The encoder is shown in Figure 2-1. Motion from frame to frame is estimated using a hierarchical block-matching motion estimator. The motion estimator produces motion vectors, which are compressed and sent to the output buffer for transmission. Each frame is analyzed before being processed in the encoder loop. The motion vectors and control parameters resulting from the forward analysis are input to the encoder loop which outputs compressed prediction error to the channel buffer. The encoder loop control parameters are weighted by the buffer state which is fed back from the channel buffer.

In the predictive encoding loop, the generally sparse differences between the new image data and the motion-compensated predicted image data are encoded using adaptive transform coding. The parameters of the encoding are controlled in part by forward analysis. The data output from the encoder consists of some global parameters of the video frame computed by the forward analyzer and transform coefficients that have been selected and quantized according to a perceptual criterion.

The encoder is shown in more detail in Figure 2-2. Motion estimation compares blocks in two consecutive input frames to obtain motion vectors needed for the motion-compensated prediction. These motion vectors give the relative horizontal and vertical displacement of the most similar blocks between frames. Before processing by the prediction loop, the input frame has its mean value subtracted to produce a zero-mean input in order to maximize the efficiency of the spatial transform. The video information is first processed to compute the motion-compensated prediction error.

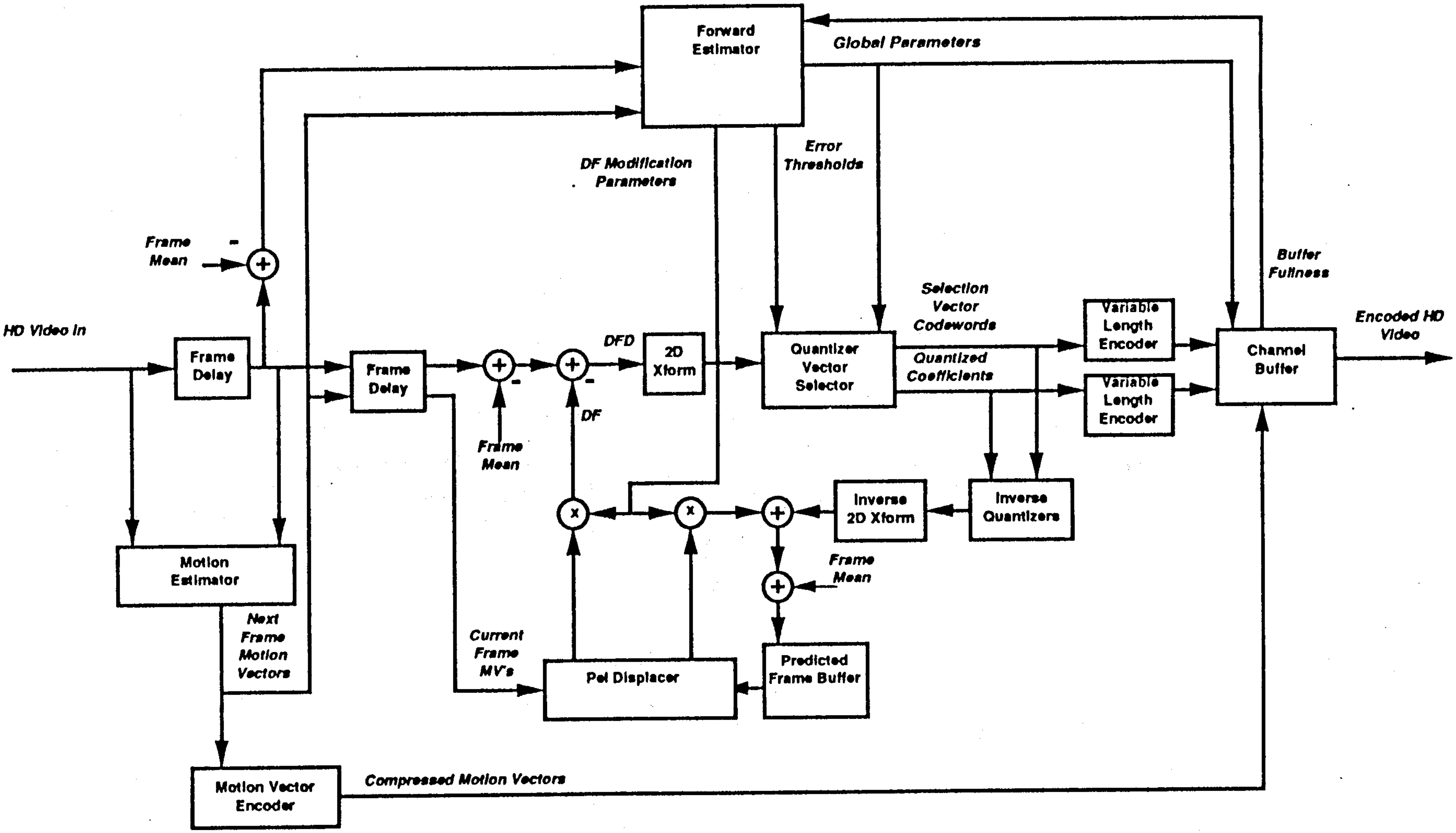
In the prediction loop, the encoded information that is to be transmitted is also locally decoded to produce a predicted frame corresponding to the previous frame (as it will be decoded by the receiver). The previously decoded image frame is displaced (motion compensated), and the result is modified by control parameters from the forward estimator. This displaced frame (DF) is subtracted from the input zero-mean frame to produce the displaced frame difference (DFD).

The DFD is encoded using a spatial transform. The resulting coefficients are



VIDEO ENCODER

FIGURE 2-1



VIDEO ENCODER BLOCK DIAGRAM

FIGURE 2-2

quantized. The quantized coefficient data and quantizer selection information are sent to the channel buffer along with compressed motion vector data and global parameters from the forward analyzer. To complete the prediction loop, the quantized coefficient data are decoded and added to the displaced frame resulting in a predicted frame which is stored as the previous frame.

Luminance and the two chrominance difference pixels are encoded separately. Chrominance difference frames are half the resolution of luminance frames horizontally and vertically. The chrominance compression results in a chrominance bit-rate, which is generally a small fraction of the total bit-rate, without perceptible chrominance distortion.

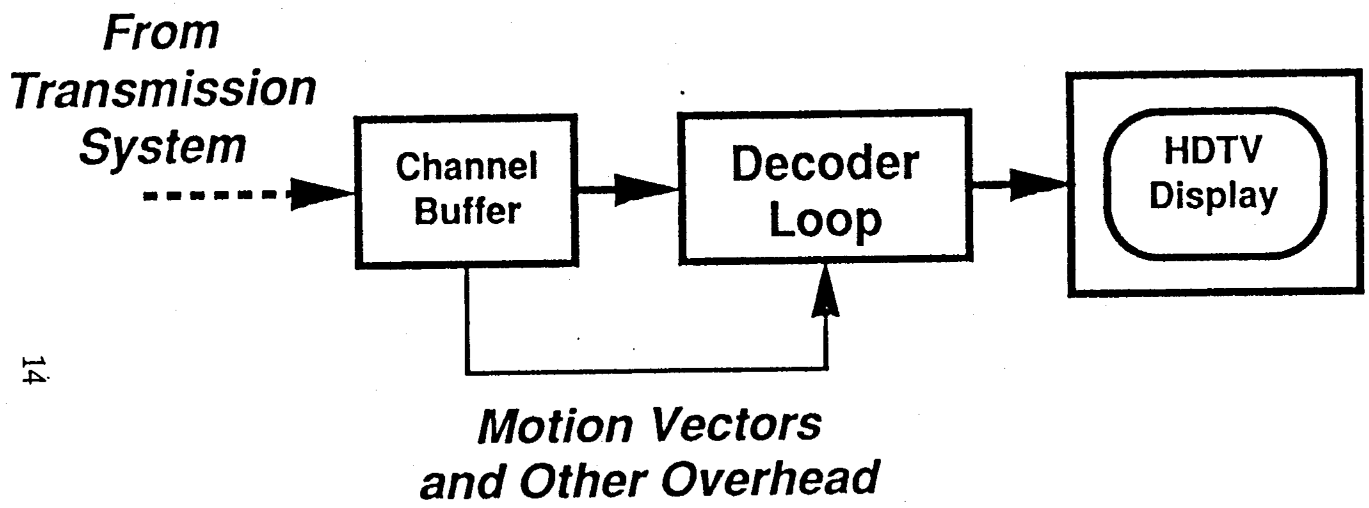
The output buffer has a variable output rate of approximately 17 Mbits/sec and has a varying input rate that depends on the image content. The buffer history is used to control the parameters of the coding algorithm so that the average input rate equals the average output rate. The feedback mechanism involves adjustment of the allowable distortion level, since increasing the distortion level (for a given image or image sequence) causes the encoder to produce a lower output bit rate.

The encoded video is packed into a special format before transmission which maximizes immunity to transmission errors by masking the loss of data in the Decoder. The duration and extent of picture degradation due to any one error or group of errors is limited.

2.3 Decoder.

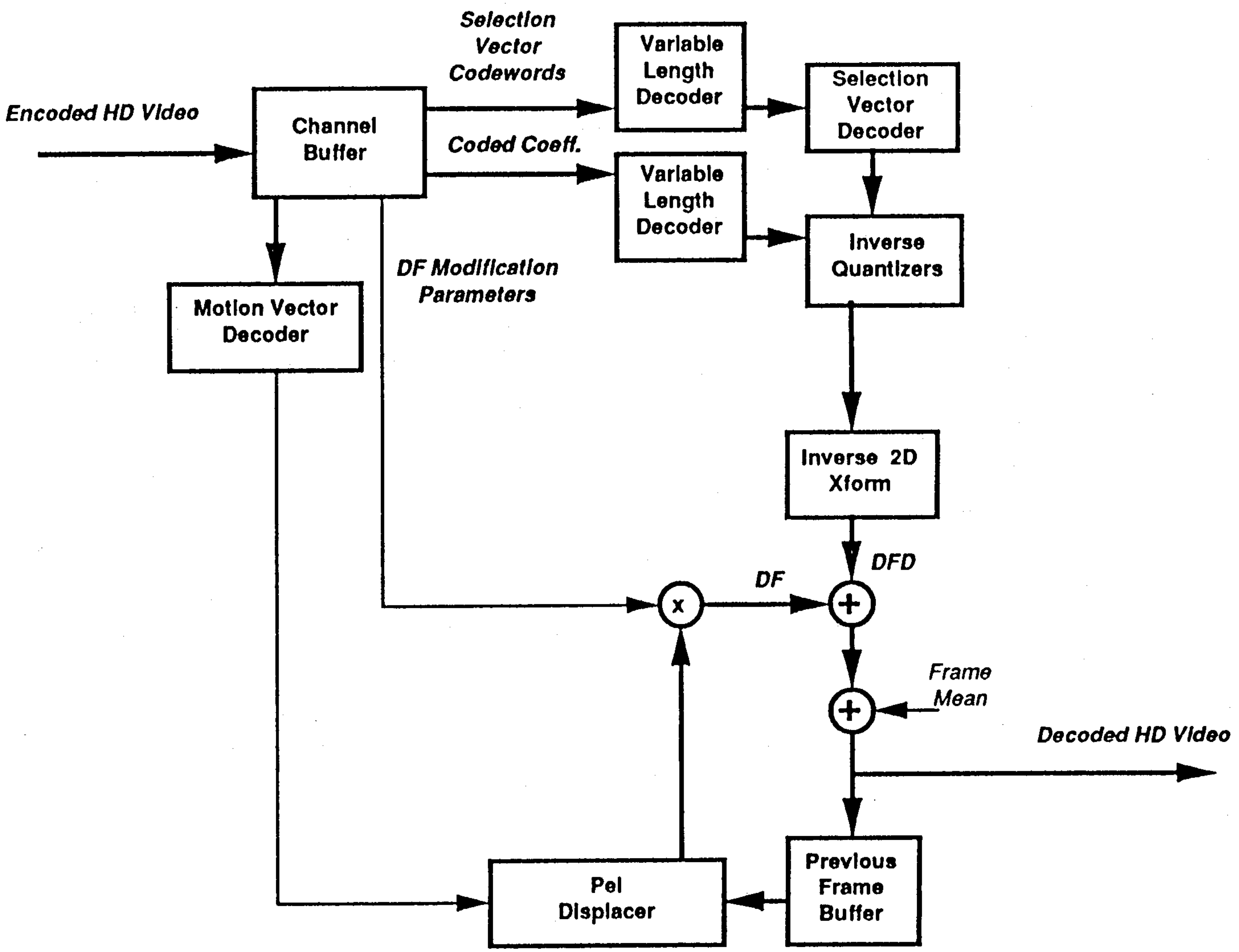
The Decoder is shown in Figure 2-3. The compressed video data enters the buffer which is complementary to the compressed video buffer at the encoder. The decoding loop uses the motion vectors, transform coefficient data, and other side information to reconstruct the HDTV images. Channel changes and severe transmission errors are detected in the decoder causing a fast picture recovery process to be initiated. Less severe transmission errors are handled gracefully by several algorithms depending on the type of error.

The detailed decoder loop shown in Figure 2-4 has as its input compressed video information received from the transmission channel. The motion vectors are first decoded, and used to displace blocks of picture elements resulting in the displaced frame (DF). The decoded DFD is added to the displaced frame resulting in



VIDEO DECODER

FIGURE 2-3



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VIDEO DECODER BLOCK DIAGRAM

FIGURE 2-4

the reconstructed frame for display. The reconstructed frame is stored in the previous frame buffer in preparation for the next frame reconstruction.

Processing and memory in the Decoder are minimized. Processing consists of one inverse spatial transform and a variable length decoder. The spatial transform and the variable length decoder are each realizable in one VLSI chip. Memory in the decoder consists of one full frame and a few compressed frames.

2.4 Principal Features of the Compression Algorithm.

The video compression algorithm includes a unique set of features that maximizes picture quality within the available channel bandwidth. The principal features are:

- Hierarchical, subpixel motion estimation within a motion vector budget
- Handling of scene changes with no perceptible distortion
- Quick buildup of picture after channel change by the viewer
- Adaptive post-processing of reconstructed images to improve picture quality
- Perceptual quantization and dropping of transform coefficients
- Vector quantization of quantizer selection patterns
- Perceptual criterion optimized for human vision
- Smooth control of quantization based on buffer fullness history
- Forward analyzer to determine coding parameters of each new frame
- Randomizing and limiting effects of transmission errors

2.5 Motion Estimation.

Motion is estimated in stages on a block by block basis using only the luminance frames. At each stage the best block match is defined to be that which has the least absolute difference. The results from one stage are used as a starting point for the next stage to minimize the number of block matches per image. The motion estimator is capable of handling large frame-to-frame displacements typical of entertainment and sport scenes. Finally, the resolution of motion estimation is adapted spatially to those places in the picture which could have the most benefit within the limit of the compressed motion vector bit rate.

The motion estimator compares a block of pels in the current frame with a block in the previous frame by forming the sum of the absolute differences between the pels, known as the prediction error. Each block in the current image is compared to many blocks at different locations in the previous image and the displacement vector that gives the minimum prediction error is chosen as being the best representation of the motion of that block. This is the motion vector for that block. The end result of motion estimation is to associate a motion vector with every block of pels in the image.

To reduce the complexity of the search, a hierarchical motion estimation is used in which a first stage of coarsely estimating the motion is refined by a second, finer estimation. The first stage matching is performed on the images after they have been filtered and reduced in resolution by a factor of two both vertically and horizontally. This reduces both the block size and the search area by factors of four. The motion vectors that are generated are passed to the second stage which performs a search centered around this coarse estimate. A filter is used prior to subsampling. The motion vectors generated from the first stage are sent to a finer motion estimator that can predict the motion of small blocks to within sub-pixel accuracy.

The second motion estimator stage generates the prediction errors of the small blocks for location in the image. These are passed on to the prediction error calculator which sums the prediction errors of the small blocks that form each coarse block, generating the prediction errors of the coarse blocks with no further searching required. The final stage of the motion estimator uses the prediction errors to generate the motion vectors by finding the minimum prediction error for all blocks in every location. The resulting motion vectors are then passed on to the vector coding stage. The best motion vector is defined to be that having the minimum prediction error.

Given the motion vectors from the motion estimator, the motion vector encoder must select the set of motion vectors that will give the best prediction of the next frame while limiting the bit rate of the compressed motion vector data to be in a range. This is achieved by sending two resolutions of motion vectors. The first set represents the motion vectors of the coarse blocks which are unconditionally transmitted, and the second set represents the motion vectors for small blocks. However, not all of the small block motion vectors are transmitted, but only those which can be sent within the bandwidth remaining after the coarse motion vectors have been sent.

2.6 Adaptive Postprocessing.

Under certain circumstances, coarse quantization of the transformed DFD coefficients can produce temporally repeating patterns of distortion resulting in increased visibility. To avoid this potential flickering of quantized information, postprocessing is applied at the receiver. At each pixel a weighted average of temporally successive pixels is stored in the predicted frame buffer if it differs from the current pixel by an amount less than some threshold. If the pixel differs by an amount larger than the threshold, the new pixel is used without averaging.

2.7 Spatial Transform.

Blocks of pixels containing the displaced frame difference are transformed using a spatial transform. The transform is implemented using an algorithm to reduce the number of multiplications required. Sufficient accuracy is maintained throughout to ensure that the transform is not a source of quantization noise.

2.8 Adaptive Quantization of Transform Coefficients.

A principal means of reducing the number of bits needed to represent the images is to control the number of bits used to represent the individual transform coefficients. The algorithm described here recognizes that transform coefficients vary in importance depending on scene content and motion. By adjusting the coarseness of quantization of individual coefficients to local regions of the image, the algorithm can minimize the amount of transmitted information, while retaining the flexibility to apply better coefficient precision where needed.

A set of nonuniform quantizers is used to quantize the coefficients. Each quantizer has a zero level and is adaptively scalable to maximize its efficiency given the amplitudes of coefficients. A coefficient may also be dropped or forced to zero. The quantized coefficients are variable length-encoded using a different codebook for each quantizer.

2.9 Vector Quantization of Selection Patterns.

A variety of quantizers are available for each coefficient. However, constraints on the selection of quantizers is needed to accommodate the quantizer selection overhead. Within the bit budget, Vector Quantization is used to represent the possible combinations or patterns of quantizers which can be applied to a given block of coefficients. Coding efficiency is achieved by compressing and transmitting the index associated with a given quantizer selection pattern instead of the pattern itself.

Additional coding efficiency is achieved by applying the same quantizer pattern to all of the coefficients in a spatial block. The block size for the chrominance difference coefficients is larger than the luminance block size, and the number of chrominance patterns can be smaller than the luminance patterns with no perceptible chrominance quantization noise.

2.10 Selection of Quantizer Patterns.

An important principle of the proposed coding algorithm is that the perceptible distortions should be minimized. Moreover, perceptibility of errors and distortions should be equally visible throughout the image. Quantizer selection patterns are chosen as follows. A target distortion is defined for every coefficient. This target distortion is a combination of local perceptual thresholds that depend on the local scene content, and on a global target distortion that is influenced by the history of buffer fullness. A selection error is computed for every coefficient using the target distortion and the actual quantization for that coefficient. For every coefficient, the information rate (number of bits) for a particular quantizer is computed. For every allowable pattern of quantizers, the absolute value of the selection errors and the information rate are computed for all of the coefficient data in a block and added together. The pattern of quantizers with minimum selection error is selected. If the minimum selection errors are within a small number, the pattern with minimum information rate is chosen. Variable Length Coding is applied to indices (referring to the patterns) because some patterns are statistically much more likely than others.

2.11 Variable Length Coding.

The data representing information like motion vectors, quantizer pattern selections, and transform coefficients, are seldom statistically uniform. Usually, the data are statistically clustered, and the probability distributions can be estimated from analysis of real scenes. The use of variable length codes takes advantage of this statistical nonuniformity by assigning short code words to the most frequent values, and assigning longer words to less frequent values.

2.12 Perceptual Criterion.

The concept of perception-based coding depends on matching the coding algorithm to the characteristics of the human visual system (HVS). If one considers the coding artifacts and the ways in which a coding algorithm can affect their distribution, it is apparent that if artifacts are concentrated in localized regions of the image, the coded image distortion will be more visible. Conversely, the visibility of coding artifacts will be minimized if the coding distortions are uniformly distributed across the image. The use of perceptual thresholds results in an allocation of coding distortions so that the visibility of distortions is uniformly distributed.

The unpredicted picture information represented by the DFD is coded into transform coefficients that will be transmitted with varying precision. The precision needed for a particular coefficient will be determined by a local perceptual threshold. For every coefficient the perceptual threshold generator produces a threshold value. The coarseness of quantization (number of bits used for sending the coefficient value to the decoder) depends on the local perceptual threshold and on a global target distortion related to the time history of buffer fullness. A lower perceptual threshold value means that more bits will be allocated for the corresponding transform coefficient.

The perceptual threshold generator produces separate luminance and chrominance (both U and V) perceptual thresholds for every coefficient in each frame. Although substantial processing is required to produce the perceptual thresholds, they are not transmitted, but in fact are used to ensure that the information transmitted is allocated in an optimum manner, minimizing perceptible artifacts and maximizing picture quality.

The output of the perceptual threshold generator is a set of thresholds, one for each location in each coefficient, which give an estimate of the relative visibility of the coding distortion. Note that these thresholds depend on the content of the original image and, therefore, the bit allocation algorithm can adapt to variations in the input. If a good mathematical model of the HVS were available, it would provide the information necessary to compute the perceptual thresholds. Unfortunately, a model like this does not exist at the present time. The visual psychophysicists have determined many of the properties of the HVS, but no one has derived a model that can predict all of the experimental results. Currently the properties that are used are: (1) Frequency Sensitivity; (2) Contrast Sensitivity; (3) Spatial Masking and (4) Temporal Masking.

Frequency sensitivity exploits the fact that the visual systems modulation transfer function (MTF) is not flat. This MTF indicates that higher distortion can be tolerated at high frequencies than at low frequencies. Therefore, the perceptual thresholds for the high frequency coefficients will be higher than those for the lower frequency coefficients. The absolute frequency at which the peak MTF response occurs depends on the size of the screen and the viewing distance. The perceptual model currently being used has been set for a viewing distance of approximately two picture heights. In addition, the HVS response is assumed to be isotropic. For this set of viewing conditions, the peak MTF response occurs near the upper end of the second lowest frequency coefficient. Also, since the HVS is sensitive to low frequency flicker, the DC threshold is set to a value substantially less then that required by the MTF. The noise visibility for a low frequency coefficient was estimated by a subjective testing procedure.

For a flat field stimulus, the HVS is most sensitive to quantization error when the flat field has a mean brightness of mid-gray and is substantially less sensitive when the mean brightness is near black or white. This is implemented by applying a correction factor to the base thresholds. The class of stimuli that has been accounted for has been expanded to flat fields of arbitrary grey level.

Up to this point, the only stimuli accounted for are flat fields of varying brightness. Extending this model to textured input requires a definition of spatial masking. The definition that has been adopted is the amount of AC energy at a given location weighted by the visibility of that energy.

The final component of the current model accounts for temporal masking.

When, at a fixed location in the scene, there is a large change in the image content between the two frames, the HVS is less sensitive to high frequency details at that location in the current frame. By detecting the occurrence of large temporal differences, the perceptual thresholds at these locations can be increased for the current frame. This allows the bits that would have been allocated to the high frequency detail at these locations to be utilized for other portions of the image .

2.13 Forward Analyzer.

The forward analyzer approximates the operation of the encoding loop in order to optimize encoding loop control parameters. These parameters depend on the results of analysis of the entire frame and would be available one frame too late if computed in the loop. Examples of control parameters are the image mean and the quantizer scaling which increase the efficiency of the quantizers. In addition, the target distortion is determined by analyzing the rate versus perceptual distortion characteristics of the new frame.

2.14 Buffer Status Control.

In general, the buffer controls the coding algorithm by feeding back the history of the buffer state to the forward analyzer. The effect of the buffer state signal is to slow the information rate out of the encoder when the buffer fullness is high, and to allow an increase in information rate from the encoder when the buffer is less full. The buffer state is controlled by the global target distortion level. If the target distortion level is increased (to decrease the buffer fullness), more distortion is allowed.

The history of the buffer state and target distortion is stored and is also used in the current target distortion calculation. The forward analyzer maintains a certain average buffer fullness without increasing the target distortion beyond perceptible limits. At a scene change, the buffer is allowed to become more full and the target distortion is allowed to increase for a few frames.

The buffer state is transmitted to the receiver for each frame. The size of the decoder channel buffer and latency in the Decoder are minimized by resetting the buffer state upon receiver startup caused by channel changes or severe loss of transmitted data.

2.15 Summary.

Transparent image quality is achieved using motion compensated transform coding coupled with a perceptual criterion to determine the quantization accuracy required for each transform coefficient. The combination of a sophisticated encoded video format and advanced bit error protection techniques results in a highly robust reception and decoding of the compressed video signal.

The DSC-HDTV Video Coder algorithm is optimized to simplify the Decoder. The motion estimator, forward analyzer, vector quantizer, and buffer state control are all functions which exist only in the encoder. An additional attribute of the DSC-HDTV Video Coder algorithm is the ability to improve the encoder in the future without modifying the Decoder. The Decoder is realizable in a small number of VLSI chips. Frame memory and processing in the receiver are minimized while maintaining transparent image quality.

SECTION 3
SPECTRUM AND INTERFERENCE ISSUES

3.1 Introduction.

It is generally agreed within the ATS Advisory Committee that the new High Definition Television Service will be an interference-limited service:

- Simulcast HDTV demands cochannel spacing as low as 100 miles because of the 6 MHz of extra spectrum required for each present Television Broadcast Station [1].
- The maximum power levels for HDTV will be determined by the tolerable cochannel and Taboo channel interference penetrations into the NTSC service areas.
- The usable ATV service area in turn will be determined by the visibility of cochannel and Taboo channel interferences from NTSC and other ATV channels. Of this the cochannel interference from NTSC will be the dominant factor.
- This usable ATV service area will have to be large enough to be commercially attractive to broadcasters and at least comparable to NTSC service areas.

In this section the noise and interference limitations of digital ATV systems are examined in general and with particular application to the new DSC-HDTV system.

3.2 Purpose of ATTC Interference Tests.

The end objective of Advanced Television Test Center (ATTC) generating interference D/U (ratio of Desired signal level to Undesired signal level) data at various desired ATV receiver input levels is to determine interference and noise limited service contours for the proposed ATV systems under common spectrum and interference constraints.

The maximum ATV Effective Radiated Power (ERP) needs to be determined from the allowable cochannel interference into the NTSC service and the cochannel spacing. The conversion from D/U interference data (taken at various desired ATV signal levels) to geographic terms of service and interference contours can be done after the interference criterion and other "ATV Planning Factors" are agreed.

A similar conversion has to be done for Adjacent and Taboo channel interferences. PS/WP-3 of the Advisory Committee has under study how to process this conversion of ATTC data. This task is not yet completed, and thus, at this time, only preliminary projections can be made based on certain assumed criteria and known or projected systems' performance.

3.3 Available Service Area Determinants.

3.3.1 Minimum Cochannel Spacing

A worst case minimum cochannel spacing of 100 miles is assumed based on PS/WP-3's analysis for 100% accommodation.

3.3.2 Derivation of Maximum ATV ERP

Prior to an input from PS/WP-3, the following approach is assumed:

- Two NTSC cochannel transmitters at 155 miles (Zone I) minimum spacing, 37 dBk ERP and 1250 feet HAAT reach each other's 28 dB D/U linear penetration point at 15 miles inside the Grade B (57 mile) contour. This assumes F(50,50)* propagation for the Desired, F(50,10) for the Undesired signal and 6 dB front-to-back (F/B) ratio for the receiving antenna.

- Given that the above cochannel interference condition into the NTSC service is also tolerable (in the worst case) for digital ATV at 100 mile spacing, then it can be shown that the ERP of the ATV transmission would have to be reduced by 12 dB to 25 dBk.

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* F(50,50) refers to the FCC NTSC Propagation Characteristics exceeded at 50% of the locations for 50% of the time.

3.3.3 Receiving Antenna Characteristics

Contrary to what was done in the NTSC Planning Factors, it is assumed, particularly in the fringe region of ATV reception, that a certain advantage can legitimately be taken from the front-to-back ratio of receiving antennas.

In absence of directives from PS/WP-3 we have assumed for the examples in this document a variable F/B ratio of 0 to 16 dB depending on the location of the receiving installation with respect to the Desired ATV and the Undesired NTSC transmitters as shown in the Examples. This can be looked upon as a first order approximation of antenna directivity. The NTSC Planning Factors of 13 dB Antenna Gain and 5 dB Downlead Loss were used yielding a net gain of 8 dB.

3.3.4 Definition of ATV Service

The grades of service in NTSC (City Grade, Grade A and Grade B) are defined by the NTSC Planning Factors which include minimum fieldstrengths expected at 50% of receiving locations for 50% of the time.

Because of the difference in behavior of signal-to-noise ratio versus carrier-to-noise ratio between digital and analog systems, it <u>may</u> be desirable to define service for digital systems with a higher confidence level than what was used for NTSC planning. This is also under study by PS/WP-3. Absent a firm recommendation, the following propagation characteristics have been assumed for the examples in this document:

for all Desired ATV Signals: F(50,90)
for all Undesired Signals: F(50,10).

The Location Variability is to be determined.

3.3.5 Receiver Noise Figure

A 10 dB (UHF) receiver noise figure is assumed for the examples in this document. This is readily achievable with present day tuner technology.

3.3.6 Carrier-to-Noise Ratio Threshold

The Carrier-to-Random-Noise Ratio at which the digital SC-HDTV system will reliably operate is well below 20 dB. Forward Error Correction (FEC) contributes to this low number.

3.3.7 Noise Limited ATV Service Area

The Noise Limited Service Area can be determined from the C/N Threshold, the receiver Noise Figure, the F(50,90) Propagation Characteristics, and the Antenna Gain.

For the above values, this results in a Noise Limited (Service) Contour (NLC) of 56 miles, nearly identical to the Grade B contour (at 57 miles) of a 12 dB higher ERP NTSC emission at the same antenna HAAT (1,250 feet).

Inasmuch as the character of 4-level digital interference into NTSC will be noise-like and relatively independent of the source or channel encoding approach, it can be expected that the NLC for all 4-level digital systems proposals using state-of-the-art FEC will be similar if the same input constraints are used.

3.3.8 ATV-to-NTSC Cochannel Interference Ratio Threshold

The above discussion is relatively generic for 4-level digital ATV systems. However, once Threshold Extension, Channel Equalization and FEC approaches are considered, more and more system specific differences can be expected. This holds in particular for the most dominant ATV Service Area determinant: the ATV-to-NTSC-Cochannel-Interference-Ratio Threshold.

Having shown in the previous subsections that a reasonable noise limited ATV service area seems to be possible without causing unreasonable cochannel interference to NTSC, we will show in two examples in the next subsection (1) what the size of the Interference Limited Service Area of a standard 4-level digital ATV system can be expected to be, and (2) how good the interference threshold performance would have to be to satisfy the Service Area objectives.

3.3.8.1 Analysis of ATV Interference Data

Two examples of NTSC cochannel interference into digital ATV reception at 100 miles transmitter spacing are shown in Figures 3-1 and 3-2. The difference between the two examples is only in the assumed Desired to Undesired Interference thresholds. A computer-aided calculation technique is described in the Appendix.

Figure 3-1 corresponds to what can be expected from a typical generic 4-Level Digital System with FEC and with Carrier-to-Noise (C/N) and Desired-to-Undesired signal ratio thresholds (D/U) of 18 and 20 dB respectively. The Noise Limited (Service) Contour (NLC) for F(50,90) propagation characteristics is at 56 miles resulting in a circular Noise Limited Service Area of 9,852 square miles. The Interference Limited Service Area is the Noise Limited Service Area minus the area where the D/U threshold is not reached. This is much smaller and corresponds to a remaining Service Area of approximately 4,000 square miles, or a loss of nearly 60%. It is, to say the least, very questionable that this result is commercially attractive to broadcasters.

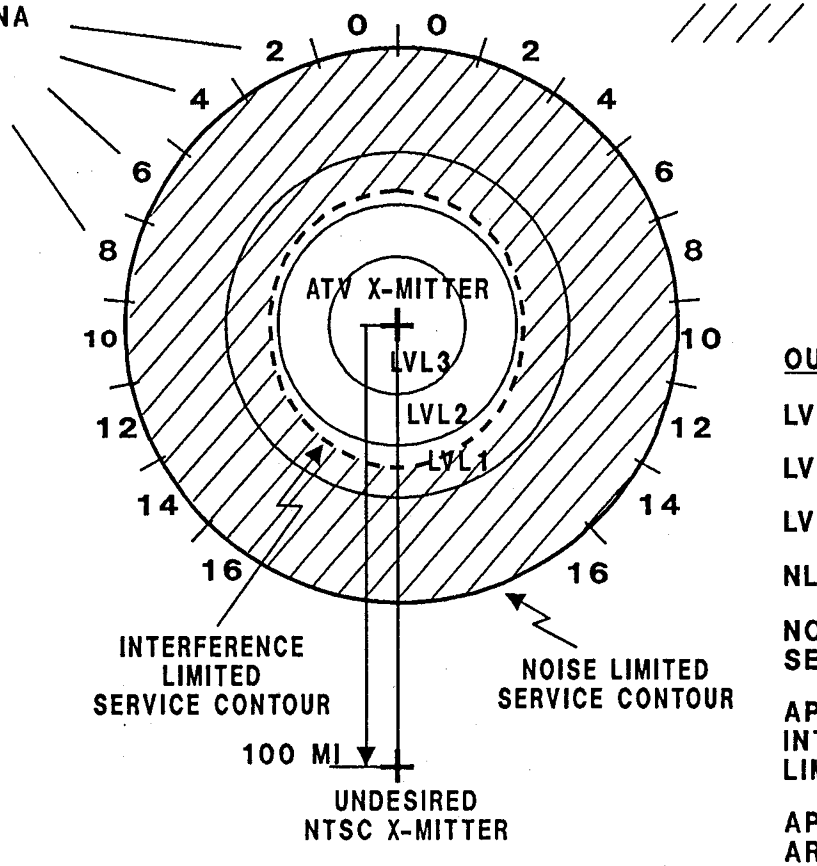
The second example, shown in Figure 3-2, has identical input conditions as that of Figure 3-1 except that the cochannel Interference Threshold has been reduced by unique system design to 3 dB. The NLC is, of course, the same, but the Interference Limited Service Area is still a respectable 7,200 square miles or a loss of only 27% of the potential maximum. These results show that for a commercially attractive service area the ATV-to-NTSC-Cochannel-Interference-Threshold ratio must be in the order of 3 dB.

3.4 Comments on Adjacent Channel Interference for Digital Systems.

Other than the predominant NTSC cochannel interference, the interference from NTSC adjacent channels is expected to be the most limiting factor on ATV Service Area. Increased requirements on the in-band flatness of the ATV channel response will result in less attenuation of the adjacent channels. Improvement will have to come from increased signal handling capability and from taking advantage of the different and non-linear behavior of digital systems with noise, interference and AGC design.

INPUTS

BAND	UHF
ATV ERP	25 dBk
NTSC ERP	37 dBk
ANT. HAAT	1250′
TRANSMITTER SPACING	100 MI
DESIRED PROPAGATION	F(50,90)
UNDESIRED PROPAGATION	F(50,10)
FRONT-TO-BACK RATIO	0-16 dB
LVL1 D/U THRESHOLD	20 dB
LVL2 D/U THRESHOLD	20 dB
LVL3 D/U THRESHOLD	20 dB
NLSC D/U THRESHOLD	20 dB
RECEIVER NOISE FIGURE	10 dB
CARRIER TO NOISE THRESHOLD	18 dB



OUTPUTS

LVL1 CONTOUR	46 MI
LVL2 CONTOUR	34 MI
LVL3 CONTOUR	21 MI
NLSC CONTOUR	56 MI
NOISE LIMITED SERVICE AREA	9852 SQ.MI.
APPROXIMATE INTERFERENCE LIMITED S.A.	3631 SQ.MI.
APPROX. SERVICE AREA LOSS	63%

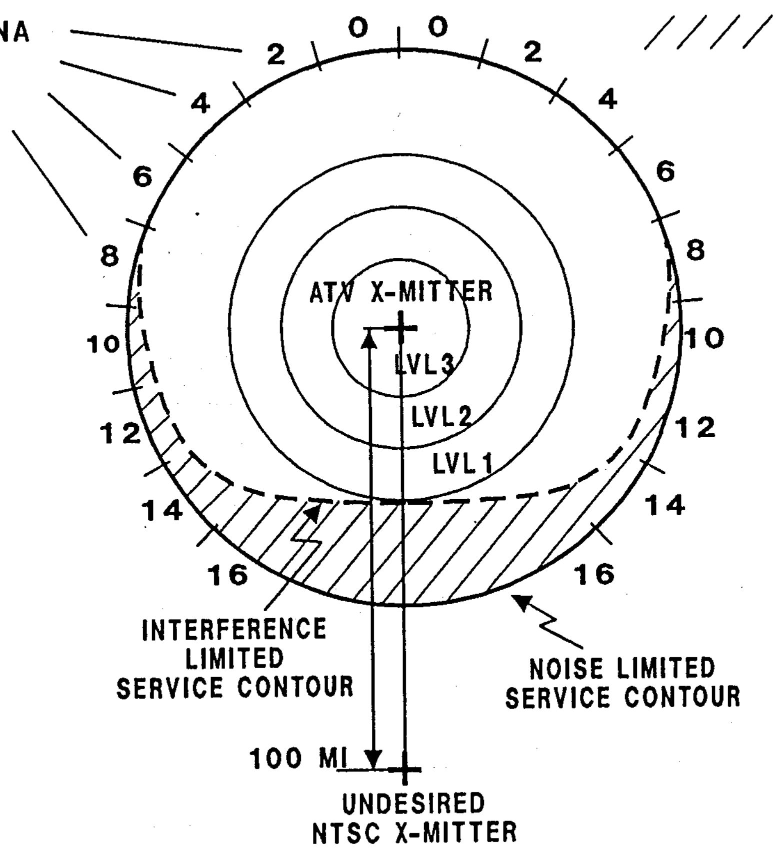
AT&T

ZENITH

NTSC INTO DIGITAL ATV COCHANNEL INTERFERENCE
D/U THRESHOLD = 20 dB

FIGURE 3-1

INPUTS	
BAND	UHF
ATV ERP	25 dBk
NTSC ERP	37 dBk
ANT. HAAT	1250′
TRANSMITTER SPACING	100 MI
DESIRED PROPAGATION	F(50,90)
UNDESIRED PROPAGATION	F(50,90)
FRONT-TO-BACK RATIO	0-16 dB
LVL1 D/U THRESHOLD	3 dB
LVL2 D/U THRESHOLD	3 dB
LVL3 D/U THRESHOLD	3 dB
NLSC D/U THRESHOLD	3 dB
RECEIVER NOISE FIGURE	10 dB
CARRIER TO NOISE THRESHOLD	18dB



OUTPUTS	
LVL1 CONTOUR	46 MI
LVL2 CONTOUR	34 MI
LVL3 CONTOUR	21 MI
NLSC CONTOUR	56 MI
NOISE LIMITED SERVICE AREA	9852 SQ.MI.
INTERFERENCE LIMITED S.A.	7192 SQ.MI.
APPROX. SERVICE AREA LOSS	27%

AT&T

ZENITH

NTSC INTO DIGITAL ATV COCHANNEL INTERFERENCE
D/U THRESHOLD = 3 dB

FIGURE 3-2

Adjacent NTSC channels should be colocated with ATV (within 10 miles) or be located approximately 10 miles outside the NLC. From a receiver performance viewpoint, colocation or near-colocation of NTSC and ATV adjacent channels appears very feasible. Requirements on the control of out-of-band emission by the NTSC transmitter may become more severe in some installations but are expected to be feasible.

3.5 Comments on Taboo Interference.

Interference into NTSC from digital ATV transmitters on Taboo channels can be expected to be significantly less than interference from NTSC into NTSC.

This is the result of the absence of picture and sound carriers as well as the chroma subcarrier in Digital ATV, and of the reduced power requirements for the same coverage. In addition the visibility and objectionability of Digital ATV into NTSC due to non-linearities in the NTSC tuner will be greatly reduced because of the absence of modulated beats or sync and picture envelopes in the caused interference.

Taboo interference into NTSC is thus not expected to be a problem with digital ATV.

Interference from NTSC transmissions into ATV channels with a Taboo relationship will be a function of the ATV tuner design as well as the system's Carrier-to-Interference-Thresholds. Satisfactory reception of DSC-HDTV can be achieved in the presence of NTSC Taboo channels with economical tuner designs.

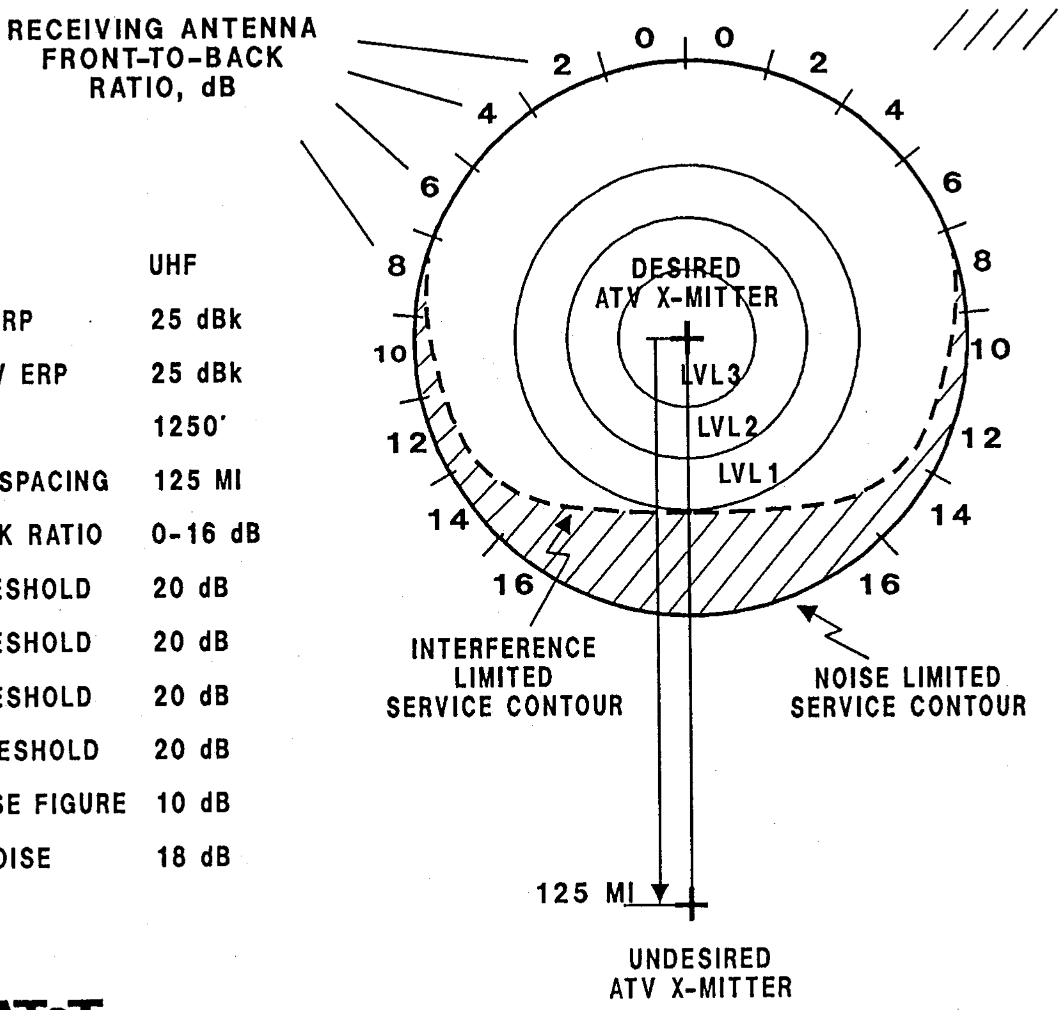
3.6 Comment on ATV to ATV Interference.

Spectrum Scenario Studies of PS/WP-3 indicate that the minimum ATV to ATV spacing will be around 125 miles. Assuming that the Carrier-to-Interference ratio (C/I) threshold, the Carrier-to-Noise ratio (C/N) threshold and also the remaining parameters are as shown in Figure 3-1, the Service and Interference Areas for this situation is shown in Figure 3-3.

It is interesting to note that the worst-case interference penetration of DSC-HDTV into DSC-HDTV is approximately the same as that from NTSC into DSC-HDTV at minimum spacing, - in both cases a worst case loss of service area of approximately 27 percent.

INPUTS

BAND	UHF
DESIRED ATV ERP	25 dBk
UNDESIRED ATV ERP	25 dBk
ANT. HAAT	1250'
TRANSMITTER SPACING	125 MI
FRONT-TO-BACK RATIO	0-16 dB
LVL1 D/U THRESHOLD	20 dB
LVL2 D/U THRESHOLD	20 dB
LVL3 D/U THRESHOLD	20 dB
NLSC D/U THRESHOLD	20 dB
RECEIVER NOISE FIGURE	10 dB
CARRIER TO NOISE THRESHOLD	18 dB



▨ AREA WHERE COCHANNEL INTERFERENCE THRESHOLD IS EXCEEDED

LVL1 CONTOUR	46 MI
LVL2 CONTOUR	34 MI
LVL3 CONTOUR	21 MI
NLSC CONTOUR	56 MI
NOISE LIMITED SERVICE AREA	9852 SQ.MI.
APPROXIMATE INTERFERENCE LIMITED S.A.	7200 SQ.MI.
APPROX. SERVICE AREA LOSS	27%

DIGITAL ATV INTO ATV COCHANNEL INTERFERENCE

FIGURE 3-3

SECTION 4
DSC-HDTV TRANSMISSION FORMAT

4.1 Data Frame.

The Video Encoder generates approximately 17 Mbits/second which have to be transmitted in a 6 MHz television channel. This is achieved in an NTSC-like transmission signal format, shown in Figure 4-1.

To avoid confusion between DSC-HDTV video source and display format on the one hand, and DSC-HDTV transmission signal format on the other, some new terms are used for the latter. These terms are summarized in the immediately following subsection 4.2.

Note in Figure 4-1 that one Data Frame corresponds to one NTSC frame, one Data Field to one NTSC field and one Data Segment to one NTSC horizontal line.

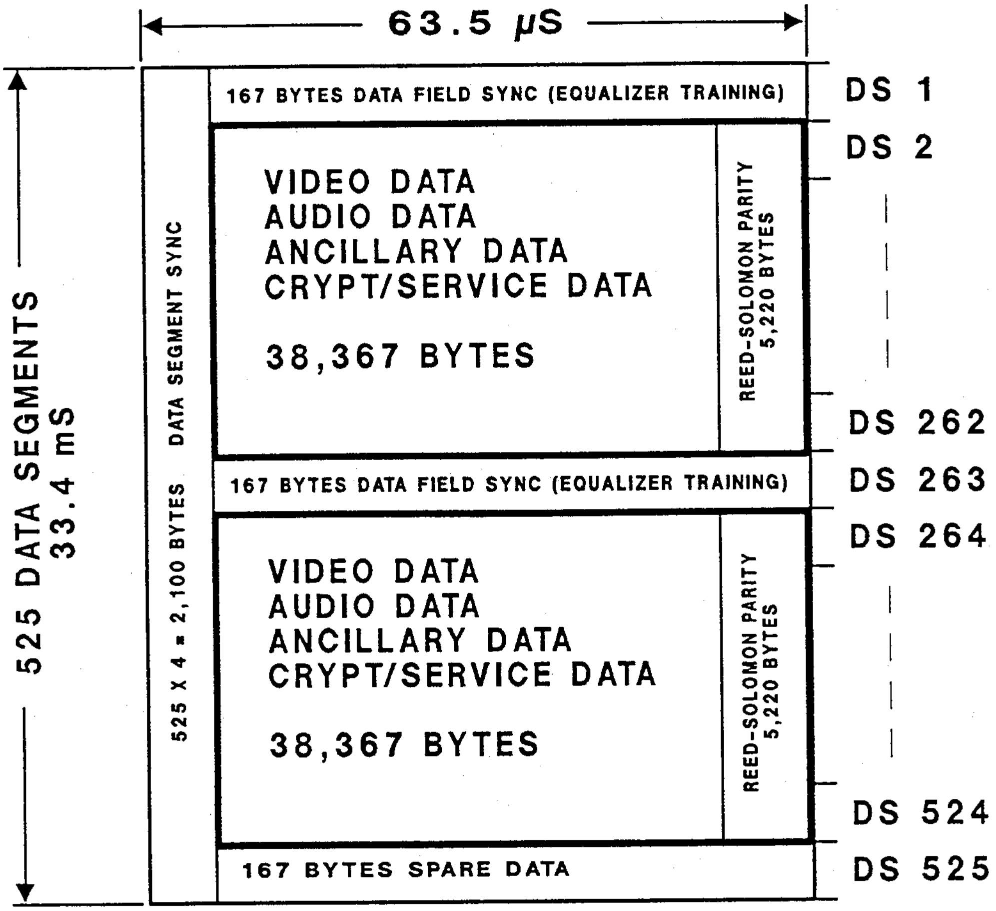
The interrelationships between the numbers in Figure 4-1 are easily verified with the help of the Table in subsection 4.2.

Note also in Figure 4-1 that all data bytes are protected by the Reed-Solomon (RS) Code except the Sync Interval bytes and the Spare Data bytes. The latter are not currently assigned. The Sync Interval bytes are not protected by the Reed-Solomon Code because sync detection must take place before error correction. Both Data Segment Sync and Data Field Sync have their own error preventing redundancy as explained below and in Section 6.

4.2 Transmission Signal Parameter Definitions.

Data Segment = A sequence of 171 bytes (684 symbols) of total duration of 63.56 microseconds (corresponding to the duration of one NTSC horizontal line period). (The terms "Horizontal Line" or "Line" are reserved for the display parameter and have a duration of 1/3 of a Data Segment).

Data Segment Sync Interval = A group of 4 (out of 171) bytes of a Data Segment. The Data Segment Sync Interval is 1.49 microseconds.



DATA SPACE: 89,775 BYTES/DATA FRAME
29.97 DATA FRAMES/SECOND
21.52 Mbits/SECOND

ONE DATA FRAME

FIGURE 4-1

Data Field = A group of 262 or 263 data segments (averaging 1/59.94 second duration, corresponding to one NTSC "field").

Data Frame = Two successive Data Fields (corresponding to one NTSC "frame"; duration 1/29.97 seconds).

The total bit rate is 21.52 Mbit/sec.

TABLE

1 Byte = 8 Bits = 4 Symbols
Bit Rate = 21.5 Mbit/seconds
Symbol Rate = 10.8 Msymbol/seconds
Symbol Interval = 92.9 nanoseconds
Byte Duration = 0.37 useconds
Byte Rate = 171 Bytes/Data Segment

NTSC Horizontal Line Frequency, $f_H = 4.5/286$ MHz = 15.734 kHz
Video Data Clock Frequency $f_d = 4 \times 7 \times 9 \times 19 \times f_H = 75.34$ MHz
Transmission Data Clock Frequency $f_t = f_d/7 = 10.76$ MHz

4.3 Data Segment Sync.

Each Data Segment starts with one byte of data dedicated to synchronization of the Receiver Video Data Clock. While all other data vary at random, depending on picture and sound, or pseudo-random (see next subsection), the Data Segment Sync identically repeats every data segment. This makes possible the reliable detection of Data Segment Sync even under severe interference conditions and without parity bits from the Reed-Solomon (RS) Code.

Figure 4-1 shows four bytes at the onset of each data segment, only one of which is used for sync. The use of the other three is explained in subsection 5.2.

4.4 Data Field Sync.

Each Data Field starts with one Data Segment of Data Field Sync. It consists of 167 bytes of pseudo-random data. The receiver compares the data from a local lookup table to the incoming pseudo-random sequence data in order to reliably establish synchronization.

To differentiate between Data Field 1 and Data Field 2, the pseudo-random sequences differ from field to field.

Data Field Sync is also used as the reference signal for Ghost-Cancellation/Channel-Equalization ("Equalizer Training" in Figure 4-1). A good explanation of the cancellation method is found in Reference [2].

4.5 Error Control.

As shown in the Table above, a Data Segment contains a total of 171 bytes of data. With four used for Sync every Data Segment (see Figure 4-1), a total of 167 bytes is available for information and error control. Twenty bytes are set aside for RS Code parity. This allows correction of a maximum of ten errors per data segment, exactly half the number of parity bytes.

Regardless of the number of bit errors in one byte, (up to 8 possible) it is counted as one byte error.

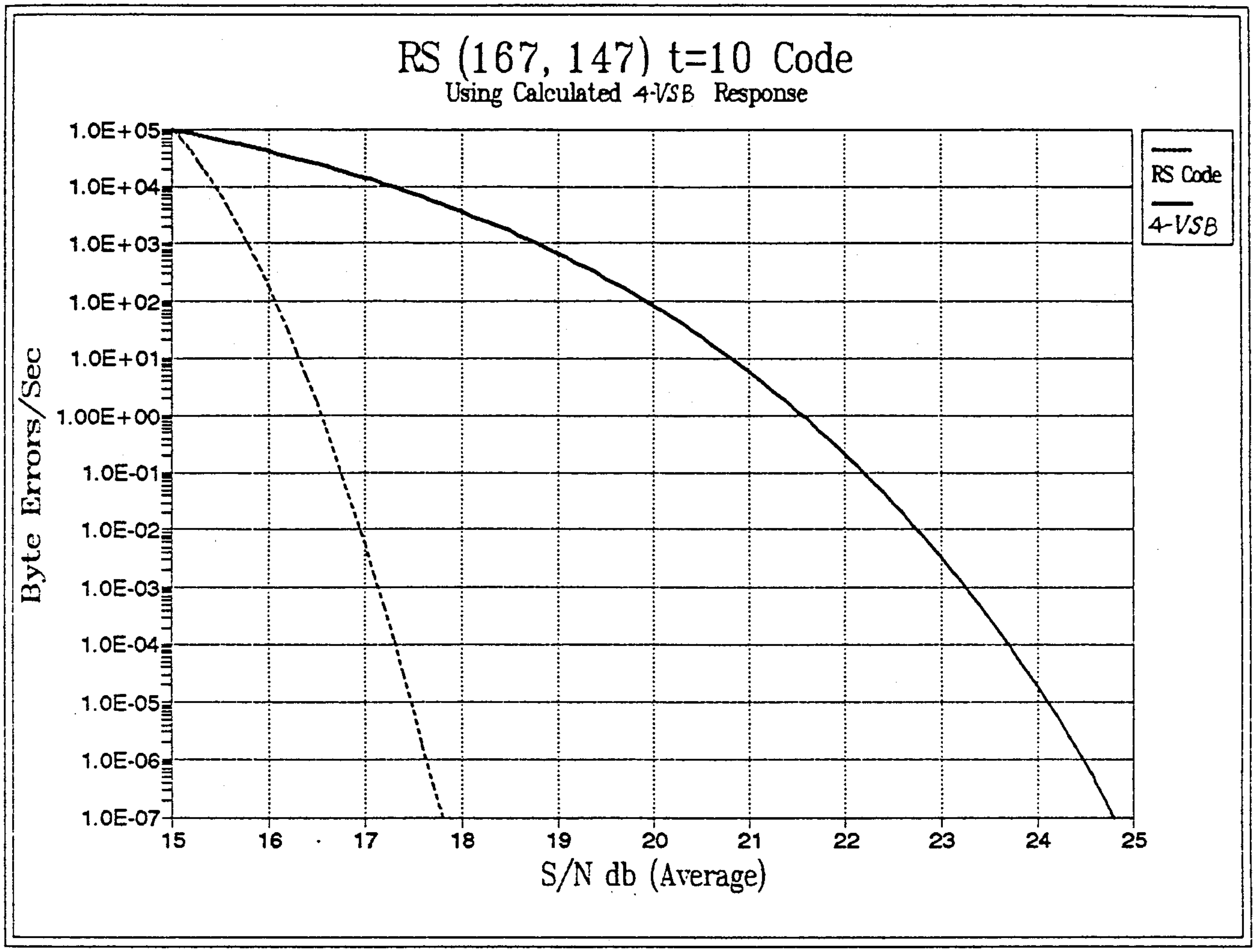
The relation between average signal-to-noise ratio and byte error time-rate is shown in Figure 4-2 for unprotected 4-VSB and for RS-protected 4-VSB. (The term "4-VSB" is explained in Section 5.3). Note that the vertical scale is given in byte errors/second. To transform this into byte errors/byte divide by 2.69×10^6.

4.6 Audio.

Each Data Field includes 1300 error protected bytes of audio data. This is sufficient to accommodate four audio channels of 125.874 kbit/seconds each plus overhead for extra error protection. The audio channel bit rate is an exact multiple (8) of the data segment frequency of 15,734 Hz.

4.7 Ancillary Data.

The current NTSC Television Broadcasting Rules (FCC R&R 73.682 (a) (21), (22)) regulate the "transmission of a program related data signal which, when decoded, provides a visual depiction of information simultaneously being presented on the aural channel", -- in short, "Captioning." The Rules also provide for transmission of "data signals which are not program related," familiarly known as "Tele-



BYTE ERROR RATE

FIGURE 4-2

text."

Data signals are also used for the transmission of test signals, cue and control signals, identification signals, Alert/Emergency signals, decoder box addressing and encryption.

The DSC-HDTV Transmission signal format allots approximately 1200 bytes every Data Field for such ancillary services.

Current NTSC practice uses the DSC-HDTV equivalent of 1 Byte per Data Field for captioning and 35 Bytes per Data Field for every NTSC horizontal line per field of Teletext.

Even when the equivalent of several NTSC horizontal lines/field is to be accommodated for Teletext, the total bytes of Captioning and Teletext is small compared to the available bytes.

SECTION 5
THE DIGITAL SC-HDTV TRANSMITTER

5.1 Block Diagram.

The Block Diagram of the Digital SC-HDTV Transmitter referred to earlier in Section 1.9 is found in Figure 1-1.

Video R, G and B source signals are analog-to-digital (A/D) converted, if not yet in digital form, and are subsequently fed to the Video Encoder. Here, the video is compressed, as described in Section 2, and converted into a continuous digital bit stream of approximately 17 Mbit/second.

In the next block, "Data Formatter and Error Control," the video bit stream is combined with digital audio, ancillary data and Reed-Solomon (RS) error control bytes into the format shown in Figure 4-1.

5.2 Pre-Filter.

The next block of Figure 1-1, "Pre-Filter", combines several functions. The first function involves pre-processing for the NTSC Interference Filter in the receiver (this filter is identified by a block in Figure 1-2).

The second function is related to the pilot signal added to the transmission signal to aid carrier recovery at the receiver. The Pre-Filter performs a sequence manipulation operation that has as its purpose the minimizing of the interference of the data signal into the pilot recovery process at the receiver. Information regarding the manipulation operation is encoded in the last three bytes of the Data Segment Sync.

Thirdly, encoded synchronization signals are added in the Pre-Filter block.

The combining of Digital Audio, Ancillary Data, Error Control Data, Sync Data and the approximate 17 Mbit/sec Video Data results in a transmission bit rate of 21.5 Mbit/second.

5.3 Modulator.

In the subsequent block in Figure 1-1, "Modulator, SAW Filter, Dispersion", a modulation method has been chosen that can handle 21.5 Mbit/sec in a 6 MHz simulcast channel.

One aspect of the new method is to use symbols of 4 discrete levels corresponding to 2 bits/symbol. This results in a symbol rate of 10.8 Msymbols/second which can be accommodated in a 6 MHz band. The modulation method is vestigial sideband (VSB) and the nominal band is shown in Figure 5-1. The term chosen for the modulation method is "4-VSB."

The suppressed carrier is located near the lower band edge of a 6 MHz channel as shown in Figure 5-2.

The skirt selectivity is made the same on the vestigial sideband side as on the high-frequency side. Also, the skirt selectivity is equally divided over transmitter and receiver. This is the optimum arrangement for best signal-to-noise ratio [3].

The spectrum rolloff factor (R-factor) of the baseband equals 0.31/5.38 = 0.058. Such a low value causes significant overshoots but their average amplitude is reduced by the choice of four-level symbols.

Figure 5-2 also illustrates an NTSC cochannel on the same frequency scale as the DSC-HDTV channel. Note that the vertical scales are unrelated. The NTSC nominal transmitted signal is drawn in bold outline; the dashed diagonal line represents the nominal NTSC receiver skirt selectivity (actually, the upper skirt at I.F.).

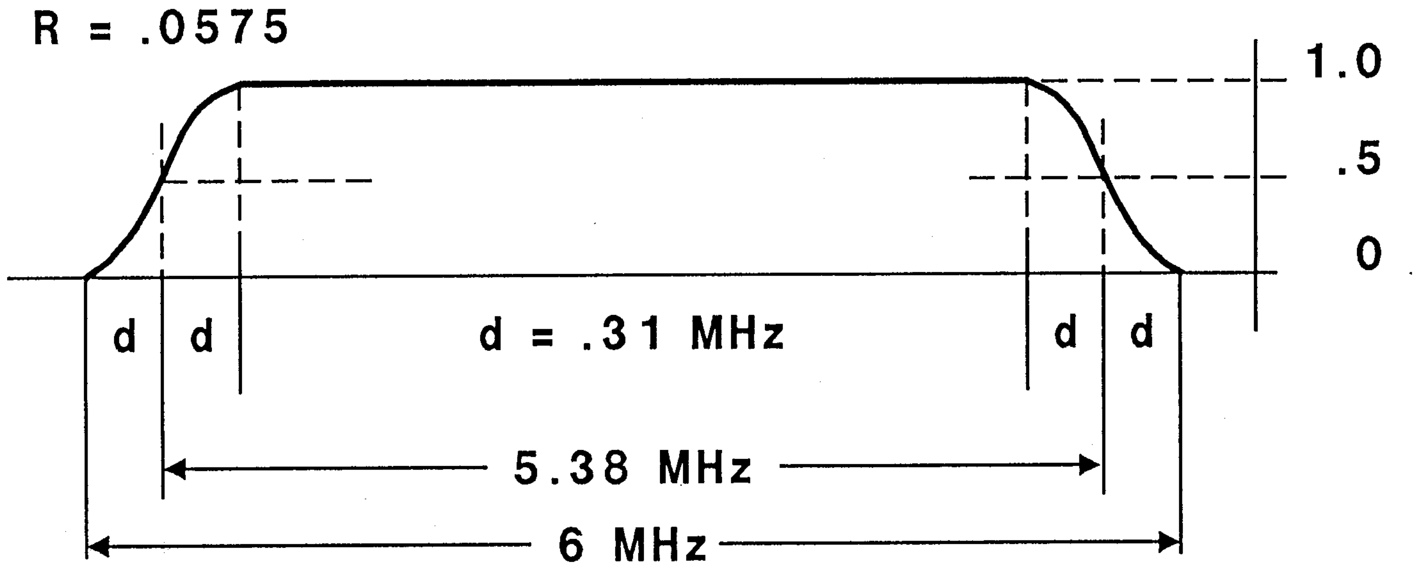
The nominal bandpass characteristic of the SAW Filter following the Modulator is the upper curve in Figure 5-2.

The Dispersion function also indicated in the Modulator block in Figure 1-1, is described next.

5.4 Dispersion.

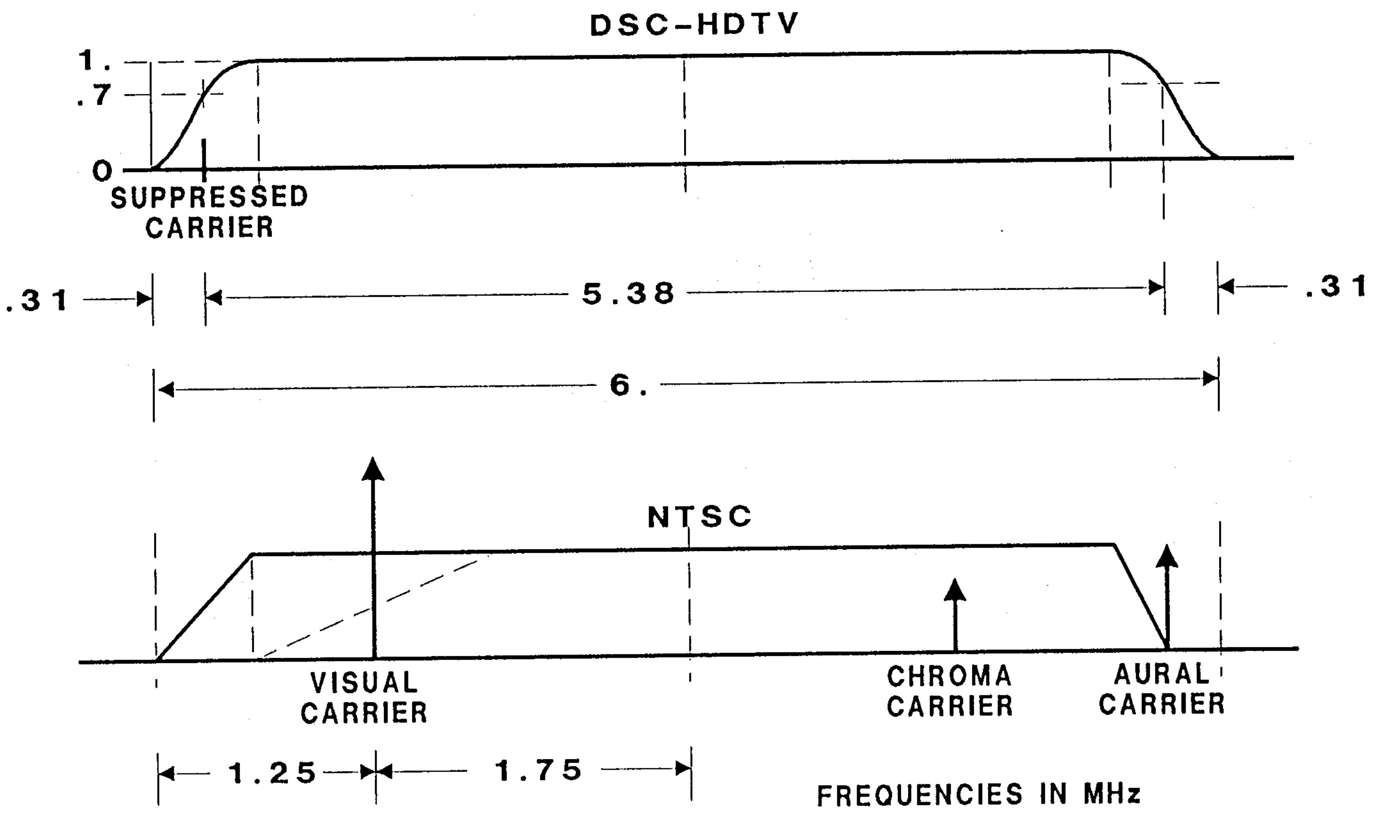
As long as the DSC-HDTV RF data stream is truly random, the cochannel interference into an NTSC channel has a random noise-like character and is of minimum visibility. The one exception to randomness of the data is the one byte of Data Segment Sync which occurs every NTSC line at the same place and in the same format. As interference into the NTSC victim channel, it stands out because of its regularity. It cannot be randomized because reliable Data Segment Sync detection depends on exact repetition for a number of data segments.

Dispersion is introduced to remove the repetitive character of the sync



NOMINAL 4-VSB CHANNEL

FIGURE 5-1



AT&T

ZENITH

DSC-HDTV/NTSC RF COCHANNELS

FIGURE 5-2

portion. Since the sync is preceded and followed by random pulse signals, dispersion causes a portion of the preceding (or following) random signal to be superimposed on the non-random sync signal and so gives it a measure of randomness.

The dispersion is achieved in the transmitter SAW filter by a delay tilt. Complementary dispersion is implemented in the receiver SAW I.F. filter.

Receiver dispersion spreads any sharp transition of the NTSC cochannel interference into DSC-HDTV and so contributes to reducing the effect of the interference.

5.5 Low-Power Transmitter.

Modern NTSC TV transmitters use a two-step modulation process. The first step is, usually, modulation on an I.F. carrier which is the same for all channels. The second modulation stage translates the filtered output of the first stage to the final spectrum position.

This efficient method will be applied for DSC-HDTV as well.

5.6 RF Carrier Frequency Offset.

RF carrier frequency offset can provide benefits to situations of NTSC/DSC-HDTV cochannel interference due to the similar transmission signal timing.

Offset can cause the interference into NTSC to change polarity every horizontal line and so provide some visual cancellation. The noise-like character of the DSC-HDTV transmission signal, however, has already contributed to minimizing the interference. The interference polarity change every data segment in DSC-HDTV makes the sync detection more reliable.

SECTION 6
DIGITAL SC-HDTV RECEPTION

6.1 Introduction.

The receiver block diagram is shown in Figure 1-2. The processing principally follows the transmitter processing in reverse. Specific to the receiver are sync and clock recovery. Also specific to the receiver is the Ghost-Canceler/Channel-Equalizer.

General descriptions are given in the following subsections.

6.2 Receiver Front-End.

The Tuner and I.F. are mostly conventional. The SAW Filter has the same bandpass characteristic as the transmitter as shown in Figure 5-2, top part. Just as dispersion is applied in the Transmitter SAW Filter, complementary dispersion is applied in the Receiver SAW filter.

The Synchronous Demodulator uses a Frequency-and-Phase-Locked Loop (FPLL) [4]. The FPLL combines a wide pull-in range with a narrow hold-in range and stable operating points at 90 degrees and at 270 degrees, all necessary features for reliable operation under strong cochannel interference conditions. The functions of automatic carrier frequency control (AFC), automatic carrier phase control (APC) and automatic gain control (AGC) are all performed under control of the FPLL. The Synchronous Demodulator has in-phase and quadrature outputs.

6.3 Data Clock Synchronization.

The composite baseband data signal coming from the Synchronous Demodulator is sampled and analog-to-digital converted.

Data clock synchronization requires the recognition of the precise instant of the zero crossing of the Data Segment Sync in-phase component among all the other zero crossings from constantly varying data patterns. This is accomplished in a Correlator Circuit, using the periodic recurrence of the identical sync quadrature component every data segment. Random data patterns equal to the sync pattern could occur but have such low probability of repeating a sufficient number of data segments in the same location that false detection is prevented. The circuit has excellent signal-to-noise ratio.

When Data Segment Sync is detected, the Video Data Clock and the Transmission Data Clock are synchronized.

6.4 Data Field Synchronization.

The Data Field Reference signal timing for Field 1 is illustrated in Figure 6-1. The signal consists of four pseudo-random two-level sequences of 255 symbols each with the first and the last truncated. Data Field Sync detection is achieved by comparing incoming signal data to local lookup table data, data segment by data segment. At the instant of equality a large output is produced signifying synchronization. Even under strong ghosted conditions of the incoming sequences the correlation is high and Data Field Sync detection is secure.

6.5 NTSC Interference Rejection.

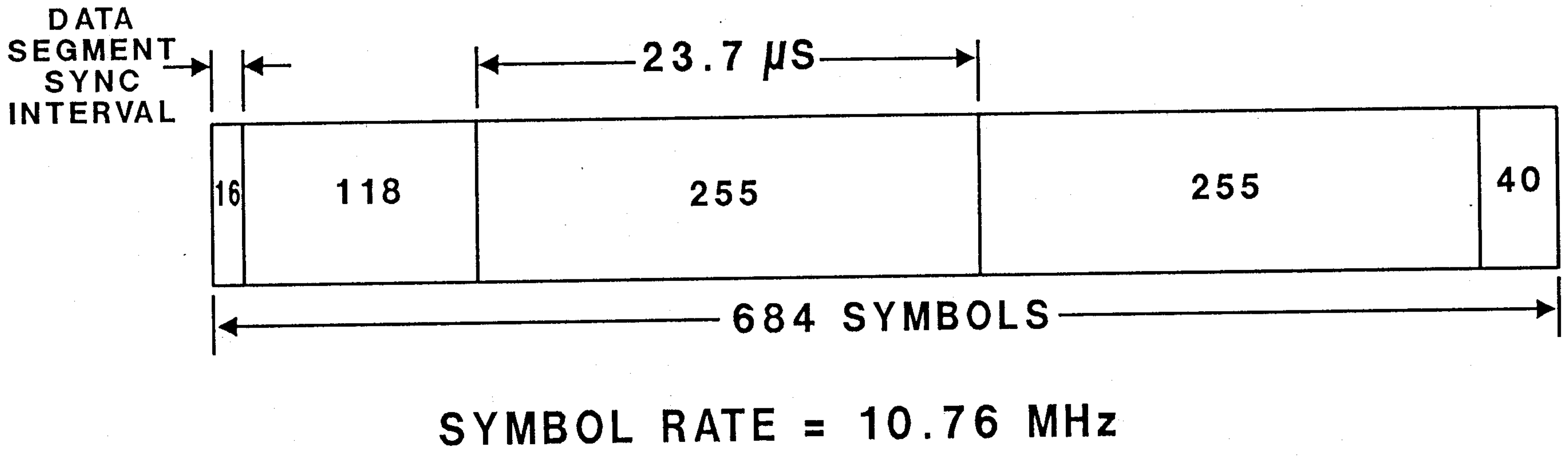
The NTSC Interference Filter works in conjunction with the Pre-Filter in the Transmitter. The NTSC Interference Filter achieves a significant reduction in interference from an NTSC cochannel, if needed.

6.6 Channel Equalizer.

The Data Field Synchronization signal is also the Channel-Equalizer/Ghost-Canceler training signal.

The difference between the incoming training signal and the local reference signal is used to compute the tap weights according to a Least-Mean-Square (LMS) algorithm.

The operation of a ghost canceler/channel equalizer for digital signals is less critical than one for analog signals. Just as a digital system can totally eliminate thermal noise as long as it is of a level below a certain threshold, ghosts in the transmission signal are unnoticed at the display, provided that they remain below certain threshold values. The canceler's function is to reduce ghosts and channel distortions below this threshold value. As long as a reasonable (equivalent) eye



DATA FIELD REFERENCE SIGNALS

FIGURE 6-1

height is reached in the pulse detection process, ghosts and distortion effects are totally absent from the picture. For analog transmissions, cancelers have to leave much smaller residual ghosts to make them invisible.

6.7 Error Correction

The analog equivalent of the digital signal delivered by the Channel Equalizer has optimized eye height. The bit-error rate assumes negligible proportions for the particular Reed-Solomon Code applied when the signal-to-noise ratio or signal-to-interference ratio is approximately 18 dB, the value used in Section 3.3.8.1.

6.8 Deformatter.

The corrected data stream consists of a sequence of zeros and ones. This data stream is now separated into the original sequence of video bits, digital audio bits and ancillary data bits. Obviously, the error correction bits have been removed, after having accomplished their intended task.

6.9 Video Decoder.

The video bit stream is applied to the Video Decoder which regenerates the R, G and B signals as described in Section 2.

SECTION 7

APPLICATION TO OTHER DISTRIBUTION MEDIA

7.1 Cable.

The low RF signal power and absence of high level carriers are in the interest of cable operation, just as in the case of analog/digital SC-HDTV.

The all-digital format can prevent noise accumulation due to regeneration over multiple amplified sections.

The all-digital format also is ideal for encryption and many encryption/decryption cycles will not cause picture deterioration.

Present-day cable systems have considerably fewer free channels than there are Taboo channels in terrestrial broadcasting. Initially, the need for HDTV channels probably will be limited to a few. Spectrum space can easily be found in a few unused channels or even in the FAA level-limited channels or above the current band where increased noise levels will not harm the digital signal. As more channels are needed, fiber backbone operation of the trunks can provide many extra channels.

After HDTV really comes into its own, there are many other solutions available.

The use of simulcasting now will result in the ultimate abandoning of NTSC which will then eliminate the principal system limitation of composite triple beat intermodulation.

7.2 Satellite.

For satellite operation it is desirable to recode the DSC-HDTV signal into a phase modulated constant amplitude Minimum-Shift Keyed (MSK) signal. A RF bandwidth of approximately 20 MHz must be accommodated.

7.3 VCR.

VCR Recording and Playback of the entire 6 MHz digital signal can be accomplished with current consumer VCR technology, both electrical and mechanical.

Processing the encoded signal widens the encryption options and opens the possibility of excluding the recording of decrypted material. This prevents the unauthorized distribution of decrypted material.

7.4 Fiber-Optic Transmission.

The DSC-HDTV signal is adaptable to transmission over fiber-optic links either in its 6 MHz format as on fiber backbone or in satellite format or in PCM format.

SECTION 8
CONCLUSION

The Digital Spectrum-Compatible High-Definition Television system is a system that can operate simulcast-fashion in the current NTSC environment under interference-limited service conditions. All current NTSC terrestrial broadcasters can be assigned a second channel for DSC-HDTV which will provide HDTV noise-free performance throughout a service area equal to or, in most cases, greater than the current NTSC service area.

A video signal of up to 34 MHz bandwidth, progressively scanned, is encoded by an algorithm that achieves the compression needed for transmission in a 6 MHz channel without sacrificing image quality.

The system has features that are attractive to all of the alternate television delivery means of terrestrial broadcasting, cable, satellite, VCR and fiber.

SECTION 9
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APPENDIX - COMPUTER PROGRAM FOR INTERFERENCE AND NOISE CALCULATIONS

A computer program was developed to process the ATV receiver interference and noise data, as well as other Service Area determinants, into service and interference contours. It utilizes the FCC Propagation characteristics, interpolated to one mile intervals, for Low VHF, High VHF and UHF. Any appropriate radiated power (ERP) and antenna height (HAAT) can be chosen.

For the Desired Signal F(50,50) or F(50,90) can be chosen, while for the Undesired Signal F(50,10) propagation is used.

From the fieldstrength curves, antenna gain, downlead loss, receiver Noise Figure and Carrier/Noise threshold, the Noise Limited Service Contour and the Noise Limited Service Area are determined.

The interference contours are determined from the Desired and Undesired fieldstrengths, the (measured or assumed) receiver D/U thresholds and the receiving antenna front-to-back ratio. The latter is a variable that ranges from its maximum value for receiver locations between the Desired and Undesired transmitters around the periphery of the Noise Limited Service Contour to zero at the location farthest removed from the interfering transmitter.

ATTC determines the lowest Desired ATV signal level by injecting a certain noise power and then determining the signal threshold. The other two Desired Signal levels are 15 and 30 dB above this level. This allows the geographic signal contours and the location of intersections of Desired-to-Undesired signal ratios to be determined, resulting in a graphic display of Noise Limited and Interference Limited Service Areas.