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Digital Video Tape Recorder For Digital HDTV

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Field of the Invention

This invention is related to the field of digital video signal processing, and more particularly to processing a digital high definition television signal by a digital video tape recording/reproducing system.

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Background of the Invention

Digital high definition television (HDTV) systems have recently been proposed. One such system, proposed by the Advanced Television Research Consortium and generally known as the AD-HDTV system, prioritizes and digitally processes a high definition television signal subjected to MPEG-like variable length coding. MPEG is a standardized coding format being established by the International Organization for Standardization. The standard is described in the document "International Organization for Standardization," ISO/IEC DIS 11172, CD 11172-1, CD 11172-2, CD 11172-3 Rev. 1, version of January 21, 1992, Coding for Motion Pictures and Associated Audio for Digital Storage Media, which document is incorporated herein by reference for description of the general code format. Aspects of the AD-HDTV system are described in US Patent 5,168,356-Acampora et al. In the system described by Acampora, codewords are prioritized to reflect high priority and relatively lower priority standard priority information in a digital datastream. Codewords are formed into transport packets, or cells. Each transport packet includes a packed data payload section prefaced by a header which contains information identifying the associated payload data.

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It is desirable to record and reproduce (playback) such a digital HDTV signal by means of a device such as a consumer video cassette recorder (VCR) for example. Such a device uses two



5 or more magnetic heads mounted on the periphery of a rotating drum. The heads are physically separated by a predetermined amount, and record/reproduce a signal in alternate successive angled tracks on a magnetic tape. Both consumer and professional VCRs often include provision for special "trick" features such as variable speed forward (eg., fast search), reverse and freeze-
10 frame. The disclosed recording/reproducing apparatus is capable of reproducing pre-recorded media, and can record both a received broadcast high definition television such as a signal in accordance with the AD-HDTV format, as well as live pictures from a camera. The present invention is directed to means for
15 facilitating the operation of high definition digital video recorder/reproducing apparatus, with respect to special features operation in particular.

Summary of the Invention

20 In accordance with the principles of the present invention, digital video tape recording/reproducing apparatus suitable for processing a high definition television signal includes provision for controlling the occurrence of high priority image information. Such information is selectively recorded at normal speed at
25 predetermined regions on tape tracks so as to be appear along a tape head scanning path associated with specific reproducing speeds greater than normal (eg., 20x normal). Input high priority data may be reordered or duplicated for recording in predetermined tape regions. In either case, input data is
30 manipulated to produce a viewable image during reproduction at higher than nominal reproduction speeds, eg., in a fast search mode. In an illustrated system for receiving an MPEG coded datastream, an output datastream at greater than normal reproduction speed comprises either intracoded I-frame data cells
35 only, or a whole Group of Pictures (GOP).



5 In accordance with a feature of the disclosed system, feature bits/indicators containing operating instructions for subsequent receiver circuits are added to the datastream.

In accordance with another feature of the disclosed system, information is processed at the MPEG codeword level. An input MPEG coded datastream is decoded to MPEG words, then selected
10 MPEG words are re-coded and recorded in tape packets.

Brief Description of the Drawings

In the drawing:

15 Figure 1 illustrates a portion of a magnetic tape showing a helical tape recording format.

Figure 2 illustrates the head scanning path of magnetic tape tracks during normal play.

Figure 3 illustrates the head scanning path of magnetic tape tracks in fast scan modes.

20 Figure 4 illustrates data recovery areas in fast tape scan modes.

Figures 5 and 6 illustrate the recorded position of high priority (HP) information for fast scan reproduction in accordance with the present invention.

25 Figure 7 illustrates the relationship between picture, datastream and magnetic tape information in a fast forward features mode, in the context of Figure 6.

30 Figure 7a is a block diagram generally illustrating functional aspects of the fast forward features mode described in connection with Figures 6 and 7.

Figure 8 is a representation of datablock groups consistent with the MPEG standard.

Figure 9 is a generalized pictorial representation of a hierarchical data format consistent with the MPEG standard.

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5 Figures 10, 11 and 12 show functional details, in block diagram form, of a cell-level video tape recording/ reproducing system employing the invention.

Figures 13-16 illustrate aspects of data cells processed by tape recording/reproducing apparatus according to the invention.

10 Figure 17 shows details of the operating structure of a portion of the system shown in Figure 12.

Figure 18 shows details of a known transport block (packet) header component for the AD-HDTV system.

15 Figure 19 illustrates the relationship between high priority (HP) and low/standard priority (SP) data channels in an HDTV system, and a picture frame sequence according to the MPEG standard.

Figure 20 is a table illustrating aspects of a slow features operating mode of a tape recording/reproducing system according to the invention.

20 Figure 21 is a pictorial helpful in understanding the development of output frame data in fast forward reproducing mode.

25 Figures 22 and 23 show functional details, in block diagram form, of an MPEG-level video tape recording/ reproducing system employing the invention.

Figure 24 illustrates the general configuration of a tape packet locally generated by the recording/reproducing system.

Detailed Description of the Drawing

30 By way of background, and as an aid to understanding the operation of the invention, Figure 1 shows a segment of magnetic tape recorded in conventional helical format. Helical-scan tape tracks are oriented at an angle as shown, and are alternately recorded at different azimuths, "a" and "b," in accordance with
35 conventional practice. Also in accordance with conventional



practice, longitudinal tracks disposed along an outer edge of the tape contain servo and timing information.

- 5 In normal VHS television format, each track encompasses one image field interval. In the case of the tape wrapping around the rotating drum 180 degrees, and with two recording/playback heads, the drum completes one revolution in two fields (1/30 second) at a drum speed of 1800 rpm. To obtain more bandwidth
- 10 for digital recording, each field/frame may be segmented into five portions, for example. Such segmentation does not present a problem since data headers provide a reliable means of identifying data segments to be recombined into an image. In such a digital system the drum spins five times as fast (9000 rpm).
- 15 This speed is assumed to be acceptable for accomodating a 35 Mbps (bits per second) gross data rate, or about 24 Mbps net video rate, eg., after error correction, control and audio data). Bandwidth capacity may be further increased by increasing the number of tracks and associated heads. At 35 Mbps, each track
- 20 contains 115 Kilobits or 14.5 KiloBytes. This amount of data is equivalent to about 100 transport packets in the AD-HDTV system. In a digital system, each track may contain more or less than a field/frame of information due to the nature of the variable length coded data associated with each transport packet.
- 25 Head gaps are skewed with respect to the direction of tape head motion by a few degrees, with alternate heads tilted in opposite direction, as is known (azimuth recording/reproducing). When recording, the tracks overlap so that the tape head is completely covered with abutting tracks. When reproducing at a
- 30 normal speed, each head is centered on its associated track with the correct tilt and adjacent track signals are greatly attenuated by the effect of the azimuth and are thus effectively disregarded. This normal mode process is illustrated by Figure 2, showing the paths taken by first and second heads over respective (white and
- 35 shaded) tracks during successive passes of the respective heads.



In a special "features" mode, such as fast search, each head
5 passes across the tape at an angle to the recorded tracks. This
process is illustrated in Figure 3 for fast-search speeds 2x, 8x and
20x faster than normal. In effect, each head drifts across the tape
tracks from one edge to the other at a rate that is a function of the
tape speed. In the higher speed modes, data recovered by each
10 head appears in the form of a burst of good data cells followed by
a gap as the head passes over a track section recorded with the
other azimuth angle, then a burst of good cells from somewhere
else in the picture. In this regard it is noted that the likelihood of
picture data continuity diminishes with increasing tape speed due
15 to the increasing number of tracks crossed as the head transits the
tape from edge to edge. The data disruption (gaps) produced by
high speed tape operation is illustrated by Figure 4. The data gaps
are caused by the tape head skipping tracks rather than following
a given track continuously as in the normal speed mode, coupled
20 with the inability of a given head intended to operate with respect
to a track recorded at one azimuth (shaded track) to recover data
from an adjacent (white) track recorded at a different azimuth.

The fast search speed range is dictated by the ability to
search the tape rapidly while obtaining a reasonable preview of a
25 displayed picture. A speed range from about 10x to 30x normal
generally satisfies this objective. At slower speeds, a viewer may
become impatient. The high end of this speed range may be too
fast for skipping television commercials, for example, but would
still be useful for searching a tape.

30 Fast features are distinguished by the fact that the head
cannot cover all of the tape area, whereby only a portion of the
available data becomes available for display. In accordance with
the principles of the present invention, it is recognized that this
deficiency may be significantly compensated for by managing the
35 data so as to determine which data subset on the tape becomes
available for display at one or more predetermined tape speeds.



To this end certain data cells are massaged, eg., duplicated or re-ordered, to permit reproduction from the tape in a desired temporal sequence at predetermined tape speeds. Specifically, high priority data are positioned on the tape so as to be reproducibly scanned by the head at selected tape speeds. This process is facilitated by the packetized datastream, and in particular by indentifying and timing information contained in the headers associated with the data packets, as will be explained in connection with subsequent Figures. In the AD-HDTV system HP cells contain the most important information required to reproduce the picture. The HP cells are treated in a manner which minimizes the chances of the information being lost. In over-the-air transmission the HP information is sent at a higher power level than the LP information. For tape recording, it may be advantageous to record the HP cells more than once.

Since at high tape scanning speeds the reproduced/displayed information is otherwise unpredictable, in the disclosed system certain high priority information which is known to produce a good image is recorded at specific track locations which are traversed by the head at selected tape speeds. This high priority information includes low video frequencies including DC, important AC image information, audio and synchronizing information, for example. This recorded data format is illustrated by Figure 6, which is derived from Figure 5.

One function of the HP information is synchronization of the data presentation with the arrival of data in the bitstream. The video input to the system arrives as pictures or frames that occur at constant rate. The encoding process produces a variable length coded bitstream in which individual frames occupy different numbers of bits, and hence different time intervals. The receiver must produce video output frames at constant rate. In addition, the decoder must have all of the input bits required to generate an output frame at the time that the bits are needed. In the AD-



HDTV system, timing packets in the HP channel are used, in
5 conjunction with the picture header information in the bit stream
to achieve the desired synchronization. The picture header
information in the bit stream occurs in the HP data cells at the
beginning of the data for each frame. These picture headers
include an identifier for the picture sequence number. This
10 picture header sequence number is, in effect, a count, going from
0 to 1023 of frames in the video sequence. Picture (or frame) 123
follows picture 122 and is followed by picture 124. The picture
header information can be thought of as conveying the meaning:
"The following bits determine *how* to make frame 123." The
15 timing cells in the HP channel are inserted by the encoder at
approximately a constant rate, the display frame rate. The timing
cells do not align with the picture data. When each timing cell
arrives, it is time for the decoder to make an output picture. The
timing cells contain a sequence number that corresponds to the
20 picture that is to be made. At some time, a timing cell arrives,
containing a sequence number 122, indicating that frame 122 is to
be made. Very nearly one frame time later, a timing cell arrives
containing sequence number 123, indicating that frame 123 is to
be made. The time of arrival of the timing cell indicates when the
25 frame is to be generated, and the contents of the timing cell
indicates which frame is to be made. If the data for frame 123
arrives before the timing cell for frame 123, the decoder waits for
the proper timing cell. If the timing cell for cell 123 arrives at the
decoder and the buffer in the decoder contains something other
30 than the picture header for cell 123, the data in the buffer is
discarded. This recorded data format is illustrated by Figure 6,
which is derived from Figure 5. The timing cell information can
be thought of as conveying the meaning: "Now is the *time* to
make frame 123."
35 Additional redundant information is carried in the timing
cell, such as the type of frame (I,B or P). The timing cell is also the



5 vehicle for transmitting the decoder control bits or feature bits described below.

As shown in Figure 6, high priority (HP) data packets (cells) are recorded at five predetermined regions of a track, designated as HP1 through HP5. The track sections passed by the head during non-standard speed playback (eg., fast search) determine the recorded locations of HP data. HP data is spatially recorded along the track to facilitate recovery during other than nominal reproduction speeds when the head traverses multiple recorded tracks during a single pass.

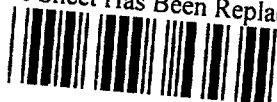
The HP data packets are located so that they encompass all of the tape track segments within each designated HP region, not only the black areas within each HP region. The black areas indicate the head contact areas along the head path at predetermined 2x, 8x and 20x normal tape speeds (see Figure 3), ie., areas where the head acquires information from the tape at these predetermined speeds. The remaining intervening regions containing head contact areas are considered as low priority (LP) regions and are designated as regions LP1 through LP3 for the 20x normal speed example. Other low priority regions, eg., between regions HP2, HP3 and between regions HP4, HP5 have not been labelled as such. Low priority data is written to the tape as it appears in the original input datastream, ie., without re-ordering.

The following discussion is made with respect to tape speed at 20x normal speed. In the AD-HDTV system, HP information includes low frequency video information and audio and synchronizing (timing) information. In the present embodiment, the HP regions are filled with re-ordered intracoded I-frame cell data, and the LP regions arbitrarily contain B frame or P frame cell data among other low priority information as received. It is noted that the HP regions are selected so that good results are produced at more than one speed, ie., HP data is predicatably



recovered at these speeds. Specifically, each of the three
 5 illustrated tape speeds (2x 8x and 20x normal) will have HP
 information recorded to coincide with the associated head path so
 that a viewable or recognizable image will be produced by a head
 following each of the associated paths. For example, the
 uppermost 20x speed path includes five designated HP regions
 10 (including one at the origin), each of which has a counterpart at
 the other designated high tape speeds. In Figure 6, the numbers
 shown in the third horizontal track from the top designate the
 nominal width of the associated HP or LP region, in data slices.
 Thus, for example, region HP1 contains 2 high priority data slices,
 15 region LP1 contains 6 low priority data slices, region HP2
 comprises 3 data slices, and so on. It is to be understood that
 these slice designations are a simplification in the interest of
 providing a clear explanation. The HP data is recorded at normal
 tape speed so that this data is traversed by the head at the
 20 selected fast forward features speeds, as will be discussed
 in connection with Figure 7.

In the recording process, the variable-length-encoded
 bitstream is put onto the tape. An example not involving
 duplication of data will be described first. The total bit rate to be
 25 recorded corresponds to the total area of tape to be recorded. In
 previous recording methods, the data to be recorded is put on the
 tape sequentially. In the current example, there is no direct
 correspondence of the position of the data on the tape to the time
 sequence of the video. The bitstream data is rearranged, cell by
 30 cell, to provide the feature mode playback. A desired pattern of
 cells on the tracks is pre-determined, based on the desired
 playback feature speeds. As shown in Figure 6, the planned
 pattern is: 2 HP cells, 6 SP cells, 3 HP cells, 1 SP cell, 4 HP cells, 5
 SP cells, 4 HP cells, 2 SP cells, 3 HP cells and 12 LP cells. The
 35 corresponding sequential regions in figure 6 are marked HP, LP1,
 HP2, (LP not-marked), HP3, LP2, HP4, (LP not-marked), HP5, and



LP3. The tape regions are filled with the next available cell of the
 5 corresponding type that is available in the prioritized bitstreams.
 In normal playback, the full data stream is recovered from the
 tape. The first 2 cells of a track go into the HP output stream, the
 next 6 cells go into the LP stream, the next 3 into HP, and so forth.

Again, with reference to Figure 6, now assume that the same
 10 tape is played back at 2x speed. Valid data is read from the tape
 in the region marked in black. The reading process starts on track
 1. The first 2 cells read are assigned to HP, the next 6 cells
 assigned to SP, the next 3 to HP, the next cell to SP and so forth.
 Somewhere in region LP3 the data becomes invalid. Valid data
 15 resumes with the other azimuth head on track 4, and repeats the
 same pattern. It can be seen that not all of the data is recovered,
 but the data that was lost was LP data. It is a characteristic of the
 prioritization of AD-HDTV that pictures can be generated from HP
 data only.

20 Figure 7 illustrates the process of tape machine operation in
 a fast forward features mode at 20x normal speed, with respect to
 cell data reordered into a desired sequence of HP and LP data
 regions as shown in Figure 6. For the purpose of the following
 example it is assumed that the reordered data placed in HP
 25 regions HP1 through HP5 is MPEG intraframe coded I-frame data,
 which is temporally coherent information independent of other
 information, unlike B-frame or P-frame data which are
 predictively coded. To simplify the following discussion of Figures
 6 and 7, it is assumed that low priority LP regions LP1, LP2 and
 30 LP3 respectively contain B1, B2 and P1 frame data in that order,
 although the actual content of the LP regions would be arbitrary,
 ie., the LP data would occur in the LP regions in the order
 received in the datastream.

To help understand this material, reference is made to
 35 Figures 8 and 9 together with pictorial (A) of Figure 7, showing
 the MPEG arrangement of a Group of Pictures (GOP). A GOP, in the



context of the MPEG standard, contains 9 image frames, beginning
5 with an I-frame followed by a sequence of B- and P-frames as
follows: I, B1, B2, P1, B3, B4, P2, B5, B6. An I-frame usually requires
many more bits than either B or P frames. A GOP exhibits a
display time of 9/30 sec., or about 0.3 seconds. At a channel rate
of 24 Mbps, an average GOP corresponds to 7.2 Mb in size (24 x
10 9/30). A GOP may vary in size from 1.2 Mb to 13.2 Mb. An AD-
HDTV receiver typically will contain two stored past and future I
and P anchor frames. When a B frame is received, an output image
frame will be generated from the stored anchor frames. When a
non-B frame is received, the existing future anchor frame is
15 moved to the position of the past anchor frame, and a new future
anchor frame is created from the received data while the past
anchor frame is being displayed.

More specifically, in this example the input datastream
comprises a data-compressed sequence of frames that are coded
20 compatible with the MPEG format. This format is hierarchical and
is illustrated in abbreviated form in FIGURE 9. The MPEG
hierarchical format includes a plurality of layers each with
respective header information. Nominally each header includes a
start code, data related to the respective layer and provision for
25 adding header extensions. Each header includes information
related to the data in the data packet with which the header is
associated. The header information aids data assembly and
synchronization eg., at a receiver, and includes information such
as service type (eg., audio, video), frame type, frame number and
30 slice number, for example. A header of this type and its
processing are described in the context of an AD-HDTV signal
processing system employing MPEG signal coding in previously
mentioned US Patent 5,168,356-Acampora et al. Figure 18 of the
present application shows details of the transport block header
35 used in the AD-HDTV system described in the Acampora et al.
patent. Figure 19 shows the timing relationship between the AD-



5 HDTV high priority (HP) and the relatively lower priority standard
priority (SP) datastreams, and the time sequence of the MPEG
coded I, B and P frames.

When referring to the MPEG compatible signal processed by
the system, what is meant is that (a) successive picture
fields/frames of video signals are encoded according to an I, P, B
10 coding sequence, and (b) coded data at the picture level is
encoded in MPEG compatible slices or group of blocks, where the
number of slices per field/frame may differ and the number of
macro blocks per slice may differ. An I coded frame is one which
is intraframe compressed (coded) such that only I frame
15 compressed data is required to reproduce an image. P coded
frames are coded according to a forward motion compensated
predictive method, where the P frame coded data is generated
from the current frame and an I or P frame occurring before the
current frame. B coded frames are coded according to a
20 bidirectionally motion compensated predictive method. The B
coded frame data is generated from the current frame and from I
and P frames occurring both before and after the current frame.

The coded signal processed by the present system is
segmented into groups of pictures (frames), or GOPs, illustrated by
25 the row of boxes L2 (FIGURE 9). Each GOP (L2) includes a header
followed by picture data segments in the form of a sequence of
nine picture frames I, B, B, P, B, B, P, B, B as illustrated by pictorial
(A) of Figure 7. The GOP header includes data related to the
horizontal and vertical picture size, the aspect ratio, the
30 field/frame rate, the bit rate and other information.

The picture data (L3) corresponding to respective
picture frames includes a picture header followed by slice data
(L4). The picture header includes a field/frame number and a
picture code type. Each slice (L4) includes a slice header followed
35 by a plurality of blocks of data MBi. The slice header includes a
group number and a quantization parameter.



Each block MBi (L5) represents a macroblock and includes a header followed by motion vectors and coded coefficients. The MBi headers include a macroblock address, a macroblock type and a quantization parameter. The coded coefficients are illustrated in layer L6. Each macroblock includes 6 blocks, including four luminance blocks, one U chrominance block and one V chrominance block, as shown in FIGURE 8. A block represents a matrix of pixels, e.g., 8 x 8, over which a discrete cosine transform (DCT) is performed in this example. The four luminance blocks are a 2 x 2 matrix of contiguous luminance blocks representing, e.g., a 16 x 16 pixel matrix. The chrominance (U and V) blocks represent the same total area as the four luminance blocks. That is, before compression the chrominance signal is subsampled by a factor of two horizontally and vertically relative to luminance. A slice of data corresponds to data representing a rectangular portion of an image corresponding to an area represented by a contiguous group of macroblocks. A frame may include a raster scan of 360 slices, 60 slices vertically by 6 slices horizontally. The block coefficients are DCT transformed one block at a time. The DC coefficient occurs first, followed by respective DCT AC coefficients in the order of their relative importance. An end-of-block code EOB is appended at the end of each successively occurring block of data.

Referring again to Figure 7, pictorial (B) is a simplified expanded view of pictorial (A). Each I, B and P frame comprises image slices with a data component and a header component which defines the associated slice data component. Pictorial (C) represents the data recovered from the magnetic tape at 20x normal speed. Each segment of recorded data (C) represents a burst of about 6-7 data cells followed by a gap of about 3-4 data cells, at 20x normal speed. The recovered data is derived from a tape with data arranged into predetermined HP/LP regions as shown in Figure 6. In the interest of clarity, pictorial (C) does not



show the data gaps resulting as the head passes over other
5 azimuth recorded tracks. Pictorial (D) illustrates the datastream at
the output of the tape machine when playing back at 20x normal
speed. The playback data (D) has been re-ordered and converted
(from recorded data C) to the standard MPEG sequence of I, B, B,
P... frames which a receiver's signal processing circuits expect to
10 see for display processing purposes. Thus pictorial (D) represents
image data in a fast forward features mode at 20x normal speed
based upon an arrangement of the tape into HP and LP segments
as shown in Figure 6.

The tape data packets are reordered into prioritized regions
15 as shown and discussed with respect to Figure 6 by using
information including timing information contained in the tape
packet headers together with an indexing system as will be
described. The recovered tape data sequence begins with I-frame
information since this information begins a GOP according to the
20 MPEG standard and is therefore readily identified. In addition, a
Picture Start codeword is associated with the beginning of a GOP.
Beginning with track 1 at 20x speed, the first recovered data from
high priority region HP1 is I frame slice information which in
pictorial (C) is shown as I₁. The next region scanned by the tape
25 head along the 20x speed path is a low priority region LP1
occurring at track 3. Data recovered from this region, assumed to
be B frame data, is shown as B₃. The third region scanned by the
tape head at 20x speed is high priority region HP3 at track 5. Data
recovered from this region is shown as I₅ in pictorial C This
30 process continues by acquiring I frame data from tracks 7, 11 and
13, B frame data from track 9, and P frame data from tracks 15-
19, in the sequence shown. In pictorial (C), the subscript
associated with a given I, B or P frame designates the track from
which the data was recovered by the head. The data recovered
35 from the LP3 region of the tape corresponds to disconnected
regions of LP data from that is probably from somewhere in



frames 15 through 19. Because of the nature of the variable-length-encoded bitstream, it is generally not possible to specifically indicate which frames of video correspond to specific regions of the tape.

The recovered data in pictorial (C) is inappropriate for processing by a receiver, since a receiver expects the see data in the I B B P B B P B B MPEG frame format. Thus the data recovered at 20x normal speed (pictorial C) must be re-converted back to an MPEG compatible datastream. Such a re-converted MPEG compatible datastream reflecting 20x tape operation is illustrated by pictorial (D) and is developed as follows. First, the tape packet headers of the recorded data in pictorial C are examined to identify the recovered information. The data is then re-ordered into the standard MPEG format by grouping I, B and P frame data together in sequence. The HP1-HP5 I frame data is placed first in sequence in the output datastream (I1, I5, I7, I11, I13...), followed by LP1 and LP2 B frame data (B3, B9...), other B frame data, and LP3 P frame data (P15-19...).

Figure 7A generally illustrates the process by which this is accomplished. In step 70, the input I, B, P datastream (pictorial B in Figure 7) is reordered so that the data cells exhibit the sequence of high and low priority regions shown in Figure 6. In step 71 tape packet header data is provided for identifying the reordered data. The reordered tape packets are recorded at normal speed, and played back at 20x normal speed in a features mode (step 72). During 20x playback the headers of the recorded packets are examined in step 73. These headers contain information identifying the I, B, P data sequence shown in pictorial (C) in Figure 7. In step 74 the data sequence is converted back to the standard MPEG sequence expected by the receiver (pictorial D). The re-converted IBBP... frame sequence is stored in a multiple page (I, B, B, P) memory (step 76), which is continually scanned for deriving output data to be applied to a tape signal

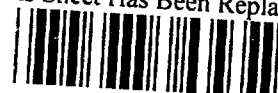


receiver via a playback output processor/buffer (step 78).

- 5 Addresses in frame stores which have not been altered to reflect reordered data remain unchanged, ie., with old data from prior tape head scans.

10 At normal tape speed, all IPB frame data derives from one tape track, in contrast to the 20x normal speed situation where, for example, I frame data are obtained from more than one track. With the disclosed technique, reordered HP I frame data is advantageously placed so as to be predictably recovered at several places along the tape head path, at more than one tape speed in this example. A visual presentation in the illustrative I frame example is a series of still image information at a refresh rate likely to be about 3 to 5 frames a second. Each frame is composed of pieces (from macroblocks, through slices to larger pieces) from the corresponding collection interval.

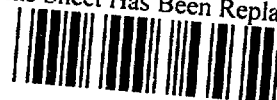
15 The disclosed technique for remapping high priority cell data into predetermined tape regions for reproducible recovery during a high speed features mode essentially first involves determining what scan rates produce good results. Typically, a scan rate that is moderate (2, 3, or 4x) is desired to allow accelerated viewing of pictures. In addition, the fastest rate that produces viewable pictures is desired (eg., 20x) to permit rapid skipping of unwanted scenes. Next, the areas of the tape traversed by the head at these scan rates is mapped, ie., the head track is determined. Finally, HP cells are assigned (re-ordered) to designated tape areas traversed by the head at selected scan rates. A duplicate of a timing cell associated with the beginning of a GOP may be placed at the beginning of a tape scan, since there is a high probability of recovering such a cell. If HP cells do not completely fill selected areas, the cells are distributed in clumps in the centers of the selected areas. It is noted that, during fast scans, as the pickup head is displaced with respect to the position centered with respect to the track (of correct azimuth), the signal



quality follows a trapezoidal shape. Specifically: the signal is not
5 present, the signal improves, the signal is good while the head is
aligned with the center of the track, the signal gets worse, and the
signal is lost. The HP data is located in the regions where the
signal is good. If the selected areas are large enough for the
original number of cells, but not large enough to hold all the
10 duplicate cells, the duplicates are distributed uniformly
throughout the area. If the selected areas are too small for the
original number of HP cells, the least useful scan rate should be
ignored and the head track is remapped at the time of product
design.

15 With this technique, the fraction of the image which is
visually good or acceptable is greater than that which would
otherwise result, even though some temporal segmentation may
be present. The amount of temporal segmentation which may
appear is a function of frame-to-frame motion, which may be
20 very little in many cases. The illustrated tape speeds are those
which are considered to give good results, but other speeds may
produce better results. The disclosed system advantageously
offers flexibility with respect to choice of speeds in the high speed
features operation mode, including speeds which are non-
25 multiples of the number of frames in a GOP.

When presenting a picture at a fast scan speed, a decision
must be made about when to present data to the output decoder.
Recall that the variable bit length encoded data recovered in a
frame time does not correspond to a frame's worth of data. One
30 frame time may contain several B-frame's worth of data or only a
fraction of an I-frame's data. The operation of an AD-HDTV
decoder or an MPEG decoder takes place in units of pictures and
frames. If a frame's time data corresponding to part of an I frame
is delivered to a decoder, only part of the picture is produced. To
35 update the entire picture with refresh action, it is necessary to
accumulate enough of the bitstream to describe how to make an



entire picture. When this information is delivered to the decoder,
5 the corresponding timing cell may be delivered to cause the generation of the frame.

In the example illustrated by Figures 6 and 7, it was assumed that I frame data is the high priority data arranged in the designated HP regions. Since the tape head will recover data
10 from both high and low priority regions at 20x normal speed, the playback data stream (Figure 7, pictorial C) will include high priority I frame data and low priority B and P frame data. When it is intended to display an image at 20x speed obtained only from I frame information, the tape machine will output only the I frame
15 data (eg., only I1-I13 in Figure 7 (C)). This may be easily accomplished by examining the headers of the playback cells and rejecting all except those cells containing I frame information. Since an I frame encompasses approximately 0.2 seconds, at 20x normal speed the cells from 4 seconds of original video will be
20 collected to produce a 0.2 second collection interval. As noted above, the output will be a series of I frames only in this case, which is illustrated by Figure 21. In Figure 21 the upper pictorial represents a portion of data recovered from the tape at 20x speed, shown relative to real time in milliseconds, where only I frame
25 cells are used. The data segments designated "not I" represent rejected low priority data. Thus the upper portion of Figure 21 corresponds to the output playback datastream shown in pictorial (C) of Figure 7 with I frame data cells grouped together and B, P frame data cells rejected. The lower pictorial of Figure 21
30 illustrates the formation of a synthetic I frame from a composite of data acquired from 20 GOPs, shown with respect to tape speed in seconds (at 20x normal speed). Although the variable length coded bitstream does not necessarily correspond to equal duration pictures, there is a maximum deviation in time of the picture data
35 in the bitstream from the time at which the timing cell causes the



generation of the output frame. This maximum time deviation is set by the buffer size, and is typically 1/4 second. If the GOP consists of 9 frames, then 20 GOPs at 20x speed are accumulated in 9 frame times ($9/30 \text{ seconds} = 0.3 \text{ second}$), and 20 GOPs of data on the tape will have passed in $0.3 + 0.25 = 0.45 \text{ second}$. Null cells are inserted in the playback datastream in place of the rejected cells to maintain datastream continuity. A visual presentation in the illustrative I frame only example is a series of still images at a refresh rate likely to be about 3 to 5 frames a second. Each frame is composed of pieces (from macroblocks, through slices to larger pieces) from the corresponding collection interval. Some I frame data may be used in more than one output frame.

Alternatively, a playback output image may be comprised of a composite GOP if all recovered HP frames and SP frames are retained in the output playback datastream (as shown in Figure 7 (C)). Since a GOP encompasses approximately 0.3 seconds in real time, at 20x normal speed the cells from approximately 6 seconds of original video will be collected to produce a 0.3 second collection interval for a GOP. In this case the 20x playback output is one GOP in which each frame is a composite of the 20 corresponding frames of input. At a 20x scan rate, 20 tape GOPs result in one output GOP. For example, the second B frame (B2) of the 20x playback output is made from the 20 2nd B frames in the sample. An advantage of acquiring a whole GOP in the high speed tape scanning function is that a picture with smoother motion may result due to the presence of spatially coded P and B frame cells, and motion vectors from the P and B frames are likely to be in approximately the correct direction. For example, consider a picture composed of a speaking person in front of a slowly panning background. In the case of fast forward playback using I frame information only, the still parts of the speaker will look good, but the moving parts of the speaker will be somewhat distorted, and the background will appear as a sequence of distorted stills. If the whole GOP is used during playback, the I



5 frame image portions appear about the same, but some blocks of the picture change as other frames of the GOP are displayed. The moving background is likely to remain distorted, but much of the picture moves smoothly in approximately the correct direction.

10 The implementation of whole GOP scanning uses a constant size interval of interest, which is 9 frames in the case of the AD-HDTV system. If the definition of a GOP changes to other than 9 frames in another system, the programming and operation of an index-index and computer controller (shown in Figures 10 and 12) are adjusted accordingly. All GOP frames are used. The start of the interval of interest is the first cell of the I frame beginning the
15 GOP. The sequence of frame types (I, B₁, B₂, P₁, B₃, B₄, P₂, B₅, B₆) within retrieved GOPs is tracked, and cells are sorted within like frames, eg., cells that came from B₃ frames are put into the B₃ output frame.

20 The process of redistributing the HP cells during recording involves buffering the cells into cell memory as they are received. A Cell Analysis Processor (as will be described) knows the time sequence of the cells being written to the memory. Specifically, the Cell Analysis Processor monitors the position of a cell in the input data stream relative to the start of a Group of Pictures. This
25 position is encoded in packet headers produced by the tape machine, eg., unit 1016 in Figure 10. This is accomplished without difficulty since the tape mechanism can maintain a precise count of the tape position in terms of the following factors: hh (hours), mm (minutes), ss (seconds), ff (frame number), tt (track number)
30 and pp (packet number). This information is unambiguous, and is mechanically derived from the head position and the longitudinal timing/sync track on the tape itself. This position information can be represented as a binary value. During the recording process, each cell is associated with a 10-bit linear temporal reference
35 number at the frame rate. When recording, the last picture header processed contains the temporal reference number. This number



is temporally stored in the recorder, and recorded in the next tape
5 related header to be written by the tape mechanism. The GOP
starting point and its temporal reference are readily determined
as noted earlier. As the (AD-HDTV) cells arrive, they are serially
numbered within a GOP beginning at the GOP start. This is a 14-
bit number. The difference between the linear temporal reference
10 and the 10 least significant bits to the tape position, along with
the 14-bit cell serial number, are included in the tape packet
header. Any packet, when recovered during the playback process,
yields this 24-bit number that can be used to regenerate the exact
time of arrival of the cell.

15 At normal speed playback, the original position of each cell
in the datastream is retrieved from the tape packet headers. The
playback cell datastream can then be rearranged in the original
order.

A general arrangement of a high definition video tape
20 recorder/reproducer and a high definition television receiver is
shown in Figure 10. A VTR 1008 receives an input HDTV signal
which is decoded by an HDTV decoder 1010. If the input signal is
of the AD-HDTV type, decoder 1010 may be arranged as described
in US Patent 5,168,356-Acampora, some aspects of which are
25 shown in Figure 11. Cell header information is analyzed by unit
1012 to obtain data about cell contents including timing and
sequence, and high priority cells are duplicated by unit 1014 as
an aid to implementing features mode operation. Specifically,
selected cells are duplicated in the recorded stream to allow fast
30 scans. In this example, where the AD-HDTV FEC function is
included in the tape machine (in decoder 1010, see unit 1154 in
Figure 11), a benefit is obtained that error related overhead does
not have to be stored. The extra storage that would have been
used for FEC bytes may now be used for redundant (duplicate)
35 cells to make certain information available during a fast search
mode. Additional storage capacity beyond the minimum required



for the storage of the original bitstream may become available
5 through the process of elimination of FEC data as described above
or may become available due to technology improvements in the
recording process. This excess capacity is used for the redundant
storage of cells to improve fast scan performance. As was
described earlier, in the design process, selected scan speeds are
10 mapped to regions on the tape in which the HP data is to be
placed. If extra tape capacity is available, the mapping shown in
Figure 6 may be done for additional scan speeds. For example, if
an additional scan speed were desired, and data at the new scan
speed was not recovered in regions HP2 and HP4, but was
15 recoverable in a region just to the left of HP2 and just to the left
of HP4, the HP data that is recorded in HP2 and HP4 could be
redundantly recorded in the right ends of regions LP1 and LP2.
The displaced LP data from LP1 and LP2 is absorbed in the extra
capacity of the media. In the illustrative example described
20 previously, HP cells 1 and 2 were recorded in region HP1, then SP
cells 1,2,3,4,5,6 recorded in LP1, then HP cells 3,4 in HP2, & etc.
Given extra capacity, the recording pattern is: HP cells 1, 2 in HP1,
LP cells 1,2,3,4,5 in LP1, then HP cells 3,4 in a new duplicate
region at the end of LP1 and the beginning of HP2, then HP cells
25 3,4 again in HP2. The pattern where the redundant cells are
stored is pre-determined when the tape machine is designed.
When playing back at normal speed or 2x, the redundant cells are
recovered. From the position along the scan, these cells are
known to be redundant, and are discarded.

30 Cells are converted to tape packets in unit 1016, eg., by
means of 8:14 modulation whereby 8 bits words are converted to
14 bit codewords for bit rate reduction as known. Tape packets
typically include a header component, an associated data
component and timing/synchronizing information. Tape packets
35 from unit 1016 are applied to an MPEG-compatible signal input of
unit 1018 which includes tape signal processing networks and a



tape transport mechanism. A non-MPEG auxiliary input of unit
5 1018 receives encoded tape packets from an auxiliary source
1020 (eg., a video camera) via a non-MPEG spatial information
tape encoder 1022. Tape output signals from unit 1018 are
provided to a unit 1030 which adaptively converts MPEG or non-
MPEG output signals to a standard RGB (Red, Green Blue) color
10 television signal format in responsive to a flag bit in the
datastream, and to a unit 1032 which converts the tape packets
back to the cell format of the input datastream. Duplicate HP cells
are eliminated by unit 1034 to provide an output signal
datastream of the format expected by the AD-HDTV decoder 1044
15 of television receiver 1040.

Standard RGB output signals from unit 1030 are applied to
one input of an input signal selector 1046 of HDTV receiver 1040.
The cell format output signal from unit 1034 is decoded by HDTV
decoder 1044 at an input of receiver 1040 before being applied to
20 another input of selector 1046. Selector 1046 provides either RGB
format signals or decoded AD-HDTV cell format signals to video,
audio, sync, etc. television signal processing and
reproducing/display circuits 1042 of receiver 1040.

Figure 11 shows HDTV decoders 1010, 1044 of Figure 10 in
25 greater detail. A received input signal is detected by modem
1150, which provides an output signal to a de-interleaver (de-
scrambler) 1152 and a Reed-Solomon forward error correcting
(FEC) decoder 1154. The corrected signal is applied to a rate
buffer 1156 which receives data at a variable rate commensurate
30 with the requirements of subsequent decompression networks in
video decoder 1160. A transport processor performs the inverse
of a data packing and prioritizing operation performed at a
receiver, and additionally performs a degree of error detection in
response to parity check bits included in the transport packets.
35 Transport processor 1158 provides output video and audio signals
to video transform decoder/decompressor 1160 and audio

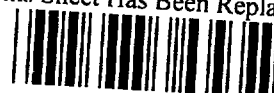
5 decoder 1162, respectively, which provide audio and video output signals with a cell format including data and header components. In an AD-HDTV system as described in US patent 5,168,356-Acampora, the modem provides two output signal associated with HP and LP channels, and the de-interleaver, FEC control and buffer functions are duplicated for both the HP and LP channels.

10 Figure 12 shows a more detailed block diagram of a video tape recording/reproducing device capable of operating at the data cell level. The system of Figure 12 includes a computer controller 1222, ie., a microprocessor, capable of making the many decisions that must be made at a packet/cell rate. Controller 1222
15 interacts with a database including cell buffer memory 1232 containing data read from the tape, and the controller maintains an index 1224 of the buffer contents. For each cell, the index contains information pertaining to cell location in the buffer; cell starts at the tape reference time indicated by factors hh, mm, ss, ff, tt, pp (described previously); cell error status; cell service type
20 (eg., audio or video) including HP/LP indicators; cell frame number; cell frame type; and information translating between the tape temporal reference and, for example, the AD-HDTV linear temporal reference. The last mentioned item can be generated at
25 the time the tape is written to, and indicates which timing packet's domain a data cell belongs to. Additional indexed information may include indicators such as an indicator indicating the validity of the next cell in sequence, a duplication indicator showing that a cell has been duplicated elsewhere, and a
30 duplication index pointer indicating the index location of the duplicated cell.

The index may contain as many as 13,000 entries (the word size of the largest GOP). The size of an index entry is about 80 bits, producing a storage requirement of about 128 KBytes for the
35 index. In addition, as an aid to controller 1222 in using the index,

an index-index 1226 is also maintained. The index-index contains pointers to frame boundaries within the index.

- 5 More specifically, in Figure 12, a camera input formatter 1210 converts an analog RGB color video signal to digital form during recording. Another block, not shown, performs the inverse function for playback. Tape read-write unit 1216 performs bit level modulation/demodulation during recording/playback, eg.,
10 using 8:14 modulation, as known, to convert an eight bit data word to a 14 bit codeword to achieve bit rate reduction. Tape motion controller 1218 contains capstan and tracking controls, and provides controlled acceleration starts and stops. In combination with unit 1216, unit 1218 manages the time-code function. Unit
15 1218 determines which track is being read, and responds to instructions to go to and pause at a specified track, and to begin playing at a given track at a certain speed, for example. Tape packet format/deformat unit 1220 creates and formats tape packets, creates or decodes tape packet headers, and performs
20 Forward Error Control and Cyclical Redundancy Checks as well as providing error indications. HDTV decoder 1212 operates as described in Figures 10 and 11 and provides an output cell stream including data bytes as well as information such as start-of-cell information, error flags, and a byte clock.
- 25 Cell analysis processor 1230 generates read/write addresses and provides data to cell memory 1232. In the recording mode, processor 1230 examines packet headers and timing packets and temporal references such as may be provided in the datastream of an AD-HDTV signal, for example. Processor 1230 additionally
30 maintains a GOP and frame count, a linear temporal reference for determining frame display, pointers to previous GOPs and frames, a tape packet record index indicating exactly where a packet should be recorded, and also controls the delivery of duplicate HP cells to packet format unit 1220. During the playback process, unit
35 1230 fills cell memory 1232 with data cells, scans the data stream and cell headers in particular, creates a cell index entry for each



cell and maintains a GOP and frame sequence state. In addition,
5 unit 1226 index-index entries are created at appropriate times to
designate significant occurrences such as GOP boundaries, frame
boundaries and timing packets in the datastream.

Cell memory 1232 is sized to accomodate a GOP, receives
cells read from analyzer 1230 and writes output cells to packet
10 formatter 1220 at a port speed of about 3 MBps. Cell index
memory 1224 writes entries while analyzer 1230 is filling cell
memory 1232. Index memory 1224 comprises the address
function of controller 1222. Index-index 1226 is associated with
memory 1224 and contains pointers to frame boundaries within
15 index 1224, as will be seen in connection with Figure 17.

Cell output processor 1240 generates read addresses for cell
memory 1232 and provides output cells from cell memory 1232
under control of controller 1222 during the playback mode. A
FIFO buffer in output processor 1240 is loaded with addresses and
20 instructions from controller 1222. Under control of unit 1222,
some data passes from memory 1232 to the output of output
processor 1240 without alteration, while other data may be
altered (eg., service type sequence counts, timing cells and
temporal reference data).

25 Computer controller 1222 implements various features such
as Fast Forward, Slow Motion and Freeze Frame in response to
input user control signals (eg., from a user interface such as a
remote control unit) by communication with cell analysis
processor 1230, cell output processor 1240 and tape motion
30 controller 1218 via flags, buffers and registers as appropriate.
Controller 1222 processes about 30,000 cells/second and exhibits
about 33 microseconds/decision, on average.

Following is a more detailed description of the information
processed by cell memory 1232 and cell index memory 1224.
35 Units 1224 and 1232 process two basic types of cells from which
FEC and error detection data have already been removed. These



cells are video cells, and timing and audio cells as shown generally
 5 in Fig. 13. In these cells ST designates the Service Type code
 portion (video, audio, timing), and H designates the Header
 portion. Every cell begins with a Service Type byte. In addition to
 the type identification (video, audio, timing...) the byte contains a
 four-bit cyclical continuity count, ie., a Service Type Sequence
 10 Number. The continuity count must be cyclical within each service
 type. If not, the associated cell is assumed to be an (otherwise)
 undetected error, eg., a lost packet. The Sequence Number also
 indicates an incorrect service type, such as if audio and video
 types are interchanged. Timing and audio cells have no specific
 15 header in this example. As illustrated by Fig. 14, the Service Type
 is a Byte indicating high priority video VH or low priority video
 VL. Similarly, Fig. 15 illustrates the Service Type byte indicating
 audio (always high priority) AH, and a timing cell TH (always high
 priority). Numbering is indicated by the symbol "nn." In video
 20 cells, the header contains a 5-bit frame number for aligning
 datastreams.. In the AD-HDTV system, there is one HP cell for
 every four LP cells. Usually the HP cell is video, occasionally the
 HP cell is audio, and once a frame the HP cell is a timing cell.

There are four types of video headers, as shown in Figure
 25 16. VH and VL designate high and low priority video components
 as discussed. B, P and I designate the frame components of a GOP.
 F designates a special case I frame, which is a high priority I
 frame containing the beginning of a frame at Slice 0. This cell
 starts with a Picture Start Code (PSC), which is followed by a
 30 temporal reference for the new frame. The symbol ff indicates the
 frame number. In the playback mode, cell memory unit 1232 is
 loaded as a ring buffer. Somewhere in the memory is the
 beginning of a GOP. This GOP boundary is defined as the first HP
 or SP cell designated by Frame Type F.

35 Temporal reference information, eg., 10-bit information, is
 sent via the datastream timing packets to establish a flywheeled



5 local linear temporal reference which determines which frame to display and when. The Temporal Reference also appears in the HP data following an MPEG Picture Start codeword, and can be recovered as the 10 bits immediately following the Picture Start codeword in a frame type "0" HP cell.

10 Figure 17 illustrates the process by which cell memory data is accessed in the system of Figure 12. While putting cells into memory 1232, cell analyzer 1230 has also filled in the cell memory index of unit 1224. When cell analyzer 1230 sees a GOP start, or other significant information, it also fills in entries in Index-index 1226. For example, when a GOP start is present, a
 15 register 1223 in computer controller 1222 indicates that location (address) 41 of Index-index 1226 is a GOP start. Register address 41 indicates that this GOP start (GS) is high priority (H) and that its index location (address) is 3210. That index location contains an entry indicating that the corresponding tape location ("i") is 4
 20 minutes, 7 seconds, 9 fields, 2 tracks, 0 packets, and that the temporal reference ("t") is 222, for example. Flags ("f") may indicate that there are no errors, that the next cell is also good, etc. Finally, the index location indicates that the actual data for the cell is located at address "12345" in the cell memory. The next
 25 Index-index entry indicates that the entry for the Group Start, low priority information (GS, L) is at index location 3333. The following Index-index entry indicates that the entry for the timing cell for this Group Start (GS, T) is at index location 3456. The next entry is for a low priority B frame (B, L).

30 Another approach to implementing features functions is recording at the level of MPEG codewords. In this example, this approach is based upon decoding an input AD-HDTV datastream to the level of a single stream of MPEG codewords. Specifically, it is herein recognized that in the interest of efficiency, only useful
 35 spatial information should be used/duplicated. Spatial and non-spatial information can be separated much more easily in an



MPEG codeword datastream than in an AD-HDTV datastream.

- 5 MPEG-level processing advantageously uses spatial slices, and slices containing significant numbers of spatial macroblocks result in smoother scan presentations.

Therefore, according to this approach, an input digital datastream is decoded to a datastream of MPEG codewords. These
10 codewords are then separated into codewords representing spatial and non-spatial information, and certain separated spatial codewords are placed into tape data packets. The tape data packets are replicated as required, and the spatial packets are recorded where a scanning head will recover the spatial
15 information at tape speeds greater than normal, such as fast search speeds. Audio information is separated from video and processed separately, and is applied to a dedicated audio input of an HDTV receiver.

A general arrangement of a high definition video tape
20 recording/reproducing device using this approach is shown in Figure 22. Elements 2210, 2218, 2220, 2222, 2230 and 2234 are similar to units 1010, 1018, 1020, 1022, 1030 and 1034, respectively, of Figure 10. In Figure 22, HP and lower priority SP video information at a video output of AD-HDTV decoder 2210 is
25 stored in an elastic buffer 2211 before being variable length decoded into MPEG codewords and merged into a single datastream of MPEG words in a unit 2212. The MPEG word datastream is separated into spatial and non-spatial data by a separator 2213, which accomplishes this by examining codeword
30 identifiers. Non-spatial codewords are applied directly to a variable length coder 2214 (ie., a data compressor) to facilitate the subsequent recording process in unit 2218. Spatial codewords are duplicated by a unit 2215 before being VLC coded by unit 2214. Only important spatial data is duplicated by unit 2215, since there
35 is a large amount of spatial data. For example, a complicated still picture may comprise 75% or more I frame data. Thus the spatial

5 data is prioritized. Spatial slices for an I frame are considered important and are duplicated, and certain B and P frame spatial slices may be duplicated. For B and P frames, if a prescribed number of slices are found to be intracoded (eg., based on adaptive weighting factors as a function of picture complexity), the slice is considered to be spatial.

10 VLC spatial and non-spatial data outputs of compressor 2214 are applied to respective inputs of a tape packet generator 2216, another input of which receives variable length coded audio representative words from an audio output of AD-HDTV decoder 2210. Figure 24 is a general representation of the tape packet
15 format. The tape packet header contains fields indicating a time stamp within the original datastream (eg., indicating hours, minutes, seconds and frame number of associated data), the slice number of the data (eg., slice 50, I frame), and continuation data, a data section containing specific slice data including starting bit
20 and ending bit information for example, and an error correction section containing FEC and CRC error detection and correction information, for example.

Continuing with Figure 22, a tape packet datastream from unit 2216 is recorded via tape transport and servo unit 2218,
25 which includes recording and playback mechanisms and electronics. An output signal is applied via a converter 2230 to an HDTV input selector as discussed in connection with Figure 10, and also to a unit 2234 which eliminates duplicate HP cells generated by unit 2215. An output signal from unit 2234 is
30 provided to an audio input of a decoder in the HDTV receiver. The output signal from unit 2234 is processed by a unit 2238 which converts the datastream from tape packets back to MPEG words and variable length decodes these words. MPEG words from an output of unit 2238 are applied to an MPEG-level video input of
35 an HDTV receiver decoder.



During playback/reproduction, the data recovered from the tape is in the form of tape packets containing variable length coded MPEG words. Merging the duplicated data into a useful MPEG datastream is facilitated by the information contained in the tape packet headers, indicating a time stamp within the original datastream, the slice number of the data and continuation data. As each packet is read by unit 2238, the data is converted from variable length code to words and is stored in memory (eg., unit 2332 in Figure 23). An index (eg., unit 2324 in Figure 23) is filled with packet header information. A computer controller (unit 2322 in Figure 23) decides which blocks of MPEG words are to be delivered to form the output MPEG word datastream.

The basic elements of an MPEG-level tape machine are shown in Figure 23. Elements 2310, 2312, 2314, 2316, 2318, 2320, 2322, 2324, 2330, 2332 and 2340 are similar in operation to elements 1210, 1212, 1214, 1216, 1218, 1220, 1222, 1224, 1230, 1232 and 1240 in Figure 12, respectively. Unit 2311 corresponds to units 2211 and 2212 in Figure 22. The elastic buffer in unit 2311 is resilient enough to allow a reasonable rate of variable length coding. Timing cell data are translated to a local frame timing signal. Variable length coder 2335 (eg., a ROM) compresses the MPEG bitstream for storage efficiency, using standard MPEG code tables. Variable length decoder 2326 subsequently undoes this coding. Decoder 2326 may be implemented by the decoder (VLD) in unit 2311 since recording and playback are not simultaneous.

Memory 2332 stores a GOP worth of MPEG codewords. Analysis processor 2330 writes data while output processor 2340 reads data. MPEG word analysis processor 2330 generates read/write addresses for word memory 2332. During recording, processor 2330 looks for Slice Start codewords in the wordstream, counts all spatial macroblocks, allocates duplicate slices, and delivers duplicate slices for recording. During playback, processor 2330 fills word memory 2332, scans tape packet headers, and



creates a slice index entry for each cell Slice index memory 2324
5 receives data from analysis processor 2330 while processor 2330
is filling word memory 2332. This memory is seen by computer-
controller 2322.

Output processor 2340 generates read addresses for
memory 2332 during playback, based upon the contents of slice
10 index memory 2324 and indices generated by controller 2322.
Controller 2322 loads a FIFO memory in output processor 2340
with address information and functional commands, and in the
playback mode controller 2322 provides slice indices to output
processor 2340. Output processor 2340 generates MPEG stream
15 levels above slice level and an output codeword stream including
a frame synchronization signal.

The operation of the MPEG-level system at slow features
speeds is generally similar to that previously described in
connection with the cell-level system. Briefly, a GOP of data is held
20 in word memory 2332. When the user (or a timer) calls for the
next frame, it is produced from the memory if possible. If such
data is not in memory, the tape is caused to move to acquire the
needed GOP data. Data to be output to the receiver is repetitively
played from memory. With this approach, frame synchronization
25 is accomplished with a locally developed signal delivered at the
start of the data for each frame. The words for an output frame
are all delivered within the frame time.

For fast features operation, the word memory is filled with
data. Slice index 2324 contains information bits indicating if an
30 entire slice was acquired (and if so, which slice), if the start of a
slice was acquired, or if only the end of a slice was acquired.
Controller 2322 rearranges the slices to form frames based upon
an examination of the contents of index 2324. Valid slices are
delivered by output processor 2340 under control of controller
35 2322.



The operations performed by the tape machine in the special features mode can be enhanced and assisted by the use of "feature (control) bits." These bits may be advantageously incorporated in the headers of the data cells of the AD-HDTV system, for example. These bits may be responded to at the television receiver to perform a given feature function by operations performed largely or entirely at the receiver, rather than at the tape machine. The AD-HDTV data format, as described previously, includes timing cells. These timing cells indicate to the decoder when to decode a specific frame. The timing cells contain the temporal reference that indicates which frame is to be decoded at the time that the timing cell arrives. There is room in the timing cell for extra information. It is in the timing cell that the extra feature bits are inserted. As the decoder requires a timing cell to decode a picture, the feature bits are available to the decoder when the picture is to be processed. The control computer 1222 in Figure 12, in response to user controls, is aware of which modes the tape machine is operating in. The control computer loads a register in the Cell Output Processor, 1240 with the values of the feature bits to be inserted in a known position in the timing cells to be produced.

A bit field may be introduced indicating and instructing a receiver to "Show the Last Frame Again." In some AD-HDTV receivers the last frame is the past (I or P) anchor frame. In other receivers, the last frame is the last frame displayed. Another bit may represent an instruction to "Decode But Don't Play." In some receivers this bit may have the effect of leaving the last frame displayed in the output buffer while generating new frames. A further bit may represent an instruction to "Accept This Frame." This instruction may be intended to accept a given frame even if it is out of an expected temporal sequence. This action would begin at the next MPEG Picture Start Code (which precedes a frame) temporal reference in the datastream that matches this



5 timing cell temporal reference. The combination of this bit and the
 “Show Last Frame Again” bit may be used by a receiver to
 generate a new frozen frame. Another bit, “Ignore Input Data,”
 may be used to ignore input video data for a given frame, leaving
 the current state unchanged (anchor frames, motion vectors, error
 concealment memory, etc.), and to disable sequential checks for
 10 data consistency. Other features bits may represent instructions to
 permit normal audio reproduction, to mute the audio completely,
 or to mute the audio selectively when there are excessive data
 discontinuities to avoid unpleasant sounds.

In a slow-speed playback features mode, the tape transport
 15 mechanism may be required to exhibit shuttle-like movements,
 passing over certain tape tracks before data is needed. The
 playback electronics include buffer memory large enough to hold
 a GOP of input data and a frame of output data for output. This is
 not an unreasonable amount of storage as the data is compressed
 20 at this point. Appropriately controlled tape acceleration can be
 achieved with currently available tape transports and controllers.
 An exemplary sequence of operations follows.

With the tape moving forward at normal speed, the cell
 buffer memory cycles through its capacity (memory addresses),
 25 storing the current GOP as it is written to the buffer. The tape
 machine features controller (eg., unit 1222 in Figure 12) is aware
 of the current position in the datastream of tape packets, and of
 the corresponding current position in the input AD-HDTV
 datastream. This information is conveyed by GOP and frame
 30 number, picture header temporal reference for the MPEG
 bitstream, timing cell temporal reference information from the
 AD-HDTV datastream, and sequence counters for all service types.
 All such information is contained in the headers inspected by the
 features controller.



When the viewer activates a "Freeze" tape control, the tape mechanism continues to read through the current GOP, filling the buffer memory with an entire GOP worth of cells. The tape controller locates the GOP boundary in term of cells by scanning HP video cell headers for frame type 0 while buffering LP data in memory, and noting the associated frame number. The stored LP cell headers are then scanned for frame type 0 with a matching frame number. The associated current timing cell temporal reference ("linearized" to indicate the established frame display order) determines the frozen frame. Other timing cells in the header are replaced by the features controller, with timing cells containing feature bits indicating that the following functions are to be performed: Freeze frame, Ignore other inputs, and Mute audio. The features controller replaces further video cells with null cells while the Freeze frame feature persists. The insertion of null cells into the datastream during the freeze frame mode advantageously avoids the need to stop and start the datastream, thereby avoiding timing and synchronizing problems. In the replacement null cells, the associated Service Type Sequence Number in the header is generated sequentially by the features controller to validate the datastream with the replacement cells. This Sequence Number is used in the AD-HDTV system, for example, to aid in discovering lost or erroneously positioned packets, or interchanged service types.

The tape drive transport mechanism, having read to the end of the GOP, gently slows down the tape, backs up slightly, and prepares to resume reading the tape packets for the next GOP. At this point the user is still seeing the frozen frame display. At this time likely user instructions include Next Frame, Previous Frame, or Play.

If the user requests the next frame, the following steps occur. If the next frame is not in memory, the tape moves forward. The first frame written into buffer memory is the I frame at the beginning of the next GOP, after which the following



B and P frames are written to the memory whereby the buffer
 5 contains the entire new GOP. Video service type cells for the next
 frame are transmitted in order to the receiver. Again, video cells
 not within the next frame are replaced by null cells. The timing
 cell corresponding to the next frame may or may not be in the cell
 buffer. If the features controller senses that it is in the buffer, it is
 10 altered by the controller to match the artificial timing and
 sequencing being generated by the tape machine. If it is not in the
 buffer, the (timing flywheel in the) tape machine causes a timing
 cell to be generated. This timing cell contains an "Accept This
 Frame" features bit and a "Show Last Frame Again" features bit,
 15 which cause the receiver to update the displayed picture by
 showing the last frame.

If the user requests the previous frame, the following steps
 occur. The features controller knows which anchor frames are
 stored in the receiver. If the requested previous frame can be
 20 generated from the existing anchor frames stored in the receiver
 and from the input data for the requested frame (ie., the
 requested frame is a B frame following a P frame in transmission
 order), the cells to update the receiver display are produced using
 the procedure described in the preceding paragraph. If the
 25 requested frame is an I frame, a P frame, or a B frame following
 an I frame, the tape is caused to reverse and play the entire
 preceding GOP.

The table shown in Figure 20 indicates the frame
 dependencies for stepping the tape forward and backward. In this
 30 table, the "transmission order" row indicates what is recorded on
 tape as appearing at the output of the video tape machine.
 Assume that the GOP consisting of frames 9 through 14 is the GOP
 in buffer memory. The "displayed frame" row indicates which
 frame could be displayed at the time the transmitted frame is
 35 available. B frames are displayable when they arrive, and anchor



frames (I and P frames) are displayable three frames after they arrive.

5 In the following examples assume that, when the tape is stepped forward, the GOP consisting of frame 9 through frame 14 has just been read from the tape. To display frame 6, frame 6 alone is required, and it is already in the receiver's anchor frame memory. The receiver always stores two anchor frames to be able
10 to create a B frame. Frame 9 is delivered and frame 6 is displayed. One more forward step requires the data for frame 7 and for anchor frames 6 and 9, which are available in the receiver's frame memory.

 When stepping backward, assume that the same GOP resides
15 in cell buffer memory (unit 1232 in Figure 12). The first frame to be displayed is frame 14. The previously displayed frame was frame 15, so frame 15 is assumed to be in receiver memory. Frame 14 requires data from anchor frame 12, and frame 12 requires data from anchor frame 9. The entire GOP must be output
20 to the receiver to prepare the receiver to display frame 14.

 Stepping back to frame 13 and then to frame 12 is less difficult, since the required anchor frames are already in receiver memory. Frame 11 requires replay of the GOP to put frame 9 into the receiver. Frames 10 and 9 follow easily. Stepping back to
25 frame 8 initiates a cascade. Frame 8 requires anchor frame 6, which isn't in receiver memory, and frame 6 is not in the current GOP in the tape machine's cell buffer memory. Frame 6 requires frame 3, which requires frame 0. Thus the entire previous GOP (frames 0-8) must be read from the tape. Accordingly, frames 0
30 and 3 are delivered to the receiver as anchor frames. Frame 6 is then delivered to the receiver, with frames 3 and 6 now being anchor frames. The GOP containing frames 9-17 is then re-acquired by going forward with the tape and storing it in the cell memory, and frame 9 is delivered to the receiver. Frames 6 and 9
35 are now the anchor frames, whereby frame 8 may be generated and delivered to the receiver.



The time to respond to a user requested step may vary,
5 depending on the type of frame which is requested. For some
frames, for which information is available in buffer memory, a
new picture can be generated and presented almost immediately,
eg., in approximately 33 milliseconds. The cascade example
described in the previous paragraph takes considerably more
10 time, since that example involved repositioning the tape to the
beginning of the previous GOP (100 ms.), reading the previous GOP
while delivering frames 0, 3 and 6 (300 ms.), reading frames 9, 7
and 8 (1/2 GOP time, 150 ms.), and presentation time (33 ms.), for
a total time of about 600 ms. This is not unreasonably long for a
15 user response time.

Other slow-speed user features, such as slow motion and
reverse, can be treated as a predictable series of still ("freeze")
frame steps. These steps are advantageously undertaken at the
receiver in response to information, such as the feature bits
20 described previously, provided to the receiver by the tape
machine. Thus, for example, it is the receiver which generates a
freeze-frame display using its internal memory and HDTV
processing/decoding circuits in response to a control bit provided
by the tape machine in response to a user control request. Slow
25 rates can be obtained by stepping and then repeating frames as
often as necessary to maintain a smooth rate.

The previously mentioned AD-HDTV system, sometimes
referred to as the ADTV system, has been submitted to the
FCC/ACATS for on-going testing and analysis by the Advanced
30 Television Test Center (ATTC).



CLAIMS

5

1. A video tape recording/reproducing system for processing a digital high definition television signal, said system exhibiting special features operation in accordance with a method comprising the steps of:

10 receiving a digital video information datastream (INPUT;(B) FIG.7A...)comprising an input arrangement of video data;

altering (70) said data arrangement so that prescribed video data, when recorded at a given speed, appears in predetermined regions of tape tracks as a function of a tape scanning path a
15 recording/reproducing head is expected to travel at a speed greater than said given speed in a special features operating mode; and

recording (72) said datastream with said altered arrangement of data.

20

2. A method according to claim 1, wherein
said recording is at said given speed; and
said data arrangement comprises a sequence of data cells
including a data component and a header component containing
25 information identifying associated data.

3. A method according to claim 1, wherein
said said given speed is a normal recording speed; and
said features operating mode is a fast search mode.

30

4. A method according to claim 1, wherein
said video data is composed of high priority (HP) significant image representative information and lower priority (LP) image information; and

35 said prescribed video data is said high priority information.





5. A method according to claim 1, wherein
5 said datastream comprises MPEG coded image
representative information.

6. A method according to claim 5, wherein
said MPEG coded image information comprises a Group Of
10 Pictures (GOP) including intercoded and intracoded picture frames
occurring in a given sequence; and
said prescribed video data is intracoded ("I") information.

7. A method according to claim 6, wherein
15 said step of altering said data arrangement subjects said
given sequence of intercoded and intracoded frames to disruption;
and
said method includes a further step (74) of converting a
disrupted sequence of intercoded and intracoded frames so as to
20 exhibit said given sequence at an output.

8. A method according to claim 7, wherein
said GOP includes an intracoded I-frame and intercoded B-
frames and P-frames in the following sequence: I, B, B, P, B, B, P, B,
25 B.

9. A method according to claim 1, wherein
said step of altering said data arrangement is accomplished
by re-ordering received input data.
30

10. A method according to claim 1, wherein
said step of altering said data arrangement is accomplished
by duplicating data.





11. Video tape recording/reproducing apparatus for
5 processing a digital high definition television signal, comprising:
input means (1212) for receiving a digital video information
datastream comprising an input arrangement of data;
means (1230, 1232, 1224, 1226, 1222) for altering said
input data arrangement so that prescribed video data, when
10 recorded at a given speed, appears in predetermined regions of
tape tracks as a function of a tape scanning path which a
recording/reproducing head is expected to travel at a speed
greater than said given speed in a features operating mode; and
means (1214-1218) for recording said datastream with said
15 altered arrangement of data at said given speed.

12. Apparatus according to claim 11 and further including
an output (78; "PLAYBACK OUTPUT, FIG. 12) to be coupled to
a receiving device (1040);
20 reproducing means (72; 1214-1218) for providing a
recorded datastream with said altered data arrangement at a
speed greater than said given speed; and
converting means (74; 1222, 1224, 1232) responsive to said
recorded datastream for providing an output datastream to said
25 output with an arrangement of data compatible with
requirements of said receiving device.

13. Apparatus according to claim 11, wherein
said datastream comprises a sequence of data cells including
30 a data component and a header component containing information
identifying associated data.

14. Apparatus according to claim 11, wherein
said given speed is a normal recording speed; and
35 said feature operating mode is a fast search mode.





15. Apparatus according to claim 11, wherein
5 said video data is composed of high priority (HP) significant image representative information and lower priority (LP) image information; and
said prescribed video data is said high priority information.

10 16. Apparatus according to claim 12, wherein
said digital datastream comprises MPEG coded image representative information including a Group Of Pictures (GOP) constituted by intercoded (B, P) and intracoded (I) picture frames occurring in a given sequence; and
15 said prescribed video data is intracoded (I) information.

17. Apparatus according to claim 16, wherein
said altering means subjects said given sequence of intracoded and intracoded frames to disruption; and
20 said converting means converts a disrupted sequence of intercoded and intracoded frames so as to exhibit said given sequence at said output.

18. Apparatus according to claim 17, wherein
25 said GOP includes an intracoded I-frame and intercoded B-frames and P-frames in the sequence: I, B, B, P, B, B, P, B, B.

19. Apparatus according to claim 1, wherein
said altered data arrangement is constituted by re-ordered
30 received input data.

20. Apparatus according to claim 11, wherein
said altered data arrangement includes duplicated data.





21. A video tape recording/reproducing system for
5 processing a digital high definition television signal, comprising:
input means (1212) for receiving a digital datastream
containing video information;
recording/reproducing means (1214-1218) responsive to
said datastream;
10 output means (1240) responsive to an output signal from
said recording/playback means for conveying recorded
information to utilization means when present;
means (1222) for generating feature control data for
determining the operation of said utilization means in a special
15 features operating mode of said video tape recording/reproducing
system; and
means (1230, 1232,...) for conveying said feature control
data to said output means.
- 20 22. A system according to claim 21, wherein
said feature control data represents an instruction for
processing an image frame.
23. A system according to claim 22, wherein
25 said feature control data represents an instruction to repeat
the display of an image frame.
24. A system according to claim 22, wherein
said feature control data represents an instruction to decode
30 but not display an image frame.
25. A system according to claim 22, wherein
said feature control data represents an instruction to accept
an out of sequence image frame.





26. A system according to claim 22, wherein
5 said feature control data represents an instruction to ignore
predetermined data for a given image frame.

27. A system according to claim 21, wherein
said feature control data represents an instruction
10 concerning the processing of audio information.

28. A system according to claim 27, wherein
said feature control data represents an instruction to mute
audio information.

15 29. A system according to claim 21, wherein
data processed by said system is in the form of transport
cells including a data component and a header component
identifying associated data.

20 30. Video tape recording/reproducing apparatus for
processing a digital high definition television signal, comprising:
input means (2210; 2312) for receiving a digital datastream
comprising an input arrangement of video data representing
25 coded video information;
means (2212; 2311) for decoding said video information to
produce data words;
means (2213, 2215; 2330,2332) for processing said data
words;
30 means (2214; 2335) for re-coding predetermined ones of
said data words;
means (2216; 2330, 2332, 2324,2326, 2322), included in
said processing means, responsive to said re-coded data words for
altering said input data arrangement so that prescribed video
35 data, when recorded at a given speed, appears in predetermined
regions of tape tracks as a function of a tape scanning path which





5 a recording/reproducing head is expected to travel at a speed greater than said given speed in a features operating mode; and means (2218; 2314-2318) for recording said datastream with said altered data arrangement at said given speed.

10 31. Apparatus according to claim 30, wherein said coded video information includes MPEG coded information;
said data words produced by said decoding means include MPEG words;
said re-coding means is an MPEG variable length coder; and
15 said datastream recorded by said recording means comprises an altered arrangement of MPEG words.

20 32. Apparatus according to claim 30, wherein said processing means includes means for separating spatial data of said datastream; means for duplicating spatial data; and means for providing duplicated spatial data from said duplicating means to said re-coding means.

25 33. Apparatus according to claim 30 and further including tape packet generator means (2216; 2320) having an input responsive to output signals from said re-coding means, and an output coupled to said recording means.

30 34. Apparatus according to claim 33 and further comprising output converter means (2238; 2340) for converting tape packet data to MPEG words.

35 35. Apparatus according to claim 30, wherein said given speed is a normal recording speed; and said feature operating mode is a fast search mode.





5 36. Apparatus according to claim 30, wherein
said video data is composed of high priority (HP) significant
image representative information and lower priority (LP) image
information; and
said prescribed video data is said high priority information.

10 37. Apparatus according to claim 30 and further including
an output (78; 2340) to be coupled to a receiving device
(1040) when present;

reproducing means (72; 2314-2318) for providing a
recorded datastream at a speed greater than said given speed to
15 said output; and

converting means (74; 2322, 2332, 2324) responsive to said
recorded datastream for providing an output datastream to said
output with a modified data arrangement compatible with
requirements of said receiving device.

20 38. Apparatus according to claim 37, wherein
said digital datastream comprises MPEG coded image
representative information including a Group Of Pictures (GOP)
constituted by intercoded and intracoded (I) picture frames in a
25 given sequence; and
said prescribed video data is intracoded information.

30 39. Apparatus according to claim 38, wherein
said altering means subjects said given sequence of
intercoded and intracoded frames to disruption; and
said converting means converts a disrupted sequence of
intercoded and intracoded frames so as to exhibit said given
sequence at said output.





40. Apparatus according to claim 38, wherein
5 said GOP includes an intracoded I-frame and intercoded B-frames and P-frames in the sequence: I, B, B, P, B, B, P, B, B.

41. Apparatus according to claim 30, wherein
said altered data arrangement is constituted by re-ordered
10 received input data.

42. Apparatus according to claim 40, wherein
said altered data arrangement includes duplicated data.



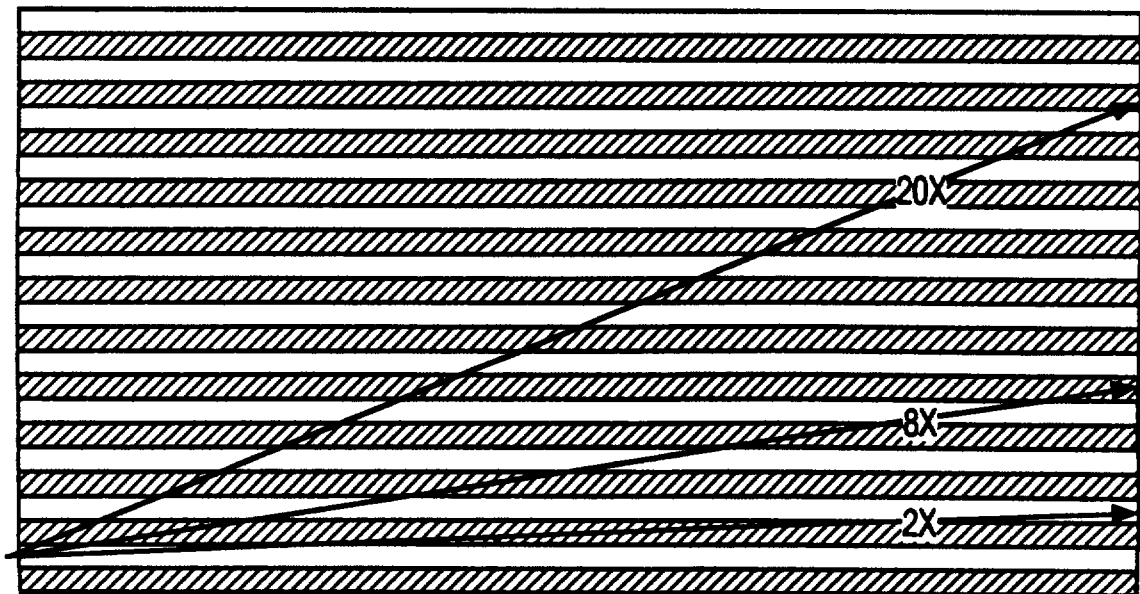
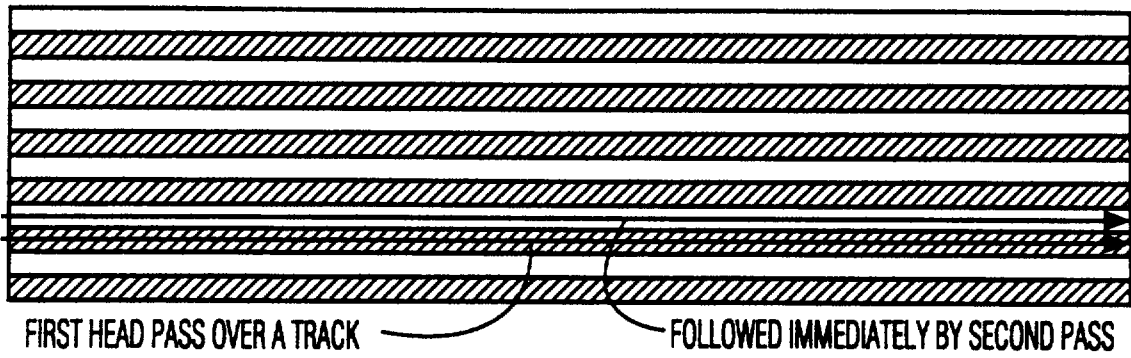
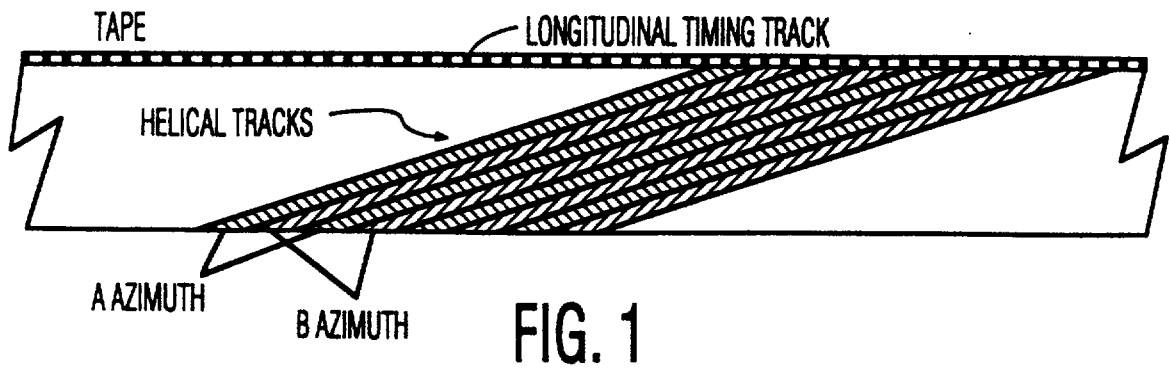
Abstract of the Invention

5

A digital video tape record/playback apparatus for processing a high definition television signal includes provision for controlling the occurrence of high priority (HP) image information. Such information is selectively recorded at normal speed in tape
10 tracks within predetermined regions (HP1-HP5) so as to be appear along a tape head scanning path associated with predetermined tape playback speeds greater than normal (eg., 20x normal). Input high priority data cells may be reordered or duplicated for recording in the predetermined tape regions in other than
15 received order. In either case, the input datastream is massaged to produce a viewable image in a fast playback mode. In an illustrated system for receiving an MPEG coded datasteam, an output datastream at greater than normal playback speed comprises either intracoded I-frame data cells only, or a whole
20 Group of Pictures (GOP).

This Sheet Has Been Replaced





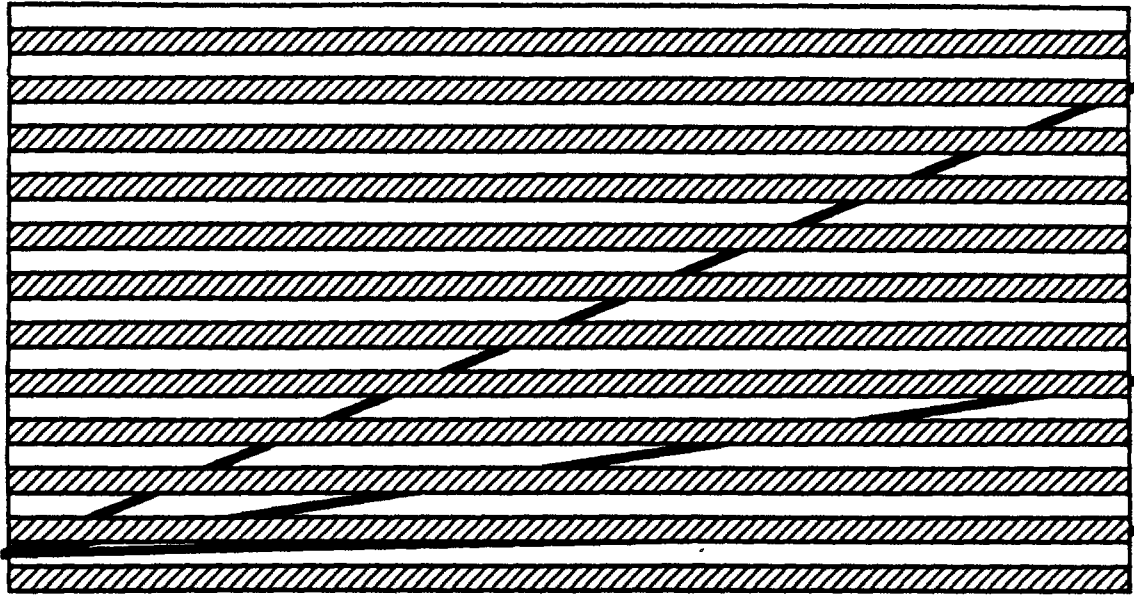


FIG. 4

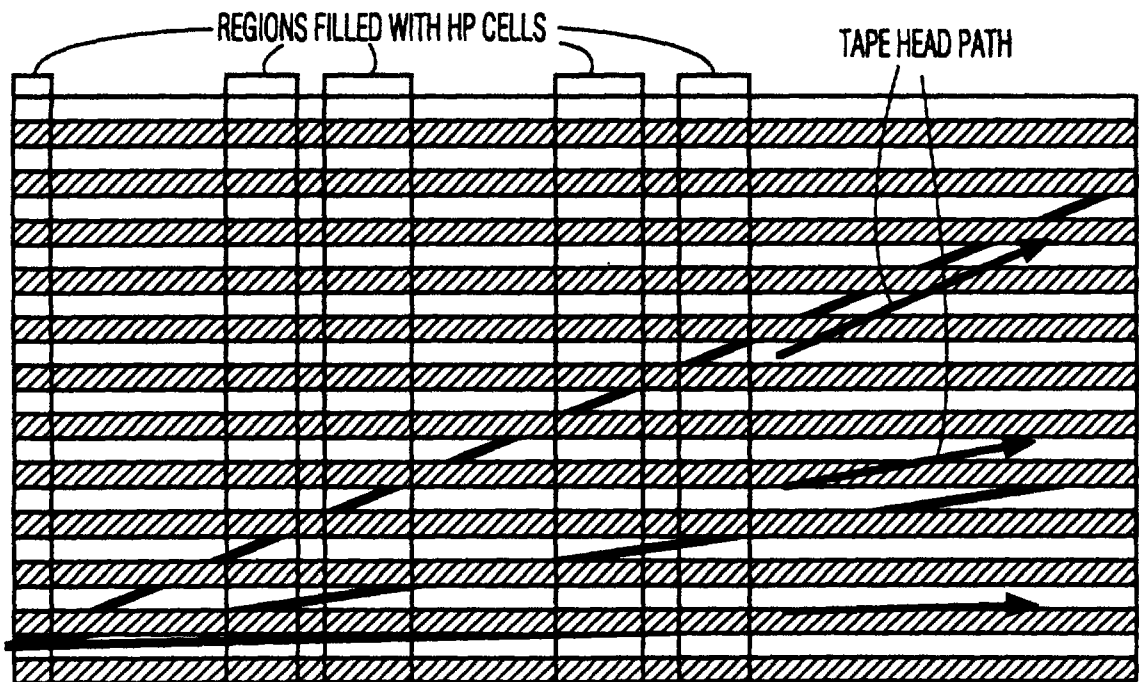


FIG. 5



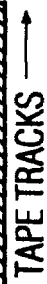


FIG. 6



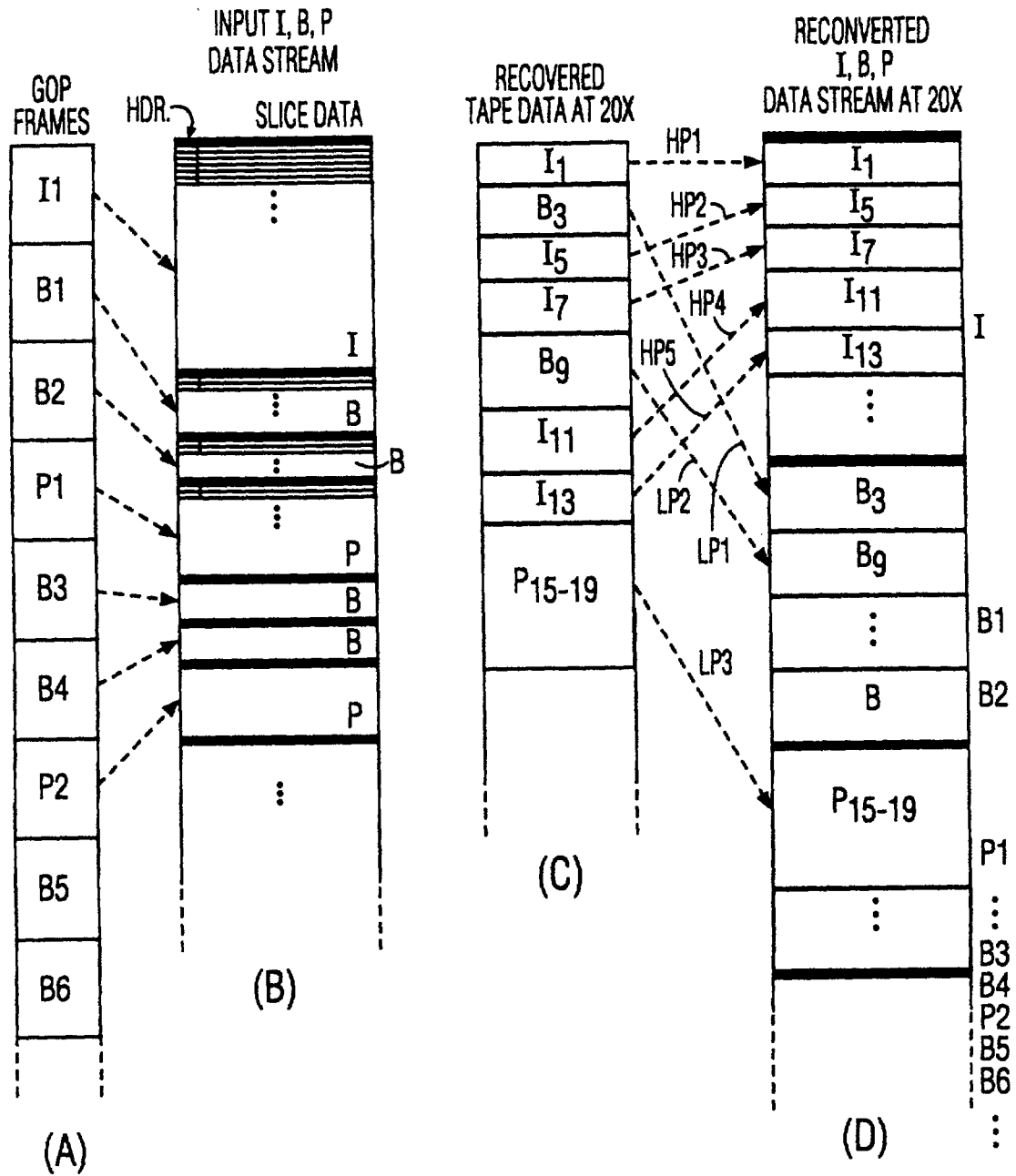


FIG. 7



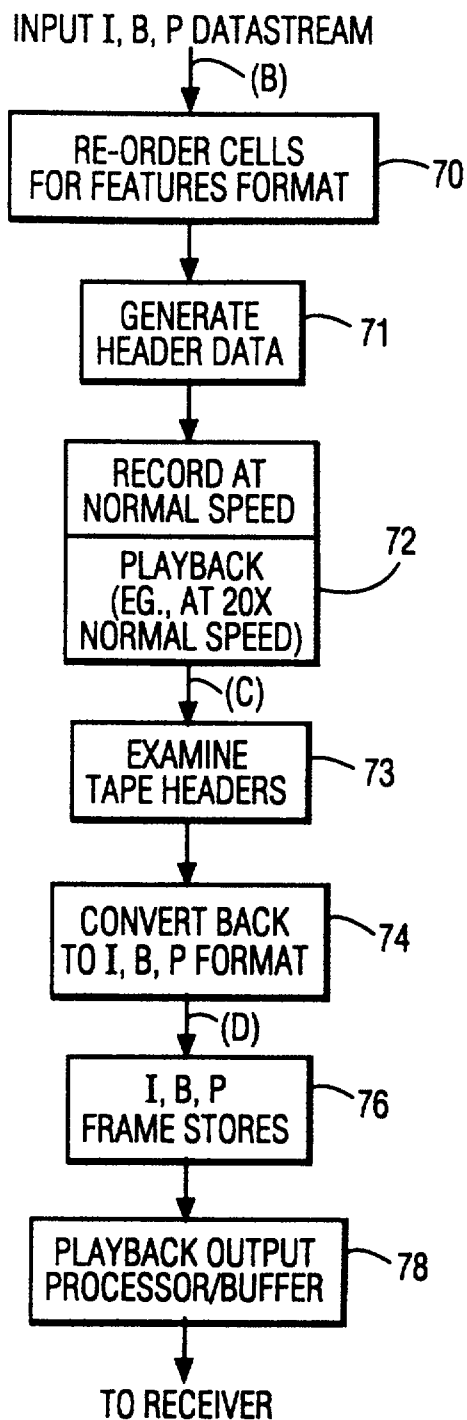


FIG. 7A

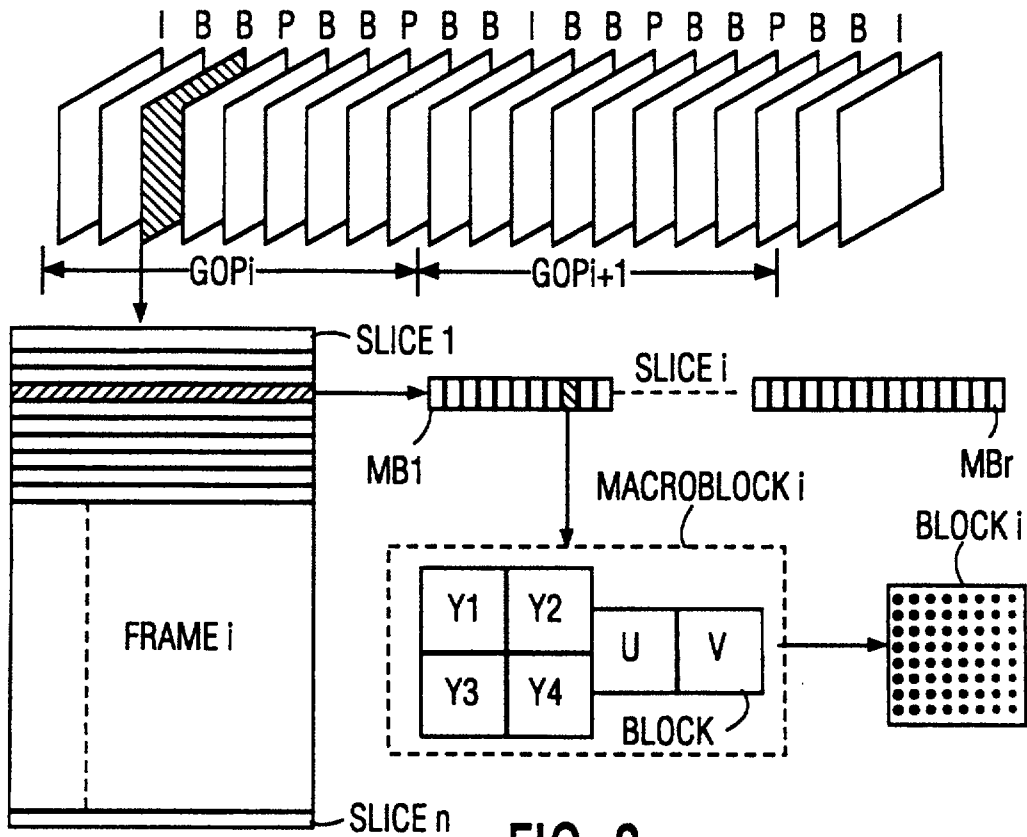


FIG. 8

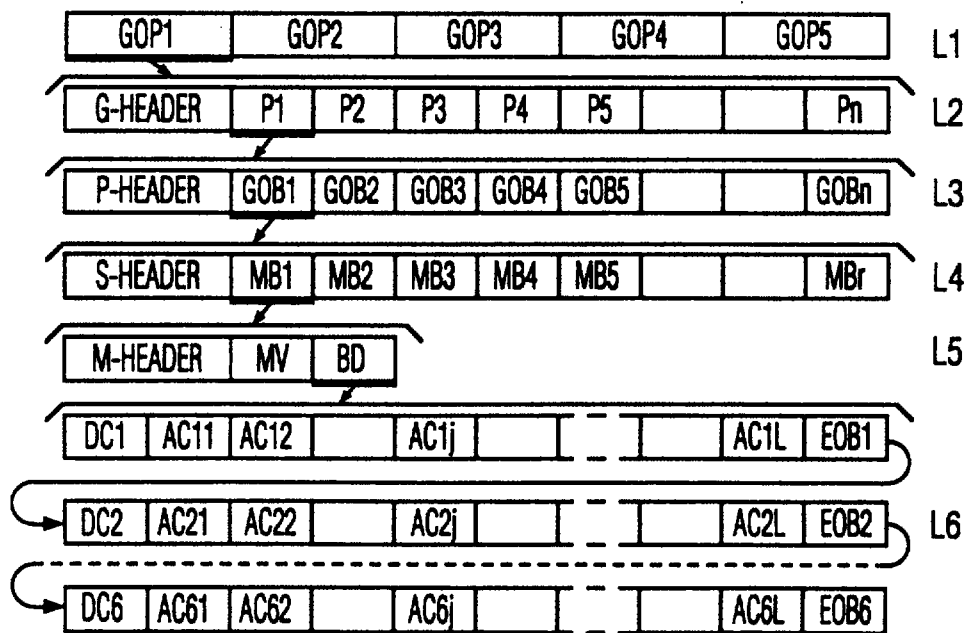


FIG. 9

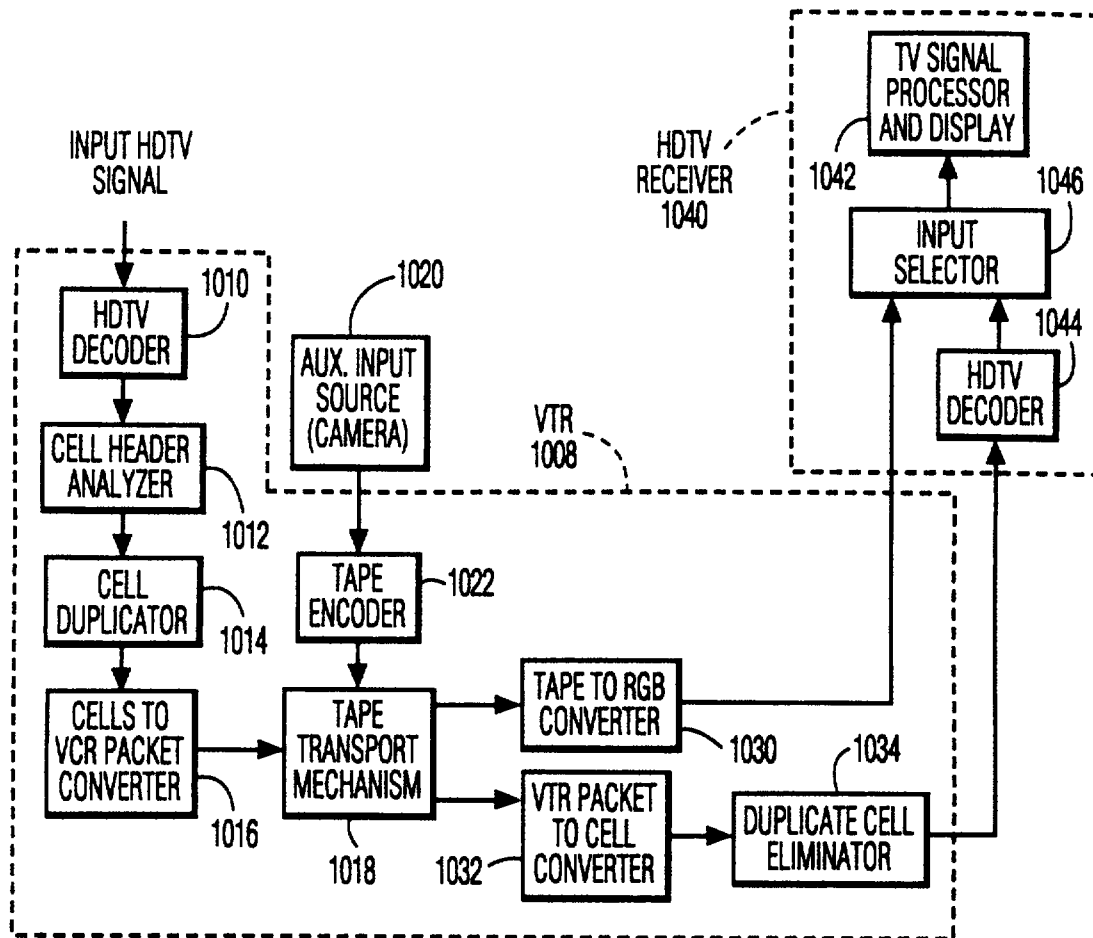


FIG. 10

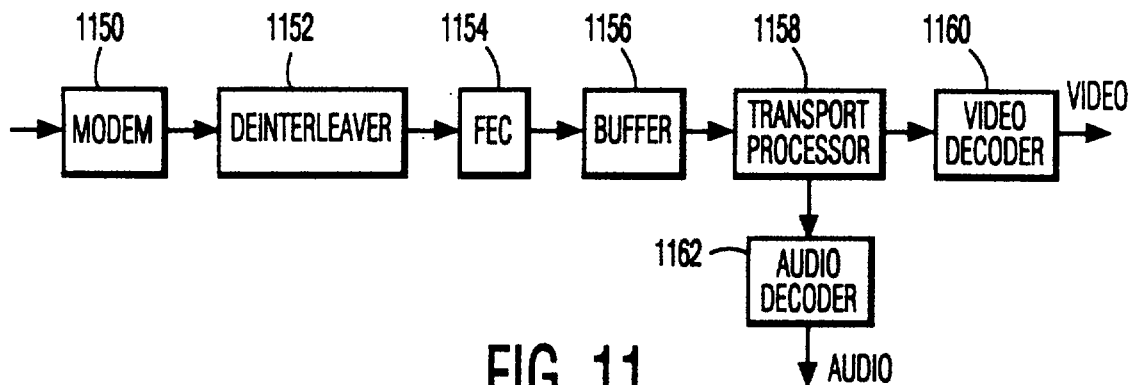


FIG. 11



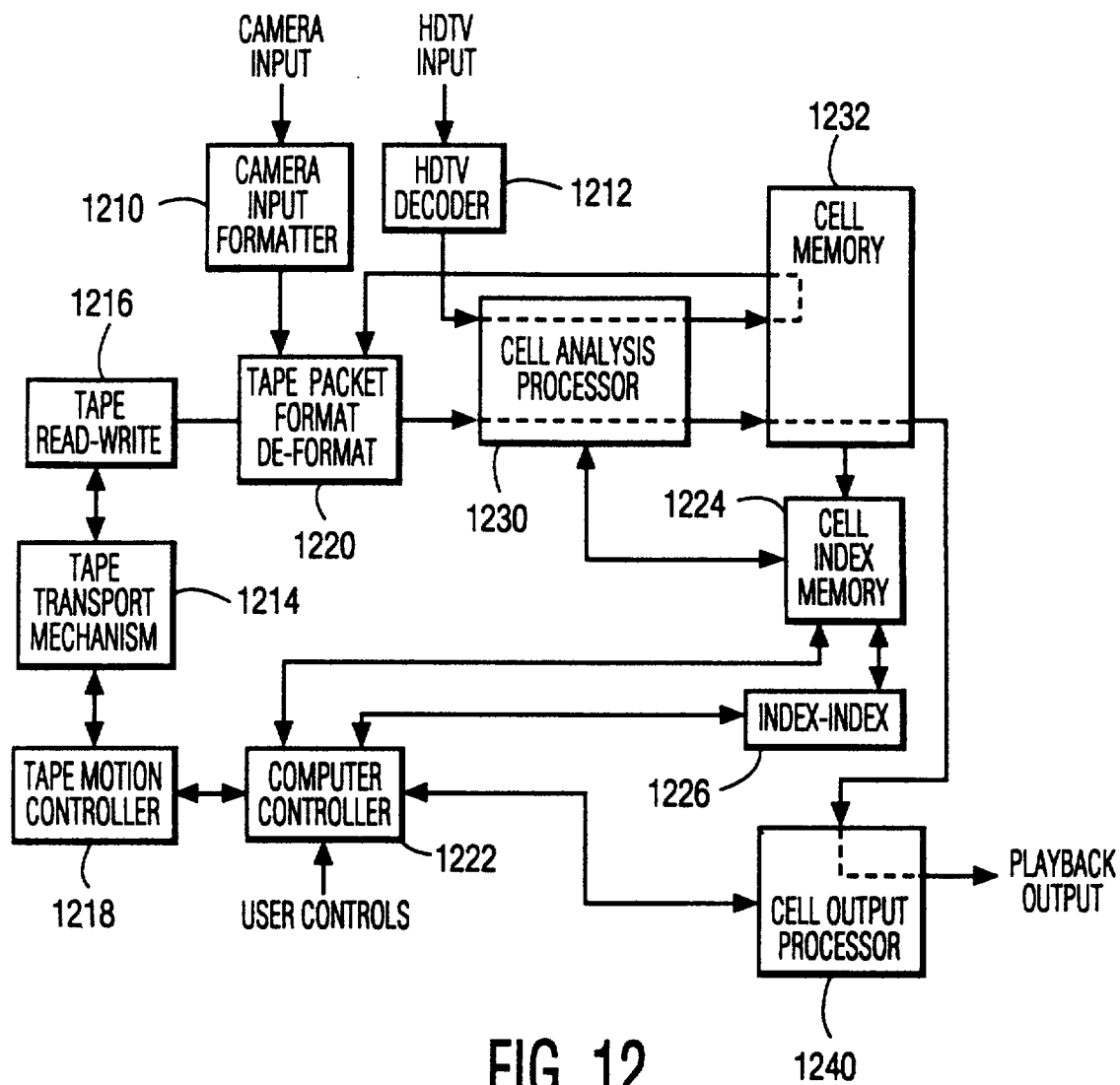
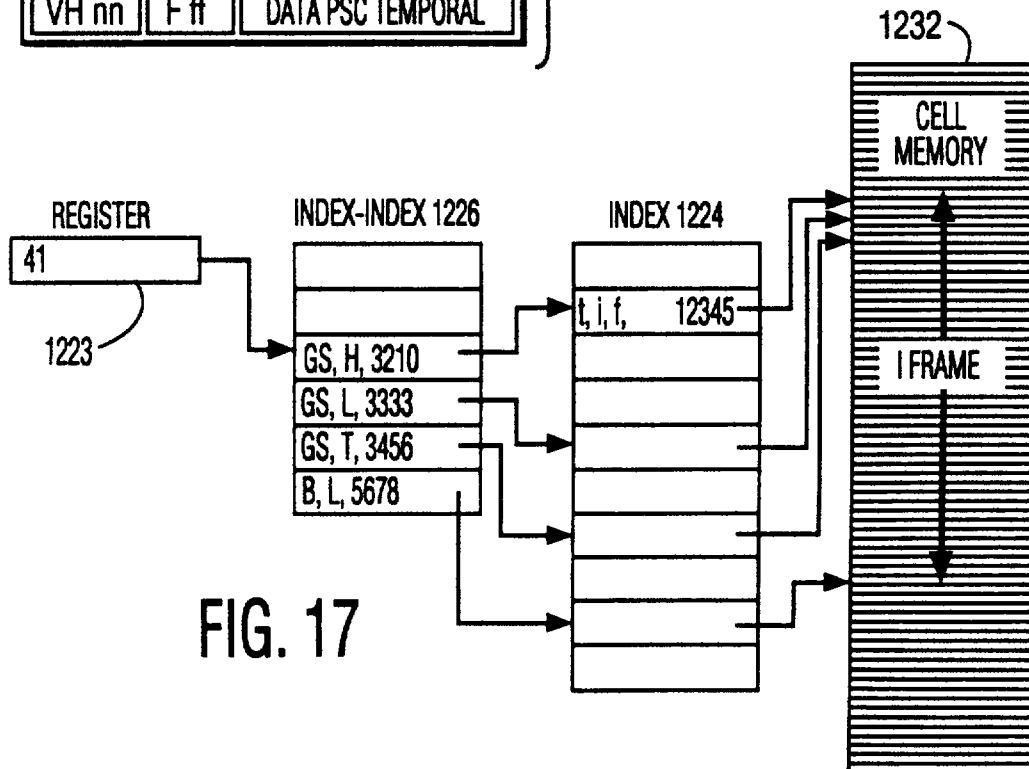
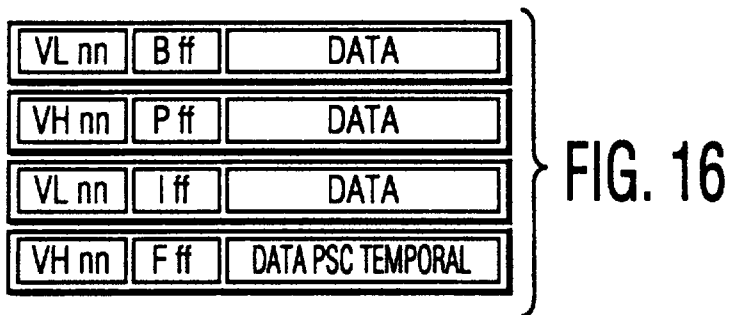
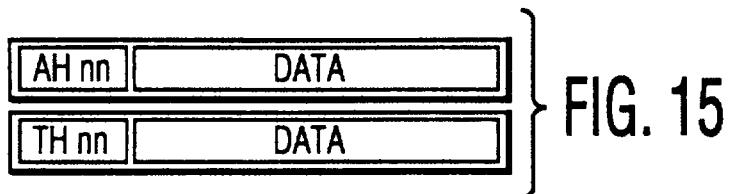
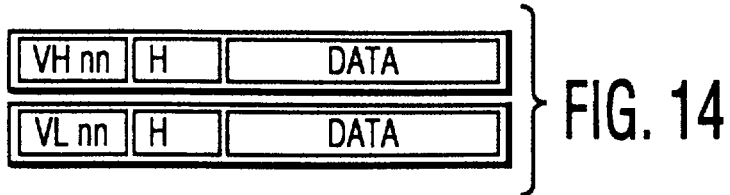
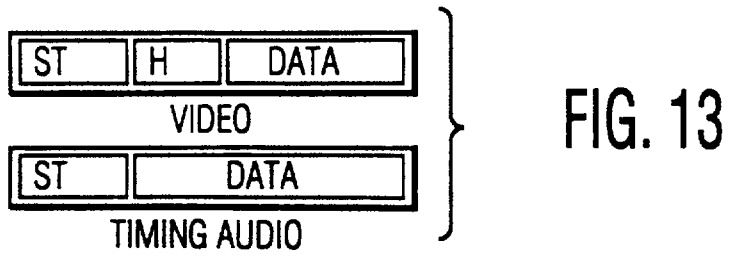


FIG. 12





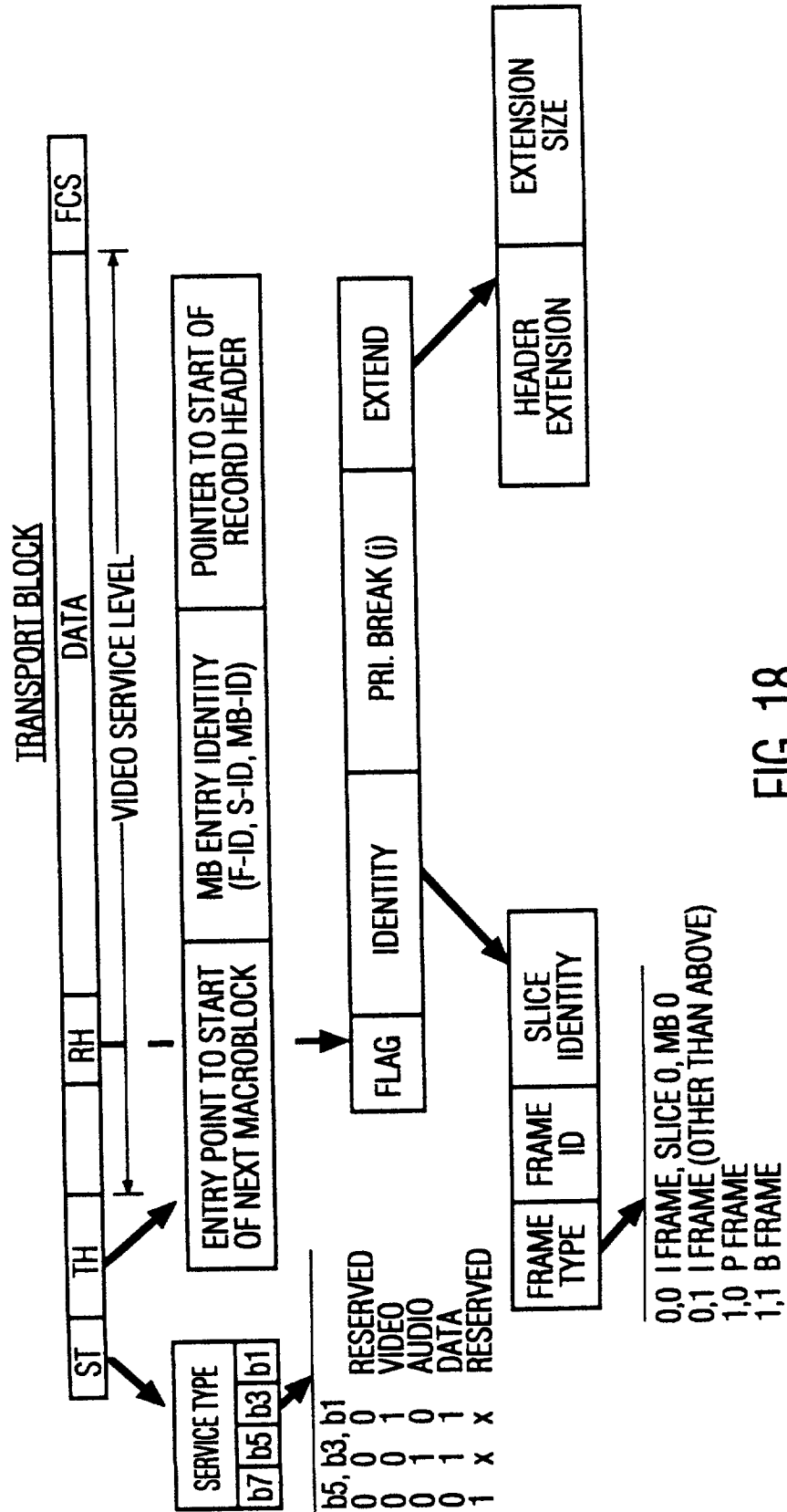


FIG. 18



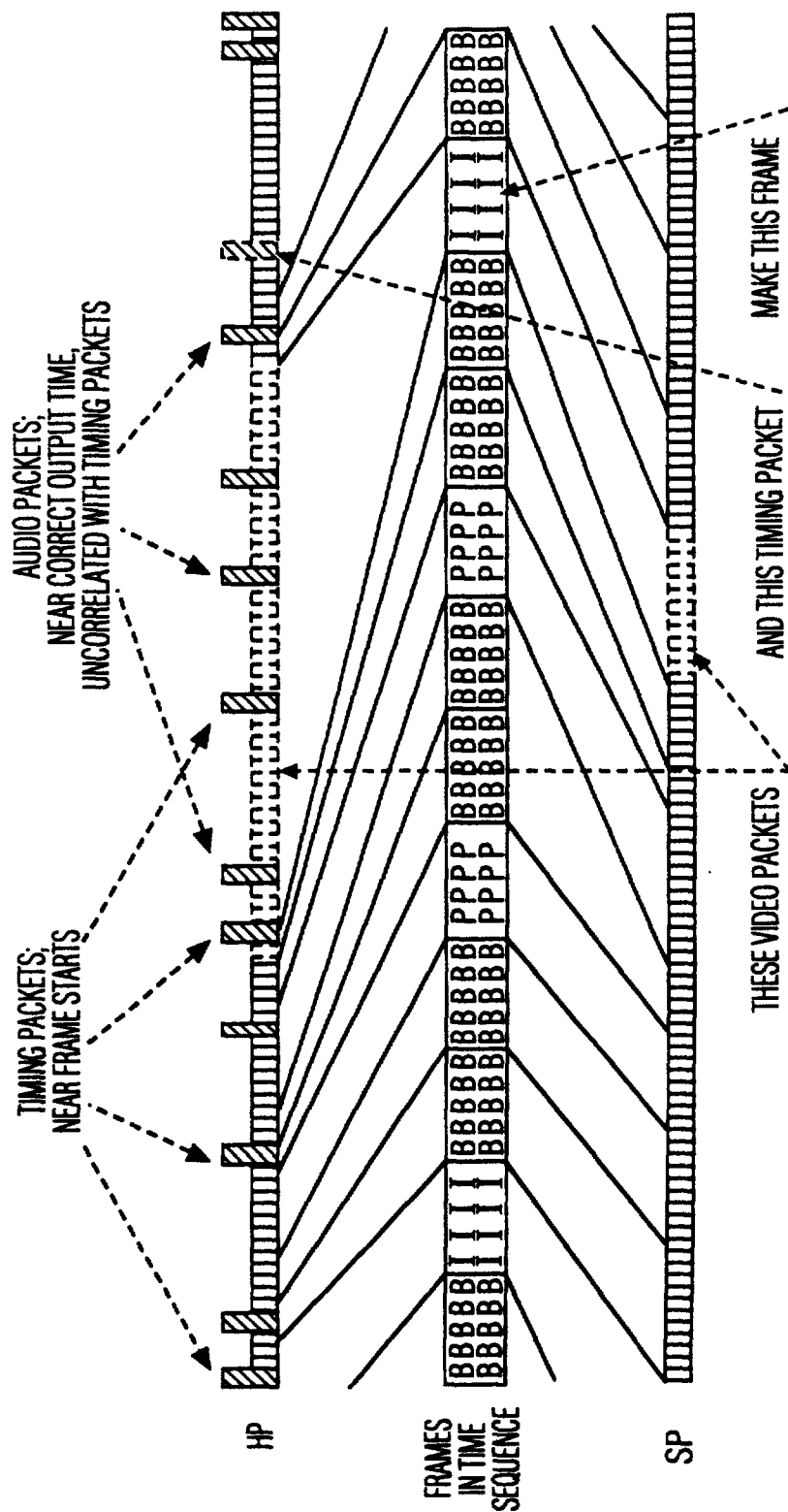


FIG. 19



FRAME TYPE	I	B	B	B	P	B	B	B	B	I	B	B	B	P	B	B	B	B	B
TRANSMISSION ORDER	0	-2	-1	3	1	2		6	4	5	9	7	8	12	10	11	15	13	14
DISPLAYED FRAME											6	7	8	9	10	11	12	13	14
GOING FORWARD								RM			•								
								RM			R	•							
								RM			R		•						
											R			•					
											R			R	•				
											R			R		•			
											R			R					
											R			R					
											R			R					
											R			R					
GOING BACKWARD	R3			R6				R			•								
	R3			R6				R			R	•							
	R3			R6				R			R		•						
											R			•					
											R			R	•				
											R			R		•			
											R			R					
											R			R			•		
											R			R			RM	•	
											R			R			RM		•

LEGEND: • REQUESTED FRAME R REQUESTED TO MAKE REQUESTED FRAME RM REQUIRED, BUT ALREADY IN MEMORY RM REQUIRED TO MAKE FRAME n

FIG. 20



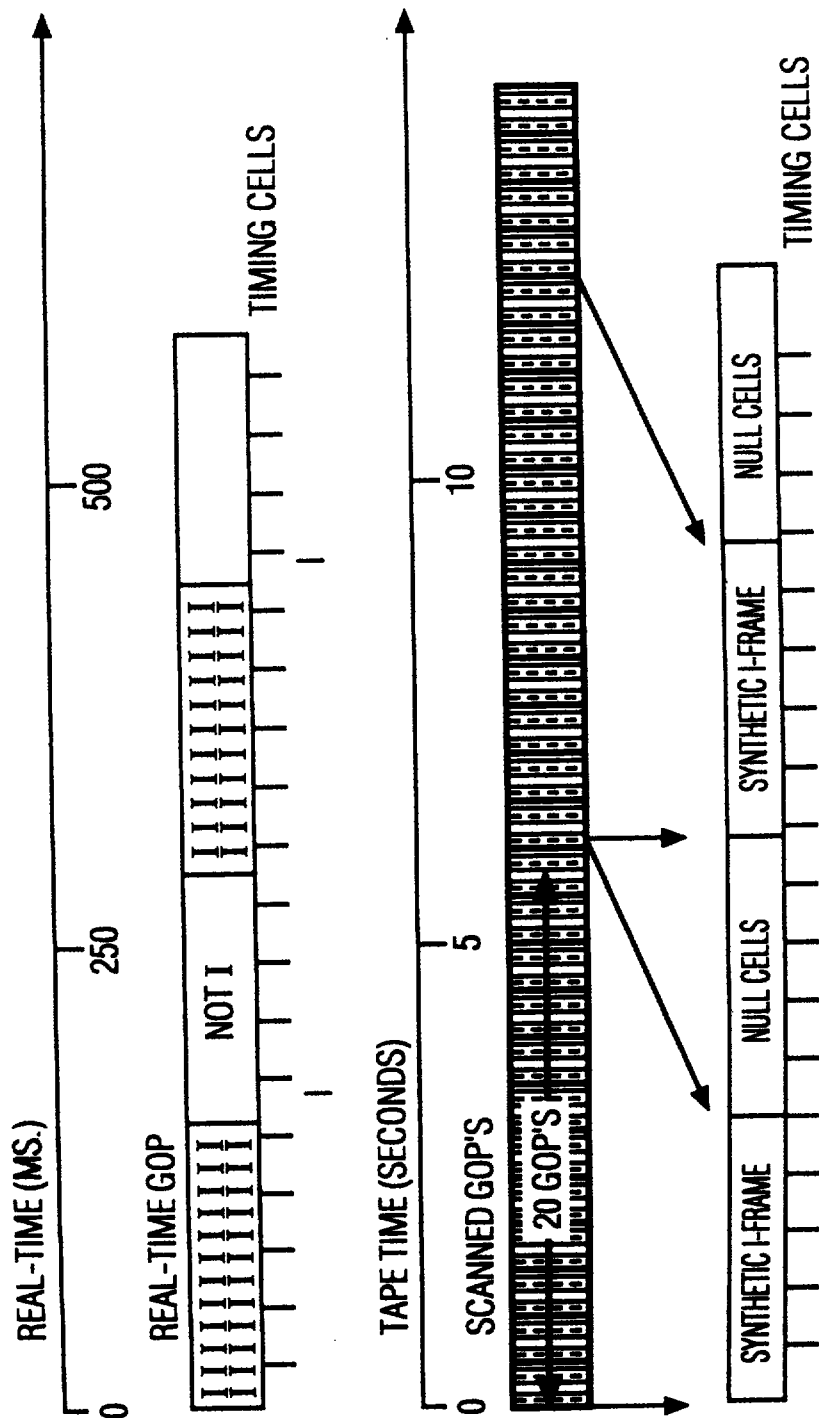


FIG. 21



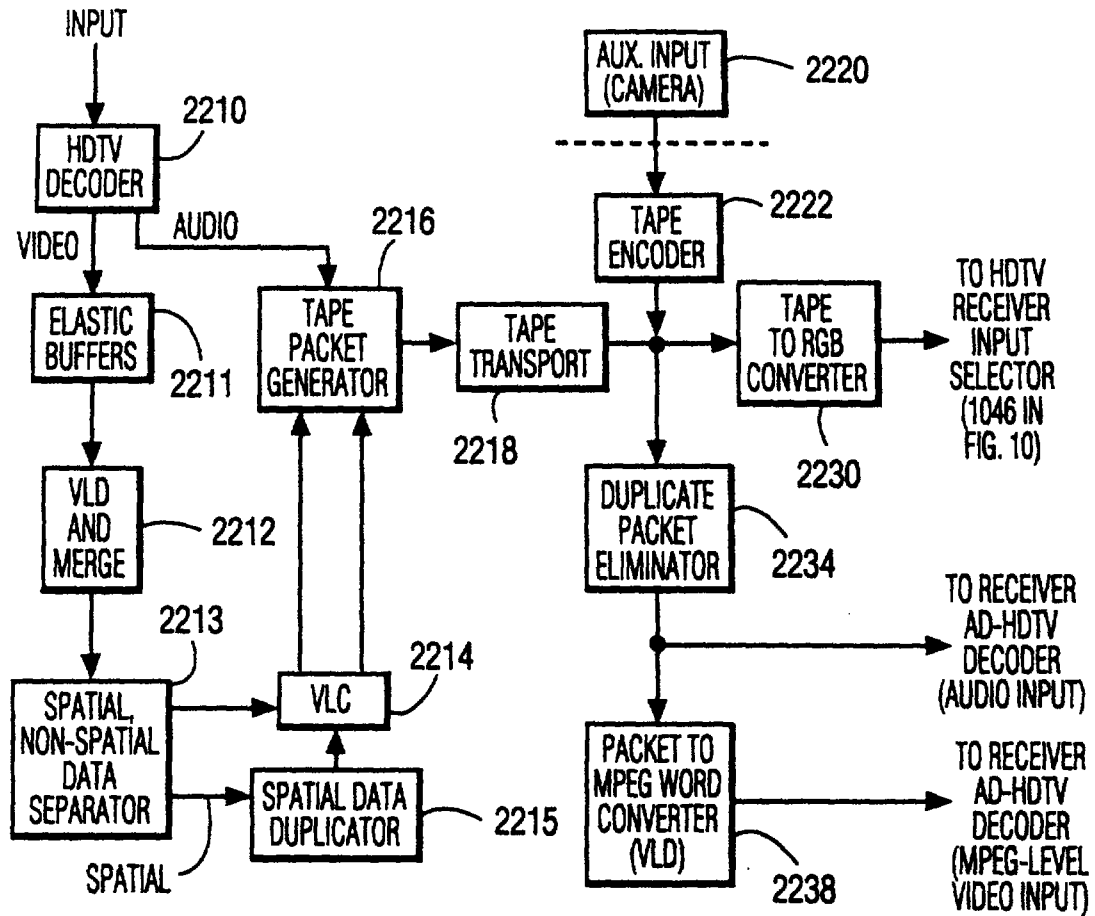


FIG. 22



FIG. 24



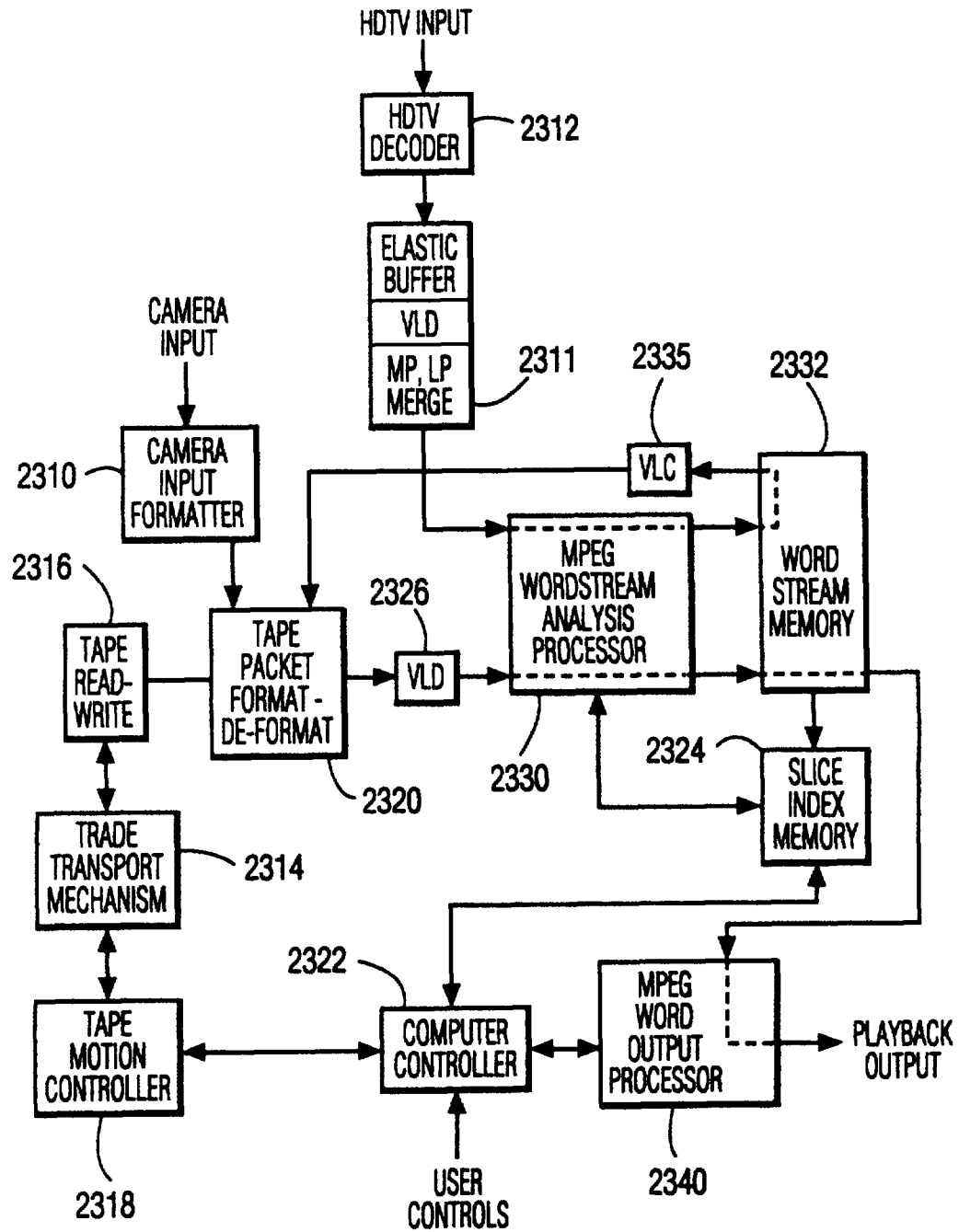


FIG. 23



30 JUL 1996

960248-3 PDS

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Digital Video Tape Recorder For Digital HDTV

5

Field of the Invention

This invention is related to the field of digital video signal processing, and more particularly to processing a digital high definition television signal by a digital video tape

10 recording/reproducing system.

Background of the Invention

Digital high definition television (HDTV) systems have recently been proposed. One such system, proposed by the

15 Advanced Television Research Consortium and generally known as the AD-HDTV system, prioritizes and digitally processes a high definition television signal subjected to MPEG-like variable length coding. MPEG is a standardized coding format being established by the International Organization for Standardization. The standard is

20 described in the document "International Organization for Standardization," ISO/IEC DIS 11172, CD 11172-1, CD 11172-2, CD 11172-3 Rev. 1, version of January 21, 1992, Coding for Motion Pictures and Associated Audio for Digital Storage Media, which document is incorporated herein by reference for description of

25 the general code format. Aspects of the AD-HDTV system are described in US Patent 5,168,356-Acampora et al. In the system described by Acampora, codewords are prioritized to reflect high priority and relatively lower priority standard priority information in a digital datastream. Codewords are formed into

30 transport packets, or cells. Each transport packet includes a packed data payload section prefaced by a header which contains information identifying the associated payload data.

It is desirable to record and reproduce (playback) such a digital HDTV signal by means of a device such as a consumer

35 video cassette recorder (VCR) for example. Such a device uses two

REPLACED SHEETS	SG
☐ Description : paged to paged	
☒ Claim(s) : paged to paged	
☐ Drawing(s) : paged to paged	
☒ Abstract : paged to paged	
DATE OF RECEIPT	

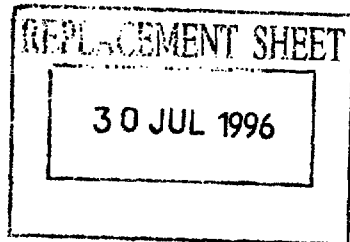
REPLACEMENT SHEETS	SG
☒ Description : paged 1 to paged 39	
☒ Claim(s) : paged 40 to paged 44	
☒ Drawing(s) : paged 45 to paged 48	
☒ Abstract : paged 49 to paged 50	
DATE OF RECEIPT 8/7/91	

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5 or more magnetic heads mounted on the periphery of a rotating
drum. The heads are physically separated by a predetermined
amount, and record/reproduce a signal in alternate successive
angled tracks on a magnetic tape. Both consumer and professional
VCRs often include provision for special "trick" features such as
variable speed forward (eg., fast search), reverse and freeze-
10 frame. The disclosed recording/reproducing apparatus is capable
of reproducing pre-recorded media, and can record both a
received broadcast high definition television such as a signal in
accordance with the AD-HDTV format, as well as live pictures
from a camera. The present invention is directed to means for
15 facilitating the operation of high definition digital video
recorder/reproducing apparatus, with respect to special features
operation in particular.

Summary of the Invention

20 In accordance with the principles of the present invention,
digital video tape recording/reproducing apparatus suitable for
processing a high definition television signal includes provision for
controlling the occurrence of high priority image information. Such
information is selectively recorded at normal speed at
25 predetermined regions on tape tracks so as to be appear along a
tape head scanning path associated with specific reproducing
speeds greater than normal (eg., 20x normal). Input high priority
data may be reordered or duplicated for recording in
predetermined tape regions. In either case, input data is
30 manipulated to produce a viewable image during reproduction at
higher than nominal reproduction speeds, eg., in a fast search
mode. In an illustrated system for receiving an MPEG coded
datastream, an output datastream at greater than normal
reproduction speed comprises either intracoded I-frame data cells
35 only, or a whole Group of Pictures (GOP).



5 In accordance with a feature of the disclosed system, feature bits/indicators containing operating instructions for subsequent receiver circuits are added to the datastream.

In accordance with another feature of the disclosed system, information is processed at the MPEG codeword level. An input MPEG coded datastream is decoded to MPEG words, then selected
10 MPEG words are re-coded and recorded in tape packets.

Brief Description of the Drawings

In the drawing:

Figure 1 illustrates a portion of a magnetic tape showing a
15 helical tape recording format.

Figure 2 illustrates the head scanning path of magnetic tape tracks during normal play.

Figure 3 illustrates the head scanning path of magnetic tape tracks in fast scan modes.

20 Figure 4 illustrates data recovery areas in fast tape scan modes.

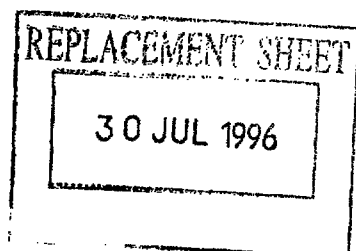
Figures 5 and 6 illustrate the recorded position of high priority (HP) information for fast scan reproduction in accordance with the present invention.

25 Figure 7 illustrates the relationship between picture, datastream and magnetic tape information in a fast forward features mode, in the context of Figure 6.

Figure 7a is a block diagram generally illustrating functional aspects of the fast forward features mode described in connection
30 with Figures 6 and 7.

Figure 8 is a representation of datablock groups consistent with the MPEG standard.

Figure 9 is a generalized pictorial representation of a hierarchical data format consistent with the MPEG standard.
35



5 Figures 10, 11 and 12 show functional details, in block diagram form, of a cell-level video tape recording/ reproducing system employing the invention.

Figures 13-16 illustrate aspects of data cells processed by tape recording/reproducing apparatus according to the invention.

10 Figure 17 shows details of the operating structure of a portion of the system shown in Figure 12.

Figure 18 shows details of a known transport block (packet) header component for the AD-HDTV system.

15 Figure 19 illustrates the relationship between high priority (HP) and low/standard priority (SP) data channels in an HDTV system, and a picture frame sequence according to the MPEG standard.

Figure 20 is a table illustrating aspects of a slow features operating mode of a tape recording/reproducing system according to the invention.

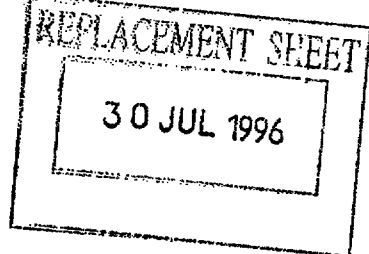
20 Figure 21 is a pictorial helpful in understanding the development of output frame data in fast forward reproducing mode.

25 Figures 22 and 23 show functional details, in block diagram form, of an MPEG-level video tape recording/ reproducing system employing the invention.

Figure 24 illustrates the general configuration of a tape packet locally generated by the recording/reproducing system.

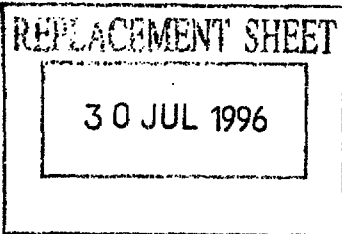
Detailed Description of the Drawing

30 By way of background, and as an aid to understanding the operation of the invention, Figure 1 shows a segment of magnetic tape recorded in conventional helical format. Helical-scan tape tracks are oriented at an angle as shown, and are alternately recorded at different azimuths, "a" and "b," in accordance with
35 conventional practice. Also in accordance with conventional



practice, longitudinal tracks disposed along an outer edge of the tape contain servo and timing information.

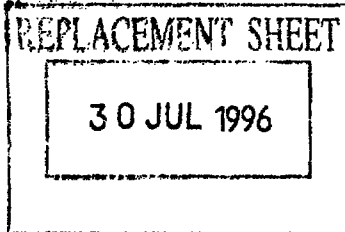
- 5 In normal VHS television format, each track encompasses one image field interval. In the case of the tape wrapping around the rotating drum 180 degrees, and with two recording/playback heads, the drum completes one revolution in two fields (1/30 second) at a drum speed of 1800 rpm. To obtain more bandwidth
- 10 for digital recording, each field/frame may be segmented into five portions, for example. Such segmentation does not present a problem since data headers provide a reliable means of identifying data segments to be recombined into an image. In such a digital system the drum spins five times as fast (9000 rpm).
- 15 This speed is assumed to be acceptable for accomodating a 35 Mbps (bits per second) gross data rate, or about 24 Mbps net video rate, eg., after error correction, control and audio data). Bandwidth capacity may be further increased by increasing the number of tracks and associated heads. At 35 Mbps, each track
- 20 contains 115 Kilobits or 14.5 KiloBytes. This amount of data is equivalent to about 100 transport packets in the AD-HDTV system. In a digital system, each track may contain more or less than a field/frame of information due to the nature of the variable length coded data associated with each transport packet.
- 25 Head gaps are skewed with respect to the direction of tape head motion by a few degrees, with alternate heads tilted in opposite direction, as is known (azimuth recording/reproducing). When recording, the tracks overlap so that the tape head is completely covered with abutting tracks. When reproducing at a
- 30 normal speed, each head is centered on its associated track with the correct tilt and adjacent track signals are greatly attenuated by the effect of the azimuth and are thus effectively disregarded. This normal mode process is illustrated by Figure 2, showing the paths taken by first and second heads over respective (white and
- 35 shaded) tracks during successive passes of the respective heads.



5 In a special "features" mode, such as fast search, each head
passes across the tape at an angle to the recorded tracks. This
process is illustrated in Figure 3 for fast-search speeds 2x, 8x and
20x faster than normal. In effect, each head drifts across the tape
tracks from one edge to the other at a rate that is a function of the
tape speed. In the higher speed modes, data recovered by each
10 head appears in the form of a burst of good data cells followed by
a gap as the head passes over a track section recorded with the
other azimuth angle, then a burst of good cells from somewhere
else in the picture. In this regard it is noted that the likelihood of
picture data continuity diminishes with increasing tape speed due
15 to the increasing number of tracks crossed as the head transits the
tape from edge to edge. The data disruption (gaps) produced by
high speed tape operation is illustrated by Figure 4. The data gaps
are caused by the tape head skipping tracks rather than following
a given track continuously as in the normal speed mode, coupled
20 with the inability of a given head intended to operate with respect
to a track recorded at one azimuth (shaded track) to recover data
from an adjacent (white) track recorded at a different azimuth.

The fast search speed range is dictated by the ability to
search the tape rapidly while obtaining a reasonable preview of a
25 displayed picture. A speed range from about 10x to 30x normal
generally satisfies this objective. At slower speeds, a viewer may
become impatient. The high end of this speed range may be too
fast for skipping television commercials, for example, but would
still be useful for searching a tape.

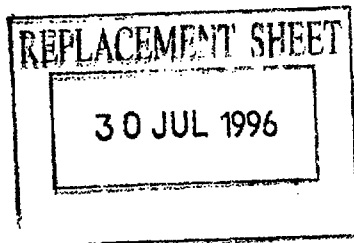
30 Fast features are distinguished by the fact that the head
cannot cover all of the tape area, whereby only a portion of the
available data becomes available for display. In accordance with
the principles of the present invention, it is recognized that this
deficiency may be significantly compensated for by managing the
35 data so as to determine which data subset on the tape becomes
available for display at one or more predetermined tape speeds.



To this end certain data cells are massaged, eg., duplicated or re-ordered, to permit reproduction from the tape in a desired temporal sequence at predetermined tape speeds. Specifically, high priority data are positioned on the tape so as to be reproducibly scanned by the head at selected tape speeds. This process is facilitated by the packetized datastream, and in particular by indentifying and timing information contained in the headers associated with the data packets, as will be explained in connection with subsequent Figures. In the AD-HDTV system HP cells contain the most important information required to reproduce the picture. The HP cells are treated in a manner which minimizes the chances of the information being lost. In over-the-air transmission the HP information is sent at a higher power level than the LP information. For tape recording, it may be advantageous to record the HP cells more than once.

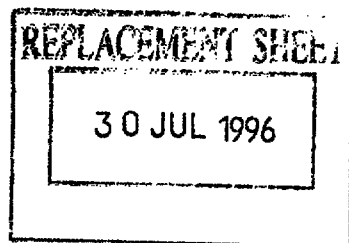
Since at high tape scanning speeds the reproduced/displayed information is otherwise unpredictable, in the disclosed system certain high priority information which is known to produce a good image is recorded at specific track locations which are traversed by the head at selected tape speeds. This high priority information includes low video frequencies including DC, important AC image information, audio and synchronizing information, for example. This recorded data format is illustrated by Figure 6, which is derived from Figure 5.

One function of the HP information is synchronization of the data presentation with the arrival of data in the bitstream. The video input to the system arrives as pictures or frames that occur at constant rate. The encoding process produces a variable length coded bitstream in which individual frames occupy different numbers of bits, and hence different time intervals. The receiver must produce video output frames at constant rate. In addition, the decoder must have all of the input bits required to generate an output frame at the time that the bits are needed. In the AD-



HDTV system, timing packets in the HP channel are used, in conjunction with the picture header information in the bit stream to achieve the desired synchronization. The picture header information in the bit stream occurs in the HP data cells at the beginning of the data for each frame. These picture headers include an identifier for the picture sequence number. This picture header sequence number is, in effect, a count, going from 0 to 1023 of frames in the video sequence. Picture (or frame) 123 follows picture 122 and is followed by picture 124. The picture header information can be thought of as conveying the meaning: "The following bits determine *how* to make frame 123." The timing cells in the HP channel are inserted by the encoder at approximately a constant rate, the display frame rate. The timing cells do not align with the picture data. When each timing cell arrives, it is time for the decoder to make an output picture. The timing cells contain a sequence number that corresponds to the picture that is to be made. At some time, a timing cell arrives, containing a sequence number 122, indicating that frame 122 is to be made. Very nearly one frame time later, a timing cell arrives containing sequence number 123, indicating that frame 123 is to be made. The time of arrival of the timing cell indicates when the frame is to be generated, and the contents of the timing cell indicates which frame is to be made. If the data for frame 123 arrives before the timing cell for frame 123, the decoder waits for the proper timing cell. If the timing cell for cell 123 arrives at the decoder and the buffer in the decoder contains something other than the picture header for cell 123, the data in the buffer is discarded. This recorded data format is illustrated by Figure 6, which is derived from Figure 5. The timing cell information can be thought of as conveying the meaning: "Now is the *time* to make frame 123."

Additional redundant information is carried in the timing cell, such as the type of frame (I, B or P). The timing cell is also the

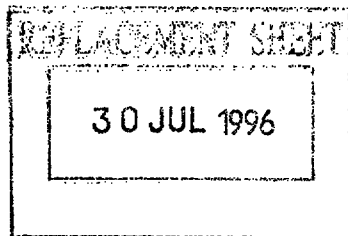


5 vehicle for transmitting the decoder control bits or feature bits described below.

As shown in Figure 6, high priority (HP) data packets (cells) are recorded at five predetermined regions of a track, designated as HP1 through HP5. The track sections passed by the head during non-standard speed playback (eg., fast search) determine the recorded locations of HP data. HP data is spatially recorded along the track to facilitate recovery during other than nominal reproduction speeds when the head traverses multiple recorded tracks during a single pass.

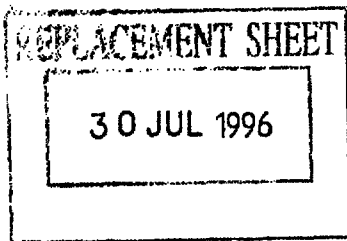
10 The HP data packets are located so that they encompass all of the tape track segments within each designated HP region, not only the black areas within each HP region. The black areas indicate the head contact areas along the head path at predetermined 2x, 8x and 20x normal tape speeds (see Figure 3), ie., areas where the head acquires information from the tape at these predetermined speeds. The remaining intervening regions containing head contact areas are considered as low priority (LP) regions and are designated as regions LP1 through LP3 for the 20x normal speed example. Other low priority regions, eg., between regions HP2, HP3 and between regions HP4, HP5 have not been labelled as such. Low priority data is written to the tape as it appears in the original input datastream, ie., without re-ordering.

25 The following discussion is made with respect to tape speed at 20x normal speed. In the AD-HDTV system, HP information includes low frequency video information and audio and synchronizing (timing) information. In the present embodiment, the HP regions are filled with re-ordered intracoded I-frame cell data, and the LP regions arbitrarily contain B frame or P frame cell data among other low priority information as received. It is noted that the HP regions are selected so that good results are produced at more than one speed, ie., HP data is predicatably



recovered at these speeds. Specifically, each of the three
5 illustrated tape speeds (2x 8x and 20x normal) will have HP
information recorded to coincide with the associated head path so
that a viewable or recognizable image will be produced by a head
following each of the associated paths. For example, the
uppermost 20x speed path includes five designated HP regions
10 (including one at the origin), each of which has a counterpart at
the other designated high tape speeds. In Figure 6, the numbers
shown in the third horizontal track from the top designate the
nominal width of the associated HP or LP region, in data slices.
Thus, for example, region HP1 contains 2 high priority data slices,
15 region LP1 contains 6 low priority data slices, region HP2
comprises 3 data slices, and so on. It is to be understood that
these slice designations are a simplification in the interest of
providing a clear explanation. The HP data is recorded at normal
tape speed so that this data is traversed by the head at the
20 selected fast forward features speeds, as will be discussed
inconnection with Figure 7.

In the recording process, the variable-length-encoded
bitstream is put onto the tape. An example not involving
duplication of data will be described first. The total bit rate to be
25 recorded corresponds to the total area of tape to be recorded. In
previous recording methods, the data to be recorded is put on the
tape sequentially. In the current example, there is no direct
correspondence of the position of the data on the tape to the time
sequence of the video. The bitstream data is rearranged, cell by
30 cell, to provide the feature mode playback. A desired pattern of
cells on the tracks is pre-determined, based on the desired
playback feature speeds. As shown in Figure 6, the planned
pattern is: 2 HP cells, 6 SP cells, 3 HP cells, 1 SP cell, 4 HP cells, 5
SP cells, 4 HP cells, 2 SP cells, 3 HP cells and 12 LP cells. The
35 corresponding sequential regions in figure 6 are marked HP, LP1,
HP2, (LP not-marked), HP3, LP2, HP4, (LP not-marked), HP5, and

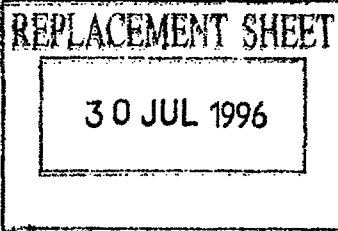


LP3. The tape regions are filled with the next available cell of the
5 corresponding type that is available in the prioritized bitstreams.
In normal playback, the full data stream is recovered from the
tape. The first 2 cells of a track go into the HP output stream, the
next 6 cells go into the LP stream, the next 3 into HP, and so forth.

Again, with reference to Figure 6, now assume that the same
10 tape is played back at 2x speed. Valid data is read from the tape
in the region marked in black. The reading process starts on track
1. The first 2 cells read are assigned to HP, the next 6 cells
assigned to SP, the next 3 to HP, the next cell to SP and so forth.
Somewhere in region LP3 the data becomes invalid. Valid data
15 resumes with the other azimuth head on track 4, and repeats the
same pattern. It can be seen that not all of the data is recovered,
but the data that was lost was LP data. It is a characteristic of the
prioritization of AD-HDTV that pictures can be generated from HP
data only.

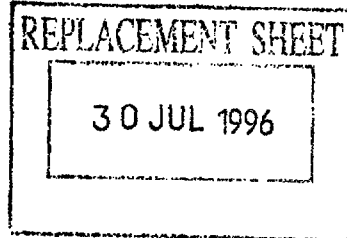
20 Figure 7 illustrates the process of tape machine operation in
a fast forward features mode at 20x normal speed, with respect to
cell data reordered into a desired sequence of HP and LP data
regions as shown in Figure 6. For the purpose of the following
example it is assumed that the reordered data placed in HP
25 regions HP1 through HP5 is MPEG intraframe coded I-frame data,
which is temporally coherent information independent of other
information, unlike B-frame or P-frame data which are
predictively coded. To simplify the following discussion of Figures
6 and 7, it is assumed that low priority LP regions LP1, LP2 and
30 LP3 respectively contain B1, B2 and P1 frame data in that order,
although the actual content of the LP regions would be arbitrary,
ie., the LP data would occur in the LP regions in the order
received in the datastream.

To help understand this material, reference is made to
35 Figures 8 and 9 together with pictorial (A) of Figure 7, showing
the MPEG arrangement of a Group of Pictures (GOP). A GOP, in the



context of the MPEG standard, contains 9 image frames, beginning
5 with an I-frame followed by a sequence of B- and P-frames as
follows: I, B1, B2, P1, B3, B4, P2, B5, B6. An I-frame usually requires
many more bits than either B or P frames. A GOP exhibits a
display time of 9/30 sec., or about 0.3 seconds. At a channel rate
of 24 Mbps, an average GOP corresponds to 7.2 Mb in size (24 x
10 9/30). A GOP may vary in size from 1.2 Mb to 13.2 Mb. An AD-
HDTV receiver typically will contain two stored past and future I
and P anchor frames. When a B frame is received, an output image
frame will be generated from the stored anchor frames. When a
non-B frame is received, the existing future anchor frame is
15 moved to the position of the past anchor frame, and a new future
anchor frame is created from the received data while the past
anchor frame is being displayed.

More specifically, in this example the input datastream
comprises a data-compressed sequence of frames that are coded
20 compatible with the MPEG format. This format is hierarchical and
is illustrated in abbreviated form in FIGURE 9. The MPEG
hierarchical format includes a plurality of layers each with
respective header information. Nominally each header includes a
start code, data related to the respective layer and provision for
25 adding header extensions. Each header includes information
related to the data in the data packet with which the header is
associated. The header information aids data assembly and
synchronization eg., at a receiver, and includes information such
as service type (eg., audio, video), frame type, frame number and
30 slice number, for example. A header of this type and its
processing are described in the context of an AD-HDTV signal
processing system employing MPEG signal coding in previously
mentioned US Patent 5,168,356-Acampora et al. Figure 18 of the
present application shows details of the transport block header
35 used in the AD-HDTV system described in the Acampora et al.
patent. Figure 19 shows the timing relationship between the AD-

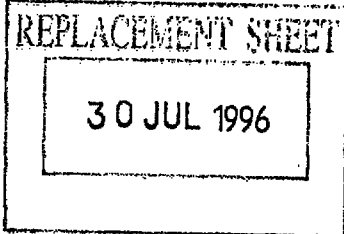


5 HDTV high priority (HP) and the relatively lower priority standard
priority (SP) datastreams, and the time sequence of the MPEG
coded I, B and P frames.

When referring to the MPEG compatible signal processed by
the system, what is meant is that (a) successive picture
fields/frames of video signals are encoded according to an I, P, B
10 coding sequence, and (b) coded data at the picture level is
encoded in MPEG compatible slices or group of blocks, where the
number of slices per field/frame may differ and the number of
macro blocks per slice may differ. An I coded frame is one which
is intraframe compressed (coded) such that only I frame
15 compressed data is required to reproduce an image. P coded
frames are coded according to a forward motion compensated
predictive method, where the P frame coded data is generated
from the current frame and an I or P frame occurring before the
current frame. B coded frames are coded according to a
20 bidirectionally motion compensated predictive method. The B
coded frame data is generated from the current frame and from I
and P frames occurring both before and after the current frame.

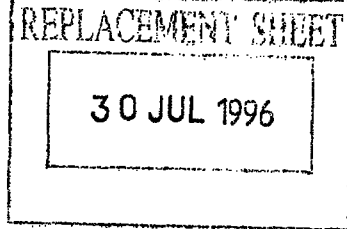
The coded signal processed by the present system is
segmented into groups of pictures (frames), or GOPs, illustrated by
25 the row of boxes L2 (FIGURE 9). Each GOP (L2) includes a header
followed by picture data segments in the form of a sequence of
nine picture frames I, B, B, P, B, B, P, B, B as illustrated by pictorial
(A) of Figure 7. The GOP header includes data related to the
horizontal and vertical picture size, the aspect ratio, the
30 field/frame rate, the bit rate and other information.

The picture data (L3) corresponding to respective
picture frames includes a picture header followed by slice data
(L4). The picture header includes a field/frame number and a
picture code type. Each slice (L4) includes a slice header followed
35 by a plurality of blocks of data MBI. The slice header includes a
group number and a quantization parameter.



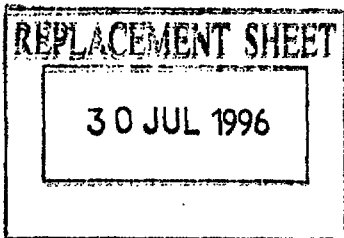
Each block MBi (L5) represents a macroblock and includes a header followed by motion vectors and coded coefficients. The MBi headers include a macroblock address, a macroblock type and a quantization parameter. The coded coefficients are illustrated in layer L6. Each macroblock includes 6 blocks, including four luminance blocks, one U chrominance block and one V chrominance block, as shown in FIGURE 8. A block represents a matrix of pixels, e.g., 8 x 8, over which a discrete cosine transform (DCT) is performed in this example. The four luminance blocks are a 2 x 2 matrix of contiguous luminance blocks representing, e.g., a 16 x 16 pixel matrix. The chrominance (U and V) blocks represent the same total area as the four luminance blocks. That is, before compression the chrominance signal is subsampled by a factor of two horizontally and vertically relative to luminance. A slice of data corresponds to data representing a rectangular portion of an image corresponding to an area represented by a contiguous group of macroblocks. A frame may include a raster scan of 360 slices, 60 slices vertically by 6 slices horizontally. The block coefficients are DCT transformed one block at a time. The DC coefficient occurs first, followed by respective DCT AC coefficients in the order of their relative importance. An end-of-block code EOB is appended at the end of each successively occurring block of data.

Referring again to Figure 7, pictorial (B) is a simplified expanded view of pictorial (A). Each I, B and P frame comprises image slices with a data component and a header component which defines the associated slice data component. Pictorial (C) represents the data recovered from the magnetic tape at 20x normal speed. Each segment of recorded data (C) represents a burst of about 6-7 data cells followed by a gap of about 3-4 data cells, at 20x normal speed. The recovered data is derived from a tape with data arranged into predetermined HP/LP regions as shown in Figure 6. In the interest of clarity, pictorial (C) does not



show the data gaps resulting as the head passes over other
5 azimuth recorded tracks. Pictorial (D) illustrates the datastream at
the output of the tape machine when playing back at 20x normal
speed. The playback data (D) has been re-ordered and converted
(from recorded data C) to the standard MPEG sequence of I, B, B,
P... frames which a receiver's signal processing circuits expect to
10 see for display processing purposes. Thus pictorial (D) represents
image data in a fast forward features mode at 20x normal speed
based upon an arrangement of the tape into HP and LP segments
as shown in Figure 6.

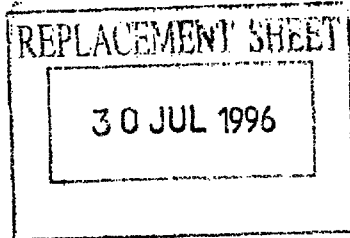
The tape data packets are reordered into prioritized regions
15 as shown and discussed with respect to Figure 6 by using
information including timing information contained in the tape
packet headers together with an indexing system as will be
described. The recovered tape data sequence begins with I-frame
information since this information begins a GOP according to the
20 MPEG standard and is therefore readily identified. In addition, a
Picture Start codeword is associated with the beginning of a GOP.
Beginning with track 1 at 20x speed, the first recovered data from
high priority region HP1 is I frame slice information which in
pictorial (C) is shown as I1. The next region scanned by the tape
25 head along the 20x speed path is a low priority region LP1
occurring at track 3. Data recovered from this region, assumed to
be B frame data, is shown as B3. The third region scanned by the
tape head at 20x speed is high priority region HP3 at track 5. Data
recovered from this region is shown as I5 in pictorial C This
30 process continues by acquiring I frame data from tracks 7, 11 and
13, B frame data from track 9, and P frame data from tracks 15-
19, in the sequence shown. In pictorial (C), the subscript
associated with a given I, B or P frame designates the track from
which the data was recovered by the head. The data recovered
35 from the LP3 region of the tape corresponds to disconnected
regions of LP data from that is probably from somewhere in



frames 15 through 19. Because of the nature of the variable-length-encoded bitstream, it is generally not possible to specifically indicate which frames of video correspond to specific regions of the tape.

The recovered data in pictorial (C) is inappropriate for processing by a receiver, since a receiver expects the see data in the I B B P B B P B B MPEG frame format. Thus the data recovered at 20x normal speed (pictorial C) must be re-converted back to an MPEG compatible datastream. Such a re-converted MPEG compatible datastream reflecting 20x tape operation is illustrated by pictorial (D) and is developed as follows. First, the tape packet headers of the recorded data in pictorial C are examined to identify the recovered information. The data is then re-ordered into the standard MPEG format by grouping I, B and P frame data together in sequence. The HP1-HP5 I frame data is placed first in sequence in the output datastream (I1, I5, I7, I11, I13...), followed by LP1 and LP2 B frame data (B3, B9...), other B frame data, and LP3 P frame data (P15-19...).

Figure 7A generally illustrates the process by which this is accomplished. In step 70, the input I, B, P datastream (pictorial B in Figure 7) is reordered so that the data cells exhibit the sequence of high and low priority regions shown in Figure 6. In step 71 tape packet header data is provided for identifying the reordered data. The reordered tape packets are recorded at normal speed, and played back at 20x normal speed in a features mode (step 72). During 20x playback the headers of the recorded packets are examined in step 73. These headers contain information identifying the I, B, P data sequence shown in pictorial (C) in Figure 7. In step 74 the data sequence is converted back to the standard MPEG sequence expected by the receiver (pictorial D). The re-converted IBBP... frame sequence is stored in a multiple page (I, B, B, P) memory (step 76), which is continually scanned for deriving output data to be applied to a tape signal



receiver via a playback output processor/buffer (step 78).

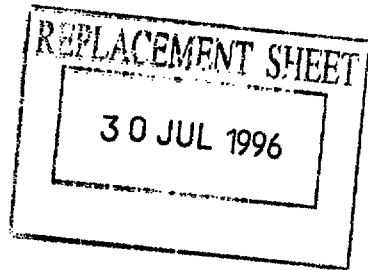
- 5 Addresses in frame stores which have not been altered to reflect reordered data remain unchanged, ie., with old data from prior tape head scans.

At normal tape speed, all IPB frame data derives from one tape track, in contrast to the 20x normal speed situation where, for example, I frame data are obtained from more than one track. With the disclosed technique, reordered HP I frame data is advantageously placed so as to be predictably recovered at several places along the tape head path, at more than one tape speed in this example. A visual presentation in the illustrative I frame example is a series of still image information at a refresh rate likely to be about 3 to 5 frames a second. Each frame is composed of pieces (from macroblocks, through slices to larger pieces) from the corresponding collection interval.

10
15

The disclosed technique for remapping high priority cell data into predetermined tape regions for reproducible recovery during a high speed features mode essentially first involves determining what scan rates produce good results. Typically, a scan rate that is moderate (2, 3, or 4x) is desired to allow accelerated viewing of pictures. In addition, the fastest rate that produces viewable pictures is desired (eg., 20x) to permit rapid skipping of unwanted scenes. Next, the areas of the tape traversed by the head at these scan rates is mapped, ie., the head track is determined. Finally, HP cells are assigned (re-ordered) to designated tape areas traversed by the head at selected scan rates. A duplicate of a timing cell associated with the beginning of a GOP may be placed at the beginning of a tape scan, since there is a high probability of recovering such a cell. If HP cells do not completely fill selected areas, the cells are distributed in clumps in the centers of the selected areas. It is noted that, during fast scans, as the pickup head is displaced with respect to the position centered with respect to the track (of correct azimuth), the signal

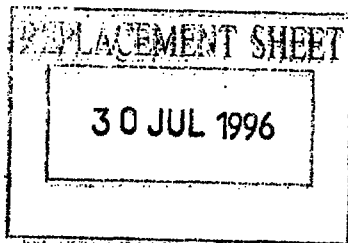
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quality follows a trapezoidal shape. Specifically: the signal is not
5 present, the signal improves, the signal is good while the head is
aligned with the center of the track, the signal gets worse, and the
signal is lost. The HP data is located in the regions where the
signal is good. If the selected areas are large enough for the
original number of cells, but not large enough to hold all the
10 duplicate cells, the duplicates are distributed uniformly
throughout the area. If the selected areas are too small for the
original number of HP cells, the least useful scan rate should be
ignored and the head track is remapped at the time of product
design.

15 With this technique, the fraction of the image which is
visually good or acceptable is greater than that which would
otherwise result, even though some temporal segmentation may
be present. The amount of temporal segmentation which may
appear is a function of frame-to-frame motion, which may be
20 very little in many cases. The illustrated tape speeds are those
which are considered to give good results, but other speeds may
produce better results. The disclosed system advantageously
offers flexibility with respect to choice of speeds in the high speed
features operation mode, including speeds which are non-
25 multiples of the number of frames in a GOP.

When presenting a picture at a fast scan speed, a decision
must be made about when to present data to the output decoder.
Recall that the variable bit length encoded data recovered in a
frame time does not correspond to a frame's worth of data. One
30 frame time may contain several B-frame's worth of data or only a
fraction of an I-frame's data. The operation of an AD-HDTV
decoder or an MPEG decoder takes place in units of pictures and
frames. If a frame's time data corresponding to part of an I frame
is delivered to a decoder, only part of the picture is produced. To
35 update the entire picture with refresh action, it is necessary to
accumulate enough of the bitstream to describe how to make an

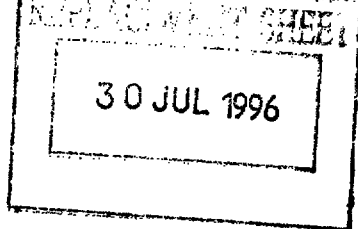


entire picture. When this information is delivered to the decoder,
5 the corresponding timing cell may be delivered to cause the
generation of the frame.

In the example illustrated by Figures 6 and 7, it was
assumed that I frame data is the high priority data arranged in
the designated HP regions. Since the tape head will recover data
10 from both high and low priority regions at 20x normal speed, the
playback data stream (Figure 7, pictorial C) will include high
priority I frame data and low priority B and P frame data. When it
is intended to display an image at 20x speed obtained only from I
frame information, the tape machine will output only the I frame
15 data (eg., only I1-I13 in Figure 7 (C)). This may be easily
accomplished by examining the headers of the playback cells and
rejecting all except those cells containing I frame information.
Since an I frame encompasses approximately 0.2 seconds, at 20x
normal speed the cells from 4 seconds of original video will be
20 collected to produce a 0.2 second collection interval. As noted
above, the output will be a series of I frames only in this case,
which is illustrated by Figure 21. In Figure 21 the upper pictorial
represents a portion of data recovered from the tape at 20x speed,
shown relative to real time in milliseconds, where only I frame
25 cells are used. The data segments designated "not I" represent
rejected low priority data. Thus the upper portion of Figure 21
corresponds to the output playback datastream shown in pictorial
(C) of Figure 7 with I frame data cells grouped together and B, P
frame data cells rejected. The lower pictorial of Figure 21
30 illustrates the formation of a synthetic I frame from a composite
of data acquired from 20 GOPs, shown with respect to tape speed
in seconds (at 20x normal speed). Although the variable length
coded bitstream does not necessarily correspond to equal duration
pictures, there is a maximum deviation in time of the picture data
35 in the bitstream from the time at which the timing cell causes the

generation of the output frame. This maximum time deviation is set by the buffer size, and is typically 1/4 second. If the GOP consists of 9 frames, then 20 GOPs at 20x speed are accumulated in 9 frame times ($9/30 \text{ seconds} = 0.3 \text{ second}$), and 20 GOPs of data on the tape will have passed in $0.3 + 0.25 = 0.45 \text{ second}$. Null cells are inserted in the playback datastream in place of the rejected cells to maintain datastream continuity. A visual presentation in the illustrative I frame only example is a series of still images at a refresh rate likely to be about 3 to 5 frames a second. Each frame is composed of pieces (from macroblocks, through slices to larger pieces) from the corresponding collection interval. Some I frame data may be used in more than one output frame.

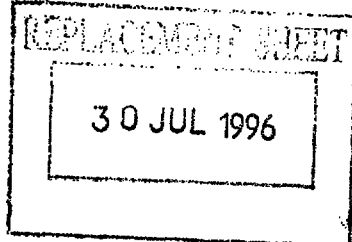
Alternatively, a playback output image may be comprised of a composite GOP if all recovered HP frames and SP frames are retained in the output playback datastream (as shown in Figure 7 (C)). Since a GOP encompasses approximately 0.3 seconds in real time, at 20x normal speed the cells from approximately 6 seconds of original video will be collected to produce a 0.3 second collection interval for a GOP. In this case the 20x playback output is one GOP in which each frame is a composite of the 20 corresponding frames of input. At a 20x scan rate, 20 tape GOPs result in one output GOP. For example, the second B frame (B2) of the 20x playback output is made from the 20 2nd B frames in the sample. An advantage of acquiring a whole GOP in the high speed tape scanning function is that a picture with smoother motion may result due to the presence of spatially coded P and B frame cells, and motion vectors from the P and B frames are likely to be in approximately the correct direction. For example, consider a picture composed of a speaking person in front of a slowly panning background. In the case of fast forward playback using I frame information only, the still parts of the speaker will look good, but the moving parts of the speaker will be somewhat distorted, and the background will appear as a sequence of distorted stills. If the whole GOP is used during playback, the I



5 frame image portions appear about the same, but some blocks of the picture change as other frames of the GOP are displayed. The moving background is likely to remain distorted, but much of the picture moves smoothly in approximately the correct direction.

10 The implementation of whole GOP scanning uses a constant size interval of interest, which is 9 frames in the case of the AD-HDTV system. If the definition of a GOP changes to other than 9 frames in another system, the programming and operation of an index-index and computer controller (shown in Figures 10 and 12) are adjusted accordingly. All GOP frames are used. The start of the interval of interest is the first cell of the I frame beginning the
15 GOP. The sequence of frame types (I, B1, B2, P1, B3, B4, P2, B5, B6) within retrieved GOPs is tracked, and cells are sorted within like frames, eg., cells that came from B3 frames are put into the B3 output frame.

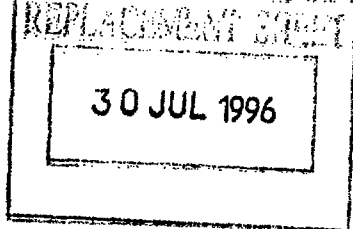
20 The process of redistributing the HP cells during recording involves buffering the cells into cell memory as they are received. A Cell Analysis Processor (as will be described) knows the time sequence of the cells being written to the memory. Specifically, the Cell Analysis Processor monitors the position of a cell in the input data stream relative to the start of a Group of Pictures. This
25 position is encoded in packet headers produced by the tape machine, eg., unit 1016 in Figure 10. This is accomplished without difficulty since the tape mechanism can maintain a precise count of the tape position in terms of the following factors: hh (hours), mm (minutes), ss (seconds), ff (frame number), tt (track number)
30 and pp (packet number). This information is unambiguous, and is mechanically derived from the head position and the longitudinal timing/sync track on the tape itself. This position information can be represented as a binary value. During the recording process, each cell is associated with a 10-bit linear temporal reference
35 number at the frame rate. When recording, the last picture header processed contains the temporal reference number. This number



is temporally stored in the recorder, and recorded in the next tape
5 related header to be written by the tape mechanism. The GOP
starting point and its temporal reference are readily determined
as noted earlier. As the (AD-HDTV) cells arrive, they are serially
numbered within a GOP beginning at the GOP start. This is a 14-
bit number. The difference between the linear temporal reference
10 and the 10 least significant bits to the tape position, along with
the 14-bit cell serial number, are included in the tape packet
header. Any packet, when recovered during the playback process,
yields this 24-bit number that can be used to regenerate the exact
time of arrival of the cell.

15 At normal speed playback, the original position of each cell
in the datastream is retrieved from the tape packet headers. The
playback cell datastream can then be rearranged in the original
order.

A general arrangement of a high definition video tape
20 recorder/reproducer and a high definition television receiver is
shown in Figure 10. A VTR 1008 receives an input HDTV signal
which is decoded by an HDTV decoder 1010. If the input signal is
of the AD-HDTV type, decoder 1010 may be arranged as described
in US Patent 5,168,356-Acampora, some aspects of which are
25 shown in Figure 11. Cell header information is analyzed by unit
1012 to obtain data about cell contents including timing and
sequence, and high priority cells are duplicated by unit 1014 as
an aid to implementing features mode operation. Specifically,
selected cells are duplicated in the recorded stream to allow fast
30 scans. In this example, where the AD-HDTV FEC function is
included in the tape machine (in decoder 1010, see unit 1154 in
Figure 11), a benefit is obtained that error related overhead does
not have to be stored. The extra storage that would have been
used for FEC bytes may now be used for redundant (duplicate)
35 cells to make certain information available during a fast search
mode. Additional storage capacity beyond the minimum required



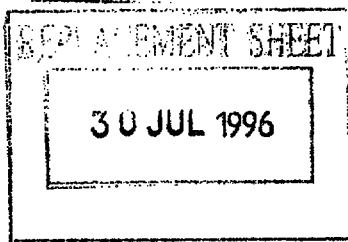
for the storage of the original bitstream may become available
5 through the process of elimination of FEC data as described above
or may become available due to technology improvements in the
recording process. This excess capacity is used for the redundant
storage of cells to improve fast scan performance. As was
described earlier, in the design process, selected scan speeds are
10 mapped to regions on the tape in which the HP data is to be
placed. If extra tape capacity is available, the mapping shown in
Figure 6 may be done for additional scan speeds. For example, if
an additional scan speed were desired, and data at the new scan
speed was not recovered in regions HP2 and HP4, but was
15 recoverable in a region just to the left of HP2 and just to the left
of HP4, the HP data that is recorded in HP2 and HP4 could be
redundantly recorded in the right ends of regions LP1 and LP2.
The displaced LP data from LP1 and LP2 is absorbed in the extra
capacity of the media. In the illustrative example described
20 previously, HP cells 1 and 2 were recorded in region HP1, then SP
cells 1,2,3,4,5,6 recorded in LP1, then HP cells 3,4 in HP2, & etc.
Given extra capacity, the recording pattern is: HP cells 1, 2 in HP1,
LP cells 1,2,3,4,5 in LP1, then HP cells 3,4 in a new duplicate
region at the end of LP1 and the beginning of HP2, then HP cells
25 3,4 again in HP2. The pattern where the redundant cells are
stored is pre-determined when the tape machine is designed.
When playing back at normal speed or 2x, the redundant cells are
recovered. From the position along the scan, these cells are
known to be redundant, and are discarded.

30 • Cells are converted to tape packets in unit 1016, eg., by
means of 8:14 modulation whereby 8 bits words are converted to
14 bit codewords for bit rate reduction as known. Tape packets
typically include a header component, an associated data
component and timing/synchronizing information. Tape packets
35 from unit 1016 are applied to an MPEG-compatible signal input of
unit 1018 which includes tape signal processing networks and a

tape transport mechanism. A non-MPEG auxiliary input of unit
5 1018 receives encoded tape packets from an auxiliary source
1020 (eg., a video camera) via a non-MPEG spatial information
tape encoder 1022. Tape output signals from unit 1018 are
provided to a unit 1030 which adaptively converts MPEG or non-
MPEG output signals to a standard RGB (Red, Green Blue) color
10 television signal format in responsive to a flag bit in the
datastream, and to a unit 1032 which converts the tape packets
back to the cell format of the input datastream. Duplicate HP cells
are eliminated by unit 1034 to provide an output signal
datastream of the format expected by the AD-HDTV decoder 1044
15 of television receiver 1040.

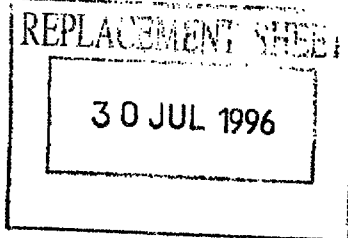
Standard RGB output signals from unit 1030 are applied to
one input of an input signal selector 1046 of HDTV receiver 1040.
The cell format output signal from unit 1034 is decoded by HDTV
decoder 1044 at an input of receiver 1040 before being applied to
20 another input of selector 1046. Selector 1046 provides either RGB
format signals or decoded AD-HDTV cell format signals to video,
audio, sync, etc. television signal processing and
reproducing/display circuits 1042 of receiver 1040.

Figure 11 shows HDTV decoders 1010, 1044 of Figure 10 in
25 greater detail. A received input signal is detected by modem
1150, which provides an output signal to a de-interleaver (de-
scrambler) 1152 and a Reed-Solomon forward error correcting
(FEC) decoder 1154. The corrected signal is applied to a rate
buffer 1156 which receives data at a variable rate commensurate
30 with the requirements of subsequent decompression networks in
video decoder 1160. A transport processor performs the inverse
of a data packing and prioritizing operation performed at a
receiver, and additionally performs a degree of error detection in
response to parity check bits included in the transport packets.
35 Transport processor 1158 provides output video and audio signals
to video transform decoder/decompressor 1160 and audio



decoder 1162, respectively, which provide audio and video output
5 signals with a cell format including data and header components.
In an AD-HDTV system as described in US patent 5,168,356-
Acampora, the modem provides two output signal associated with
HP and LP channels, and the de-interleaver, FEC control and
buffer functions are duplicated for both the HP and LP channels.
10 Figure 12 shows a more detailed block diagram of a video
tape recording/reproducing device capable of operating at the
data cell level. The system of Figure 12 includes a computer
controller 1222, ie., a microprocessor, capable of making the many
decisions that must be made at a packet/cell rate. Controller 1222
15 interacts with a database including cell buffer memory 1232
containing data read from the tape, and the controller maintains
an index 1224 of the buffer contents. For each cell, the index
contains information pertaining to cell location in the buffer; cell
starts at the tape reference time indicated by factors hh, mm, ss,
20 ff, tt, pp (described previously); cell error status; cell service type
(eg., audio or video) including HP/LP indicators; cell frame
number; cell frame type; and information translating between the
tape temporal reference and, for example, the AD-HDTV linear
temporal reference. The last mentioned item can be generated at
25 the time the tape is written to, and indicates which timing
packet's domain a data cell belongs to. Additional indexed
information may include indicators such as an indicator indicating
the validity of the next cell in sequence, a duplication indicator
showing that a cell has been duplicated elsewhere, and a
30 duplication index pointer indicating the index location of the
duplicated cell.

The index may contain as many as 13,000 entries (the word
size of the largest GOP). The size of an index entry is about 80 bits,
producing a storage requirement of about 128 KBytes for the
35 index. In addition, as an aid to controller 1222 in using the index,



an index-index 1226 is also maintained. The index-index contains pointers to frame boundaries within the index.

- 5 More specifically, in Figure 12, a camera input formatter 1210 converts an analog RGB color video signal to digital form during recording. Another block, not shown, performs the inverse function for playback. Tape read-write unit 1216 performs bit level modulation/demodulation during recording/playback, eg.,
- 10 using 8:14 modulation, as known, to convert an eight bit data word to a 14 bit codeword to achieve bit rate reduction. Tape motion controller 1218 contains capstan and tracking controls, and provides controlled acceleration starts and stops. In combination with unit 1216, unit 1218 manages the time-code function. Unit
- 15 1218 determines which track is being read, and responds to instructions to go to and pause at a specified track, and to begin playing at a given track at a certain speed, for example. Tape packet format/deformat unit 1220 creates and formats tape packets, creates or decodes tape packet headers, and performs
- 20 Forward Error Control and Cyclical Redundancy Checks as well as providing error indications. HDTV decoder 1212 operates as described in Figures 10 and 11 and provides an output cell stream including data bytes as well as information such as start-of-cell information, error flags, and a byte clock.
- 25 Cell analysis processor 1230 generates read/write addresses and provides data to cell memory 1232. In the recording mode, processor 1230 examines packet headers and timing packets and temporal references such as may be provided in the datastream of an AD-HDTV signal, for example. Processor 1230 additionally
- 30 maintains a GOP and frame count, a linear temporal reference for determining frame display, pointers to previous GOPs and frames, a tape packet record index indicating exactly where a packet should be recorded, and also controls the delivery of duplicate HP cells to packet format unit 1220. During the playback process, unit
- 35 1230 fills cell memory 1232 with data cells, scans the data stream and cell headers in particular, creates a cell index entry for each

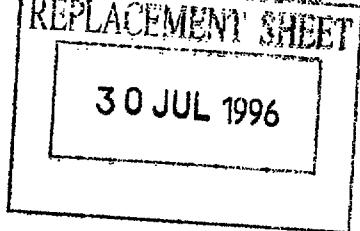
cell and maintains a GOP and frame sequence state. In addition,
5 unit 1226 index-index entries are created at appropriate times to
designate significant occurrences such as GOP boundaries, frame
boundaries and timing packets in the datastream.

Cell memory 1232 is sized to accomodate a GOP, receives
cells read from analyzer 1230 and writes output cells to packet
10 formatter 1220 at a port speed of about 3 MBps. Cell index
memory 1224 writes entries while analyzer 1230 is filling cell
memory 1232. Index memory 1224 comprises the address
function of controller 1222. Index-index 1226 is associated with
memory 1224 and contains pointers to frame boundaries within
15 index 1224, as will be seen in connection with Figure 17.

Cell output processor 1240 generates read addresses for cell
memory 1232 and provides output cells from cell memory 1232
under control of controller 1222 during the playback mode. A
FIFO buffer in output processor 1240 is loaded with addresses and
20 instructions from controller 1222. Under control of unit 1222,
some data passes from memory 1232 to the output of output
processor 1240 without alteration, while other data may be
altered (eg., service type sequence counts, timing cells and
temporal reference data).

25 Computer controller 1222 implements various features such
as Fast Forward, Slow Motion and Freeze Frame in response to
input user control signals (eg., from a user interface such as a
remote control unit) by communication with cell analysis
processor 1230, cell output processor 1240 and tape motion
30 controller 1218 via flags, buffers and registers as appropriate.
Controller 1222 processes about 30,000 cells/second and exhibits
about 33 microseconds/decision, on average.

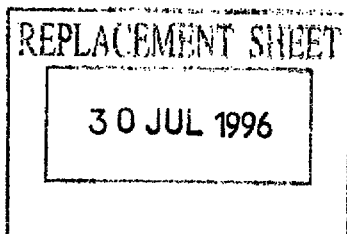
Following is a more detailed description of the information
processed by cell memory 1232 and cell index memory 1224.
35 Units 1224 and 1232 process two basic types of cells from which
FEC and error detection data have already been removed. These



cells are video cells, and timing and audio cells as shown generally
5 in Fig. 13. In these cells ST designates the Service Type code
portion (video, audio, timing), and H designates the Header
portion. Every cell begins with a Service Type byte. In addition to
the type identification (video, audio, timing...) the byte contains a
four-bit cyclical continuity count, ie., a Service Type Sequence
10 Number. The continuity count must be cyclical within each service
type. If not, the associated cell is assumed to be an (otherwise)
undetected error, eg., a lost packet. The Sequence Number also
indicates an incorrect service type, such as if audio and video
types are interchanged. Timing and audio cells have no specific
15 header in this example. As illustrated by Fig. 14, the Service Type
is a Byte indicating high priority video VH or low priority video
VL. Similarly, Fig. 15 illustrates the Service Type byte indicating
audio (always high priority) AH, and a timing cell TH (always high
priority). Numbering is indicated by the symbol "nn." In video
20 cells, the header contains a 5-bit frame number for aligning
datastreams.. In the AD-HDTV system, there is one HP cell for
every four LP cells. Usually the HP cell is video, occasionally the
HP cell is audio, and once a frame the HP cell is a timing cell.

There are four types of video headers, as shown in Figure
25 16. VH and VL designate high and low priority video components
as discussed. B, P and I designate the frame components of a GOP.
F designates a special case I frame, which is a high priority I
frame containing the beginning of a frame at Slice 0. This cell
starts with a Picture Start Code (PSC), which is followed by a
30 temporal reference for the new frame. The symbol ff indicates the
frame number. In the playback mode, cell memory unit 1232 is
loaded as a ring buffer. Somewhere in the memory is the
beginning of a GOP. This GOP boundary is defined as the first HP
or SP cell designated by Frame Type F.

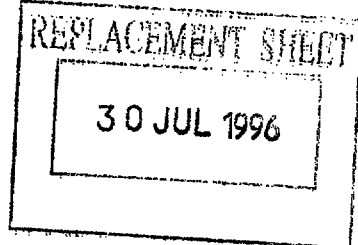
35 Temporal reference information, eg., 10-bit information, is
sent via the datastream timing packets to establish a flywheeled



5 local linear temporal reference which determines which frame to display and when. The Temporal Reference also appears in the HP data following an MPEG Picture Start codeword, and can be recovered as the 10 bits immediately following the Picture Start codeword in a frame type "0" HP cell.

10 Figure 17 illustrates the process by which cell memory data is accessed in the system of Figure 12. While putting cells into memory 1232, cell analyzer 1230 has also filled in the cell memory index of unit 1224. When cell analyzer 1230 sees a GOP start, or other significant information, it also fills in entries in Index-index 1226. For example, when a GOP start is present, a
15 register 1223 in computer controller 1222 indicates that location (address) 41 of Index-index 1226 is a GOP start. Register address 41 indicates that this GOP start (GS) is high priority (H) and that its index location (address) is 3210. That index location contains an entry indicating that the corresponding tape location ("i") is 4
20 minutes, 7 seconds, 9 fields, 2 tracks, 0 packets, and that the temporal reference ("t") is 222, for example. Flags ("f") may indicate that there are no errors, that the next cell is also good, etc. Finally, the index location indicates that the actual data for the cell is located at address "12345" in the cell memory. The next
25 Index-index entry indicates that the entry for the Group Start, low priority information (GS, L) is at index location 3333. The following Index-index entry indicates that the entry for the timing cell for this Group Start (GS, T) is at index location 3456. The next entry is for a low priority B frame (B, L).

30 Another approach to implementing features functions is recording at the level of MPEG codewords. In this example, this approach is based upon decoding an input AD-HDTV datastream to the level of a single stream of MPEG codewords. Specifically, it is herein recognized that in the interest of efficiency, only useful
35 spatial information should be used/duplicated. Spatial and non-spatial information can be separated much more easily in an

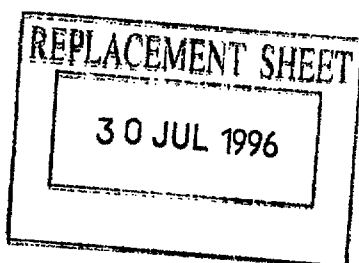


MPEG codeword datastream than in an AD-HDTV datastream.

- 5 MPEG-level processing advantageously uses spatial slices, and slices containing significant numbers of spatial macroblocks result in smoother scan presentations.

Therefore, according to this approach, an input digital datastream is decoded to a datastream of MPEG codewords. These
10 codewords are then separated into codewords representing spatial and non-spatial information, and certain separated spatial codewords are placed into tape data packets. The tape data packets are replicated as required, and the spatial packets are recorded where a scanning head will recover the spatial
15 information at tape speeds greater than normal, such as fast search speeds. Audio information is separated from video and processed separately, and is applied to a dedicated audio input of an HDTV receiver.

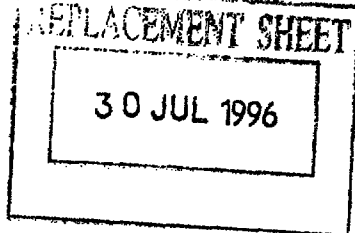
A general arrangement of a high definition video tape
20 recording/reproducing device using this approach is shown in Figure 22. Elements 2210, 2218, 2220, 2222, 2230 and 2234 are similar to units 1010, 1018, 1020, 1022, 1030 and 1034, respectively, of Figure 10. In Figure 22, HP and lower priority SP video information at a video output of AD-HDTV decoder 2210 is
25 stored in an elastic buffer 2211 before being variable length decoded into MPEG codewords and merged into a single datastream of MPEG words in a unit 2212. The MPEG word datastream is separated into spatial and non-spatial data by a separator 2213, which accomplishes this by examining codeword
30 identifiers. Non-spatial codewords are applied directly to a variable length coder 2214 (ie., a data compressor) to facilitate the subsequent recording process in unit 2218. Spatial codewords are duplicated by a unit 2215 before being VLC coded by unit 2214. Only important spatial data is duplicated by unit 2215, since there
35 is a large amount of spatial data. For example, a complicated still picture may comprise 75% or more I frame data. Thus the spatial



5 data is prioritized. Spatial slices for an I frame are considered important and are duplicated, and certain B and P frame spatial slices may be duplicated. For B and P frames, if a prescribed number of slices are found to be intracoded (eg., based on adaptive weighting factors as a function of picture complexity), the slice is considered to be spatial.

10 VLC spatial and non-spatial data outputs of compressor 2214 are applied to respective inputs of a tape packet generator 2216, another input of which receives variable length coded audio representative words from an audio output of AD-HDTV decoder 2210. Figure 24 is a general representation of the tape packet
15 format. The tape packet header contains fields indicating a time stamp within the original datastream (eg., indicating hours, minutes, seconds and frame number of associated data), the slice number of the data (eg., slice 50, I frame), and continuation data, a data section containing specific slice data including starting bit
20 and ending bit information for example, and an error correction section containing FEC and CRC error detection and correction information, for example.

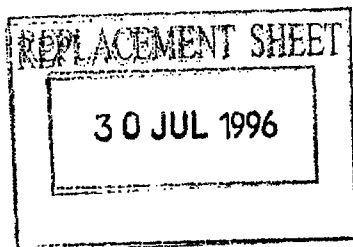
Continuing with Figure 22, a tape packet datastream from unit 2216 is recorded via tape transport and servo unit 2218,
25 which includes recording and playback mechanisms and electronics. An output signal is applied via a converter 2230 to an HDTV input selector as discussed in connection with Figure 10, and also to a unit 2234 which eliminates duplicate HP cells generated by unit 2215. An output signal from unit 2234 is
30 provided to an audio input of a decoder in the HDTV receiver. The output signal from unit 2234 is processed by a unit 2238 which converts the datastream from tape packets back to MPEG words and variable length decodes these words. MPEG words from an output of unit 2238 are applied to an MPEG-level video input of
35 an HDTV receiver decoder.



During playback/reproduction, the data recovered from the tape is in the form of tape packets containing variable length coded MPEG words. Merging the duplicated data into a useful MPEG datastream is facilitated by the information contained in the tape packet headers, indicating a time stamp within the original datastream, the slice number of the data and continuation data. As each packet is read by unit 2238, the data is converted from variable length code to words and is stored in memory (eg., unit 2332 in Figure 23). An index (eg., unit 2324 in Figure 23) is filled with packet header information. A computer controller (unit 2322 in Figure 23) decides which blocks of MPEG words are to be delivered to form the output MPEG word datastream.

The basic elements of an MPEG-level tape machine are shown in Figure 23. Elements 2310, 2312, 2314, 2316, 2318, 2320, 2322, 2324, 2330, 2332 and 2340 are similar in operation to elements 1210, 1212, 1214, 1216, 1218, 1220, 1222, 1224, 1230, 1232 and 1240 in Figure 12, respectively. Unit 2311 corresponds to units 2211 and 2212 in Figure 22. The elastic buffer in unit 2311 is resilient enough to allow a reasonable rate of variable length coding. Timing cell data are translated to a local frame timing signal. Variable length coder 2335 (eg., a ROM) compresses the MPEG bitstream for storage efficiency, using standard MPEG code tables. Variable length decoder 2326 subsequently undoes this coding. Decoder 2326 may be implemented by the decoder (VLD) in unit 2311 since recording and playback are not simultaneous.

Memory 2332 stores a GOP worth of MPEG codewords. Analysis processor 2330 writes data while output processor 2340 reads data. MPEG word analysis processor 2330 generates read/write addresses for word memory 2332. During recording, processor 2330 looks for Slice Start codewords in the wordstream, counts all spatial macroblocks, allocates duplicate slices, and delivers duplicate slices for recording. During playback, processor 2330 fills word memory 2332, scans tape packet headers, and

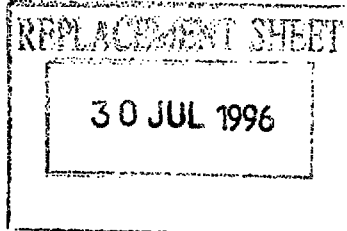


creates a slice index entry for each cell Slice index memory 2324
5 receives data from analysis processor 2330 while processor 2330
is filling word memory 2332. This memory is seen by computer-
controller 2322.

Output processor 2340 generates read addresses for
memory 2332 during playback, based upon the contents of slice
10 index memory 2324 and indices generated by controller 2322.
Controller 2322 loads a FIFO memory in output processor 2340
with address information and functional commands, and in the
playback mode controller 2322 provides slice indices to output
processor 2340. Output processor 2340 generates MPEG stream
15 levels above slice level and an output codeword stream including
a frame synchronization signal.

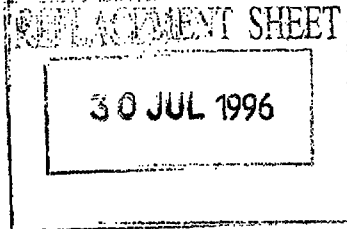
The operation of the MPEG-level system at slow features
speeds is generally similar to that previously described in
connection with the cell-level system. Briefly, a GOP of data is held
20 in word memory 2332. When the user (or a timer) calls for the
next frame, it is produced from the memory if possible. If such
data is not in memory, the tape is caused to move to acquire the
needed GOP data. Data to be output to the receiver is repetitively
played from memory. With this approach, frame synchronization
25 is accomplished with a locally developed signal delivered at the
start of the data for each frame. The words for an output frame
are all delivered within the frame time.

For fast features operation, the word memory is filled with
data. Slice index 2324 contains information bits indicating if an
30 entire slice was acquired (and if so, which slice), if the start of a
slice was acquired, or if only the end of a slice was acquired.
Controller 2322 rearranges the slices to form frames based upon
an examination of the contents of index 2324. Valid slices are
delivered by output processor 2340 under control of controller
35 2322.



The operations performed by the tape machine in the special features mode can be enhanced and assisted by the use of "feature (control) bits." These bits may be advantageously incorporated in the headers of the data cells of the AD-HDTV system, for example. These bits may be responded to at the television receiver to perform a given feature function by operations performed largely or entirely at the receiver, rather than at the tape machine. The AD-HDTV data format, as described previously, includes timing cells. These timing cells indicate to the decoder when to decode a specific frame. The timing cells contain the temporal reference that indicates which frame is to be decoded at the time that the timing cell arrives. There is room in the timing cell for extra information. It is in the timing cell that the extra feature bits are inserted. As the decoder requires a timing cell to decode a picture, the feature bits are available to the decoder when the picture is to be processed. The control computer 1222 in Figure 12, in response to user controls, is aware of which modes the tape machine is operating in. The control computer loads a register in the Cell Output Processor, 1240 with the values of the feature bits to be inserted in a known position in the timing cells to be produced.

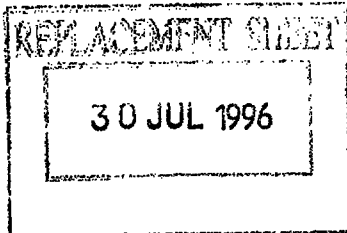
A bit field may be introduced indicating and instructing a receiver to "Show the Last Frame Again." In some AD-HDTV receivers the last frame is the past (I or P) anchor frame. In other receivers, the last frame is the last frame displayed. Another bit may represent an instruction to "Decode But Don't Play." In some receivers this bit may have the effect of leaving the last frame displayed in the output buffer while generating new frames. A further bit may represent an instruction to "Accept This Frame." This instruction may be intended to accept a given frame even if it is out of an expected temporal sequence. This action would begin at the next MPEG Picture Start Code (which precedes a frame) temporal reference in the datastream that matches this



5 timing cell temporal reference. The combination of this bit and the
"Show Last Frame Again" bit may be used by a receiver to
generate a new frozen frame. Another bit, "Ignore Input Data,"
may be used to ignore input video data for a given frame, leaving
the current state unchanged (anchor frames, motion vectors, error
concealment memory, etc.), and to disable sequential checks for
10 data consistency. Other features bits may represent instructions to
permit normal audio reproduction, to mute the audio completely,
or to mute the audio selectively when there are excessive data
discontinuities to avoid unpleasant sounds.

15 In a slow-speed playback features mode, the tape transport
mechanism may be required to exhibit shuttle-like movements,
passing over certain tape tracks before data is needed. The
playback electronics include buffer memory large enough to hold
a GOP of input data and a frame of output data for output. This is
not an unreasonable amount of storage as the data is compressed
20 at this point. Appropriately controlled tape acceleration can be
achieved with currently available tape transports and controllers.
An exemplary sequence of operations follows.

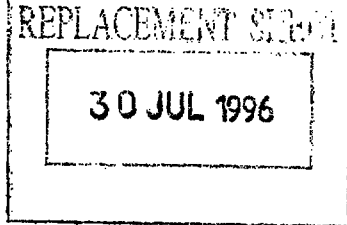
With the tape moving forward at normal speed, the cell
buffer memory cycles through its capacity (memory addresses),
25 storing the current GOP as it is written to the buffer. The tape
machine features controller (eg., unit 1222 in Figure 12) is aware
of the current position in the datastream of tape packets, and of
the corresponding current position in the input AD-HDTV
datastream. This information is conveyed by GOP and frame
30 number, picture header temporal reference for the MPEG
bitstream, timing cell temporal reference information from the
AD-HDTV datastream, and sequence counters for all service types.
All such information is contained in the headers inspected by the
features controller.



When the viewer activates a "Freeze" tape control, the tape mechanism continues to read through the current GOP, filling the buffer memory with an entire GOP worth of cells. The tape controller locates the GOP boundary in term of cells by scanning HP video cell headers for frame type 0 while buffering LP data in memory, and noting the associated frame number. The stored LP cell headers are then scanned for frame type 0 with a matching frame number. The associated current timing cell temporal reference ("linearized" to indicate the established frame display order) determines the frozen frame. Other timing cells in the header are replaced by the features controller, with timing cells containing feature bits indicating that the following functions are to be performed: Freeze frame, Ignore other inputs, and Mute audio. The features controller replaces further video cells with null cells while the Freeze frame feature persists. The insertion of null cells into the datastream during the freeze frame mode advantageously avoids the need to stop and start the datastream, thereby avoiding timing and synchronizing problems. In the replacement null cells, the associated Service Type Sequence Number in the header is generated sequentially by the features controller to validate the datastream with the replacement cells. This Sequence Number is used in the AD-HDTV system, for example, to aid in discovering lost or erroneously positioned packets, or interchanged service types.

The tape drive transport mechanism, having read to the end of the GOP, gently slows down the tape, backs up slightly, and prepares to resume reading the tape packets for the next GOP. At this point the user is still seeing the frozen frame display. At this time likely user instructions include Next Frame, Previous Frame, or Play.

If the user requests the next frame, the following steps occur. If the next frame is not in memory, the tape moves forward. The first frame written into buffer memory is the I frame at the beginning of the next GOP, after which the following



B and P frames are written to the memory whereby the buffer
5 contains the entire new GOP. Video service type cells for the next
frame are transmitted in order to the receiver. Again, video cells
not within the next frame are replaced by null cells. The timing
cell corresponding to the next frame may or may not be in the cell
buffer. If the features controller senses that it is in the buffer, it is
10 altered by the controller to match the artificial timing and
sequencing being generated by the tape machine. If it is not in the
buffer, the (timing flywheel in the) tape machine causes a timing
cell to be generated. This timing cell contains an "Accept This
Frame" features bit and a "Show Last Frame Again" features bit,
15 which cause the receiver to update the displayed picture by
showing the last frame.

If the user requests the previous frame, the following steps
occur. The features controller knows which anchor frames are
stored in the receiver. If the requested previous frame can be
20 generated from the existing anchor frames stored in the receiver
and from the input data for the requested frame (ie., the
requested frame is a B frame following a P frame in transmission
order), the cells to update the receiver display are produced using
the procedure described in the preceding paragraph. If the
25 requested frame is an I frame, a P frame, or a B frame following
an I frame, the tape is caused to reverse and play the entire
preceding GOP.

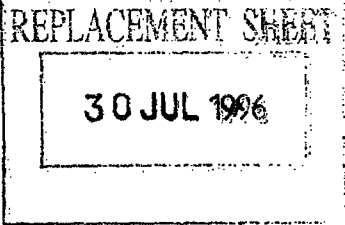
The table shown in Figure 20 indicates the frame
dependencies for stepping the tape forward and backward. In this
30 table, the "transmission order" row indicates what is recorded on
tape as appearing at the output of the video tape machine.
Assume that the GOP consisting of frames 9 through 14 is the GOP
in buffer memory. The "displayed frame" row indicates which
frame could be displayed at the time the transmitted frame is
35 available. B frames are displayable when they arrive, and anchor

frames (I and P frames) are displayable three frames after they arrive.

5 In the following examples assume that, when the tape is stepped forward, the GOP consisting of frame 9 through frame 14 has just been read from the tape. To display frame 6, frame 6 alone is required, and it is already in the receiver's anchor frame memory. The receiver always stores two anchor frames to be able
10 to create a B frame. Frame 9 is delivered and frame 6 is displayed. One more forward step requires the data for frame 7 and for anchor frames 6 and 9, which are available in the receiver's frame memory.

 When stepping backward, assume that the same GOP resides
15 in cell buffer memory (unit 1232 in Figure 12). The first frame to be displayed is frame 14. The previously displayed frame was frame 15, so frame 15 is assumed to be in receiver memory. Frame 14 requires data from anchor frame 12, and frame 12 requires data from anchor frame 9. The entire GOP must be output
20 to the receiver to prepare the receiver to display frame 14.

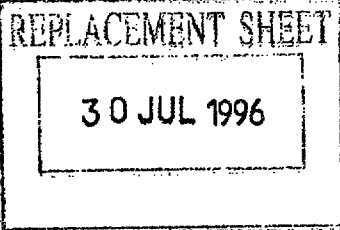
 Stepping back to frame 13 and then to frame 12 is less difficult, since the required anchor frames are already in receiver memory. Frame 11 requires replay of the GOP to put frame 9 into the receiver. Frames 10 and 9 follow easily. Stepping back to
25 frame 8 initiates a cascade. Frame 8 requires anchor frame 6, which isn't in receiver memory, and frame 6 is not in the current GOP in the tape machine's cell buffer memory. Frame 6 requires frame 3, which requires frame 0. Thus the entire previous GOP (frames 0-8) must be read from the tape. Accordingly, frames 0
30 and 3 are delivered to the receiver as anchor frames. Frame 6 is then delivered to the receiver, with frames 3 and 6 now being anchor frames. The GOP containing frames 9-17 is then re-acquired by going forward with the tape and storing it in the cell memory, and frame 9 is delivered to the receiver. Frames 6 and 9
35 are now the anchor frames, whereby frame 8 may be generated and delivered to the receiver.



5 The time to respond to a user requested step may vary,
depending on the type of frame which is requested. For some
frames, for which information is available in buffer memory, a
new picture can be generated and presented almost immediately,
eg., in approximately 33 milliseconds. The cascade example
described in the previous paragraph takes considerably more
10 time, since that example involved repositioning the tape to the
beginning of the previous GOP (100 ms.), reading the previous GOP
while delivering frames 0, 3 and 6 (300 ms.), reading frames 9, 7
and 8 (1/2 GOP time, 150 ms.), and presentation time (33 ms.), for
a total time of about 600 ms. This is not unreasonably long for a
15 user response time.

Other slow-speed user features, such as slow motion and
reverse, can be treated as a predictable series of still ("freeze")
frame steps. These steps are advantageously undertaken at the
receiver in response to information, such as the feature bits
20 described previously, provided to the receiver by the tape
machine. Thus, for example, it is the receiver which generates a
freeze-frame display using its internal memory and HDTV
processing/decoding circuits in response to a control bit provided
by the tape machine in response to a user control request. Slow
25 rates can be obtained by stepping and then repeating frames as
often as necessary to maintain a smooth rate.

The previously mentioned AD-HDTV system, sometimes
referred to as the ADTV system, has been submitted to the
FCC/ACATS for on-going testing and analysis by the Advanced
30 Television Test Center (ATTC).



40

CLAIMS

5

1. A video tape recording/reproducing system for processing a digital high definition television signal, said system exhibiting special features operation in accordance with a method comprising the steps of:

- 10 receiving a digital video information datastream (INPUT;(B) FIG.7A...)comprising an input arrangement of video data;
altering (70) said data arrangement so that prescribed video data, when recorded at a given speed, appears in predetermined regions of tape tracks as a function of a tape scanning path a
15 recording/reproducing head is expected to travel at a speed greater than said given speed in a special features operating mode; and
recording (72) said datastream with said altered arrangement of data.

20

2. A method according to claim 1, wherein
said recording is at said given speed; and
said data arrangement comprises a sequence of data cells including a data component and a header component containing
25 information identifying associated data.

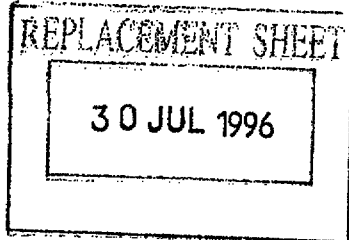
3. A method according to claim 1, wherein
said said given speed is a normal recording speed; and
said features operating mode is a fast search mode.

30

4. A method according to claim 1, wherein
said video data is composed of high priority (HP) significant image representative information and lower priority (LP) image information; and
35 said prescribed video data is said high priority information.

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5. A method according to claim 1, wherein
5 said datastream comprises MPEG coded image
representative information.

6. A method according to claim 5, wherein
said MPEG coded image information comprises a Group Of
10 Pictures (GOP) including intercoded and intracoded picture frames
occurring in a given sequence; and
said prescribed video data is intracoded ("I") information.

7. A method according to claim 6, wherein
15 said step of altering said data arrangement subjects said
given sequence of intercoded and intracoded frames to disruption;
and
said method includes a further step (74) of converting a
disrupted sequence of intercoded and intracoded frames so as to
20 exhibit said given sequence at an output.

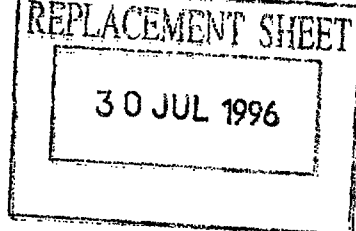
8. A method according to claim 7, wherein
said GOP includes an intracoded I-frame and intercoded B-
frames and P-frames in the following sequence: I, B, B, P, B, B, P, B.
25 B.

9. A method according to claim 1, wherein
said step of altering said data arrangement is accomplished
by re-ordering received input data.

30 10. A method according to claim 1, wherein
said step of altering said data arrangement is accomplished
by duplicating data.

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11. Video tape recording/reproducing apparatus for
5 processing a digital high definition television signal, comprising:
input means (1212) for receiving a digital video information
datastream comprising an input arrangement of data;
means (1230, 1232, 1224, 1226, 1222) for altering said
input data arrangement so that prescribed video data, when
10 recorded at a given speed, appears in predetermined regions of
tape tracks as a function of a tape scanning path which a
recording/reproducing head is expected to travel at a speed
greater than said given speed in a features operating mode; and
means (1214-1218) for recording said datastream with said
15 altered arrangement of data at said given speed.

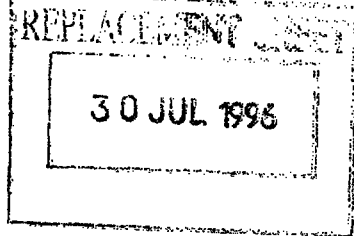
12. Apparatus according to claim 11 and further including
an output (78; "PLAYBACK OUTPUT, FIG. 12) to be coupled to
a receiving device (1040);
20 reproducing means (72; 1214-1218) for providing a
recorded datastream with said altered data arrangement at a
speed greater than said given speed; and
converting means (74; 1222, 1224, 1232) responsive to said
recorded datastream for providing an output datastream to said
25 output with an arrangement of data compatible with
requirements of said receiving device.

13. Apparatus according to claim 11, wherein
said datastream comprises a sequence of data cells including
30 a data component and a header component containing information
identifying associated data.

14. Apparatus according to claim 11, wherein
said given speed is a normal recording speed; and
35 said feature operating mode is a fast search mode.

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15. Apparatus according to claim 11, wherein
5 said video data is composed of high priority (HP) significant
image representative information and lower priority (LP) image
information; and
said prescribed video data is said high priority information.

10 16. Apparatus according to claim 12, wherein
said digital datastream comprises MPEG coded image
representative information including a Group Of Pictures (GOP)
constituted by intercoded (B, P) and intracoded (I) picture frames
occurring in a given sequence; and
15 said prescribed video data is intracoded (I) information.

17. Apparatus according to claim 16, wherein
said altering means subjects said given sequence of
intracoded and intracoded frames to disruption; and
20 said converting means converts a disrupted sequence of
intercoded and intracoded frames so as to exhibit said given
sequence at said output.

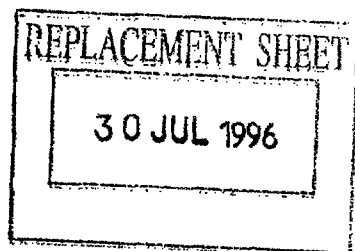
18. Apparatus according to claim 17, wherein
25 said GOP includes an intracoded I-frame and intercoded B-
frames and P-frames in the sequence: I, B, B, P, B, B, P, B, B.

19. Apparatus according to claim 1, wherein
said altered data arrangement is constituted by re-ordered
30 received input data.

20. Apparatus according to claim 11, wherein
said altered data arrangement includes duplicated data.

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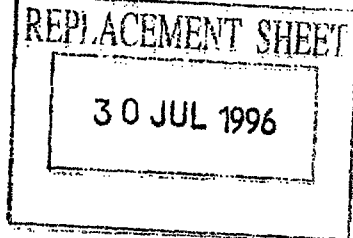


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21. A video tape recording/reproducing system for
5 processing a digital high definition television signal, comprising:
input means (1212) for receiving a digital datastream
containing video information;
recording/reproducing means (1214-1218) responsive to
said datastream;
10 output means (1240) responsive to an output signal from
said recording/playback means for conveying recorded
information to utilization means when present;
means (1222) for generating feature control data for
determining the operation of said utilization means in a special
15 features operating mode of said video tape recording/reproducing
system; and
means (1230, 1232,...) for conveying said feature control
data to said output means.
- 20 22. A system according to claim 21, wherein
said feature control data represents an instruction for
processing an image frame.
23. A system according to claim 22, wherein
25 said feature control data represents an instruction to repeat
the display of an image frame.
24. A system according to claim 22, wherein
said feature control data represents an instruction to decode
30 but not display an image frame.
25. A system according to claim 22, wherein
said feature control data represents an instruction to accept
an out of sequence image frame.

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26. A system according to claim 22, wherein
5 said feature control data represents an instruction to ignore
predetermined data for a given image frame.

27. A system according to claim 21, wherein
said feature control data represents an instruction
10 concerning the processing of audio information.

28. A system according to claim 27, wherein
said feature control data represents an instruction to mute
audio information.

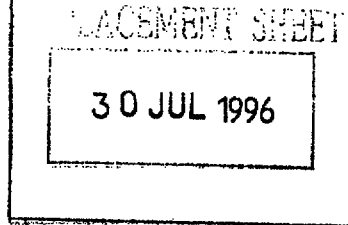
15 29. A system according to claim 21, wherein
data processed by said system is in the form of transport
cells including a data component and a header component
identifying associated data.

20 30. Video tape recording/reproducing apparatus for
processing a digital high definition television signal, comprising:
input means (2210; 2312) for receiving a digital datastream
comprising an input arrangement of video data representing
25 coded video information;
means (2212; 2311) for decoding said video information to
produce data words;

means (2213, 2215; 2330,2332) for processing said data
words;
30 means (2214; 2335) for re-coding predetermined ones of
said data words;
means (2216; 2330, 2332, 2324,2326, 2322), included in
said processing means, responsive to said re-coded data words for
altering said input data arrangement so that prescribed video
35 data, when recorded at a given speed, appears in predetermined
regions of tape tracks as a function of a tape scanning path which

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5 a recording/reproducing head is expected to travel at a speed greater than said given speed in a features operating mode; and means (2218; 2314-2318) for recording said datastream with said altered data arrangement at said given speed.

10 31. Apparatus according to claim 30, wherein said coded video information includes MPEG coded information; said data words produced by said decoding means include MPEG words; said re-coding means is an MPEG variable length coder; and 15 said datastream recorded by said recording means comprises an altered arrangement of MPEG words.

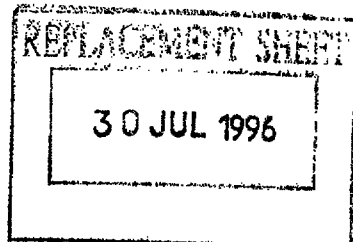
20 32. Apparatus according to claim 30, wherein said processing means includes means for separating spatial data of said datastream; means for duplicating spatial data; and means for providing duplicated spatial data from said duplicating means to said re-coding means.

25 33. Apparatus according to claim 30 and further including tape packet generator means (2216; 2320) having an input responsive to output signals from said re-coding means, and an output coupled to said recording means.

30 34. Apparatus according to claim 33 and further comprising output converter means (2238; 2340) for converting tape packet data to MPEG words.

35 35. Apparatus according to claim 30, wherein said given speed is a normal recording speed; and said feature operating mode is a fast search mode.





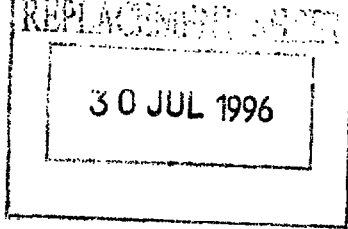
36. Apparatus according to claim 30, wherein
5 said video data is composed of high priority (HP) significant
image representative information and lower priority (LP) image
information; and
said prescribed video data is said high priority information.

10 37. Apparatus according to claim 30 and further including
an output (78; 2340) to be coupled to a receiving device
(1040) when present;
reproducing means (72; 2314-2318) for providing a
recorded datastream at a speed greater than said given speed to
15 said output; and
converting means (74; 2322, 2332, 2324) responsive to said
recorded datastream for providing an output datastream to said
output with a modified data arrangement compatible with
requirements of said receiving device.

20 38. Apparatus according to claim 37, wherein
said digital datastream comprises MPEG coded image
representative information including a Group Of Pictures (GOP)
constituted by intercoded and intracoded (I) picture frames in a
25 given sequence; and
said prescribed video data is intracoded information.

39. Apparatus according to claim 38, wherein
said altering means subjects said given sequence of
30 intercoded and intracoded frames to disruption; and
said converting means converts a disrupted sequence of
intercoded and intracoded frames so as to exhibit said given
sequence at said output.





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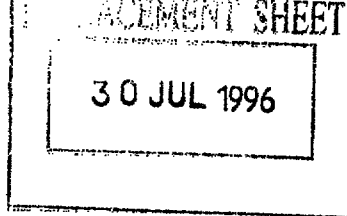
40. Apparatus according to claim 38, wherein
5 said GOP includes an intracoded I-frame and intercoded B-
frames and P-frames in the sequence: I, B, B, P, B, B, P, B, B.

41. Apparatus according to claim 30, wherein
said altered data arrangement is constituted by re-ordered
10 received input data.

42. Apparatus according to claim 40, wherein
said altered data arrangement includes duplicated data.

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DIGITAL VIDEO TAPE RECORDER FOR DIGITAL HDTV

Abstract of the Invention

5 A digital video tape record/playback apparatus for processing a high definition television signal includes provision for controlling the occurrence of high priority (HP) image information. Such information is selectively recorded at normal speed in tape
10 tracks within predetermined regions (HP1-HP5) so as to be appear along a tape head scanning path associated with predetermined tape playback speeds greater than normal (eg., 20x normal). Input high priority data cells may be reordered or duplicated for recording in the predetermined tape regions in other than
15 received order. In either case, the input datastream is massaged to produce a viewable image in a fast playback mode. In an illustrated system for receiving an MPEG coded datastream, an output datastream at greater than normal playback speed comprises either intracoded I-frame data cells only, or a whole
20 Group of Pictures (GOP).

Figure 6

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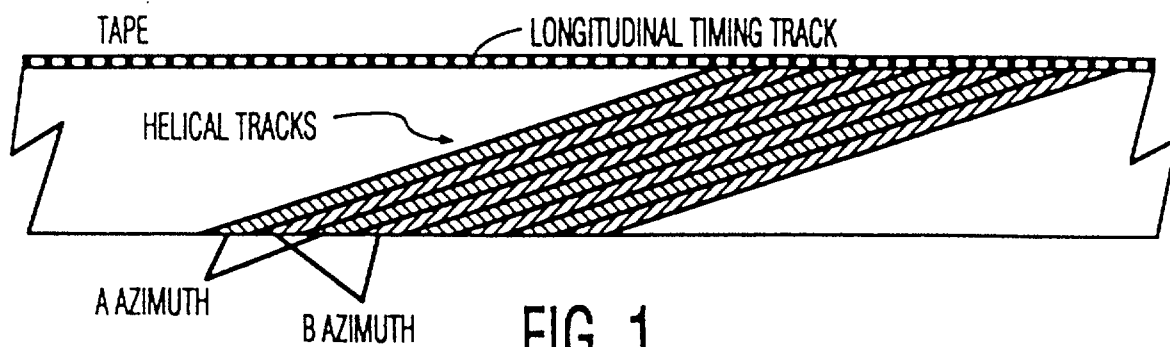


FIG. 1

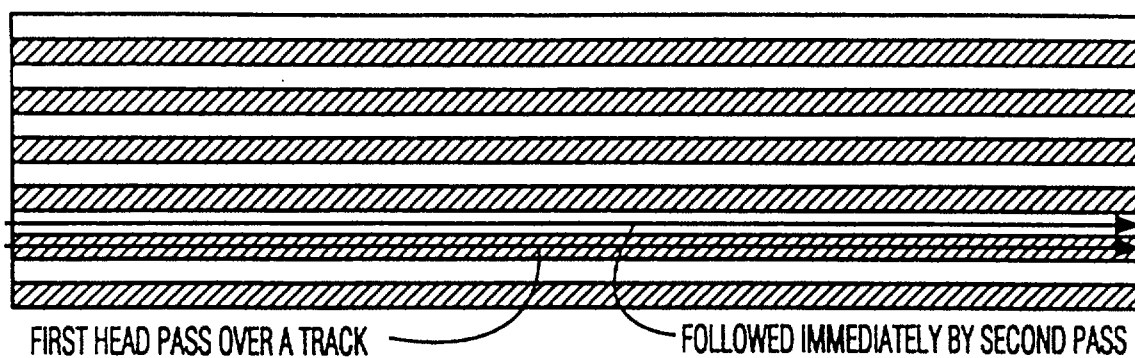


FIG. 2

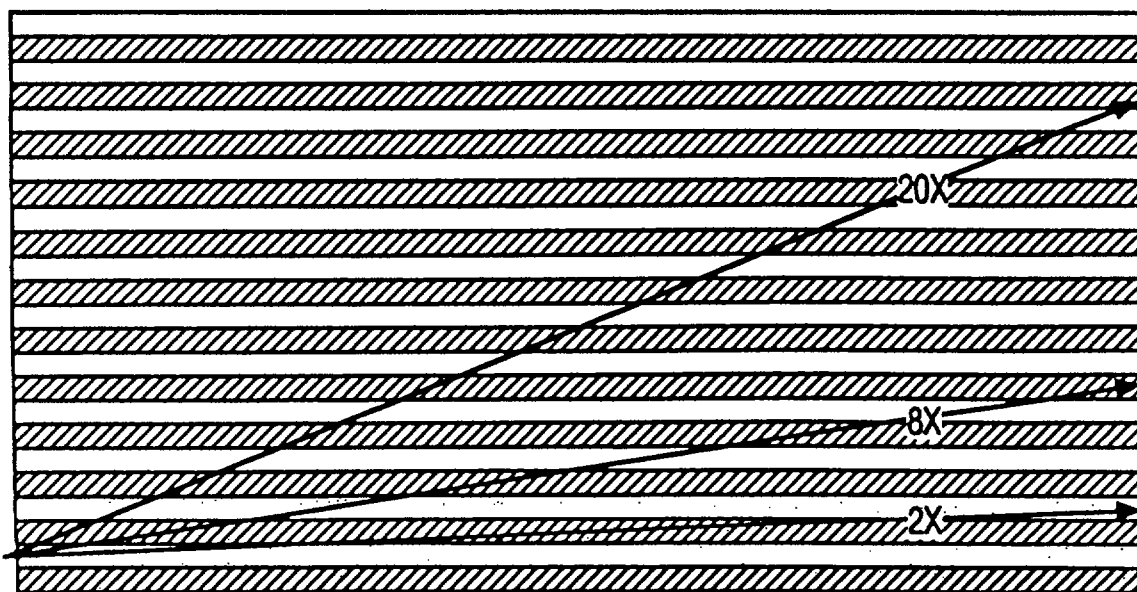


FIG. 3

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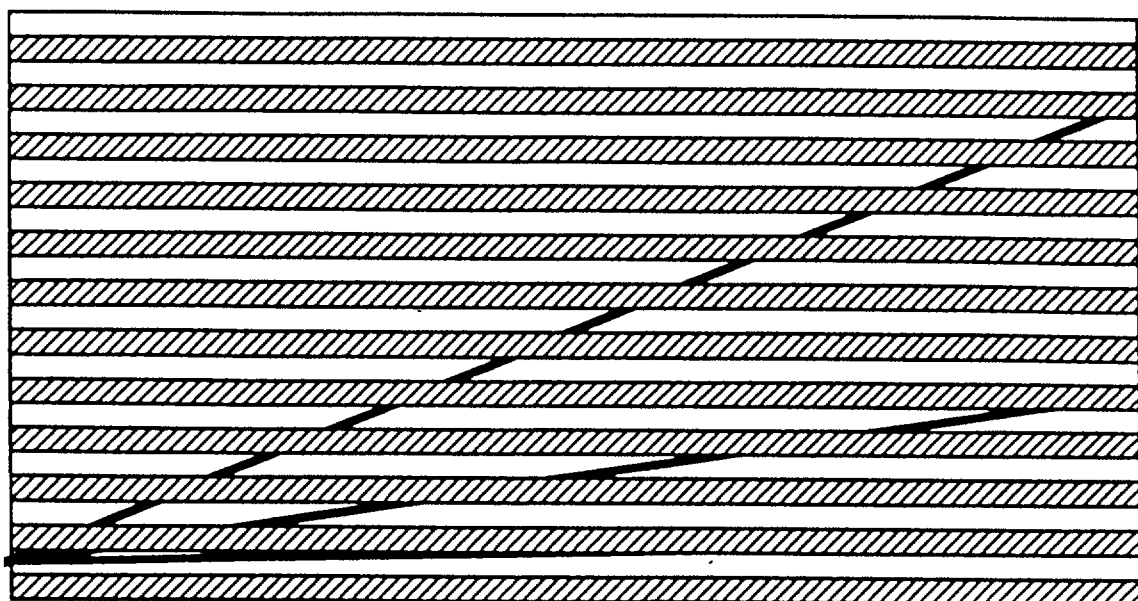


FIG. 4

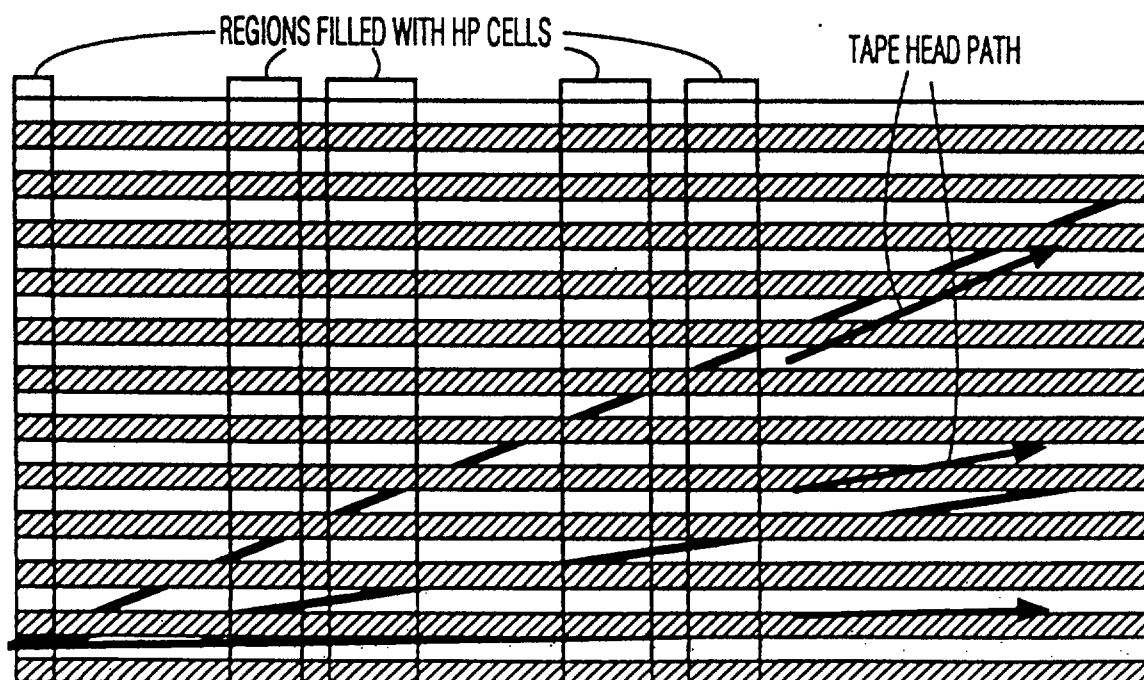


FIG. 5

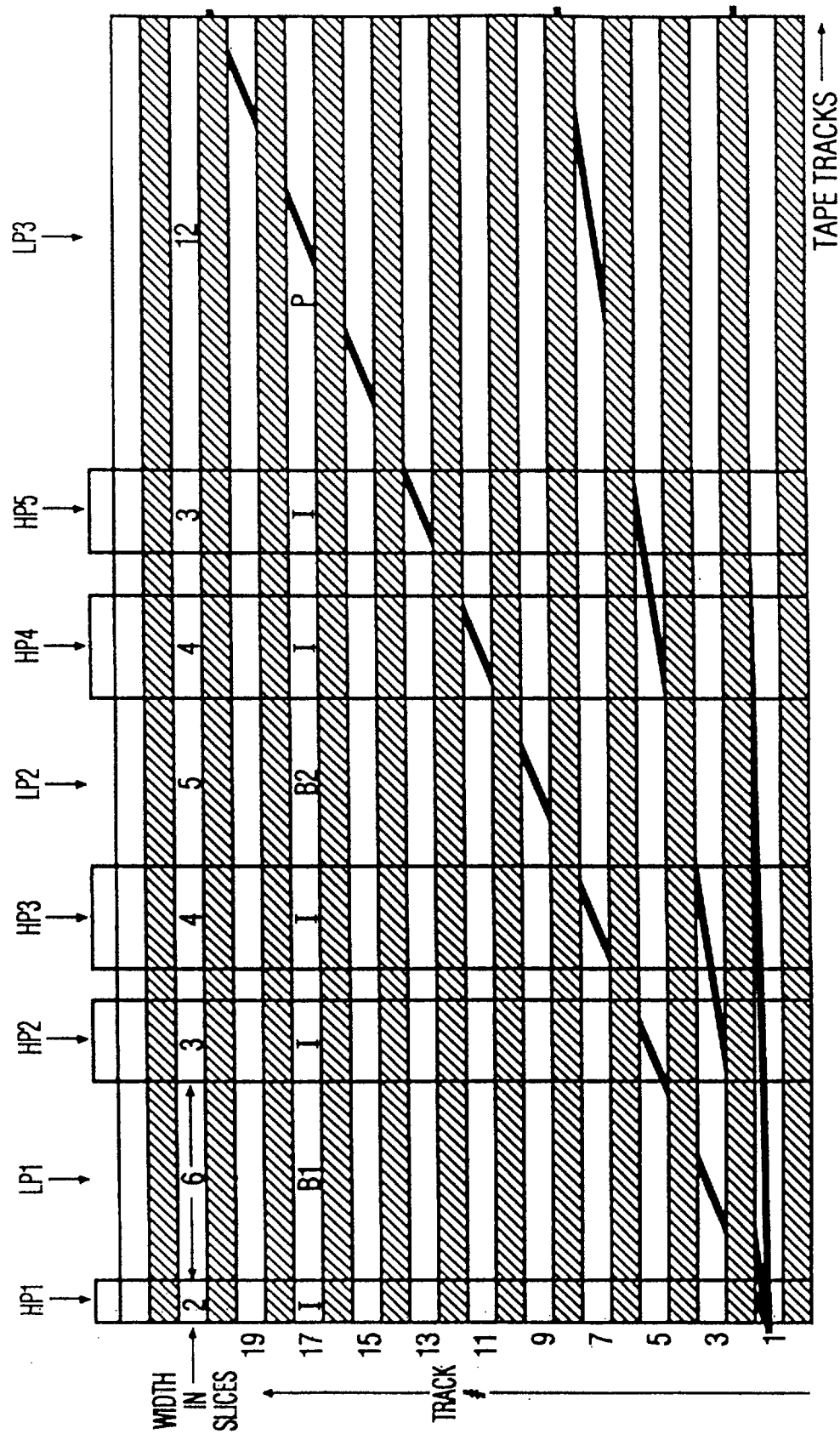


FIG. 6

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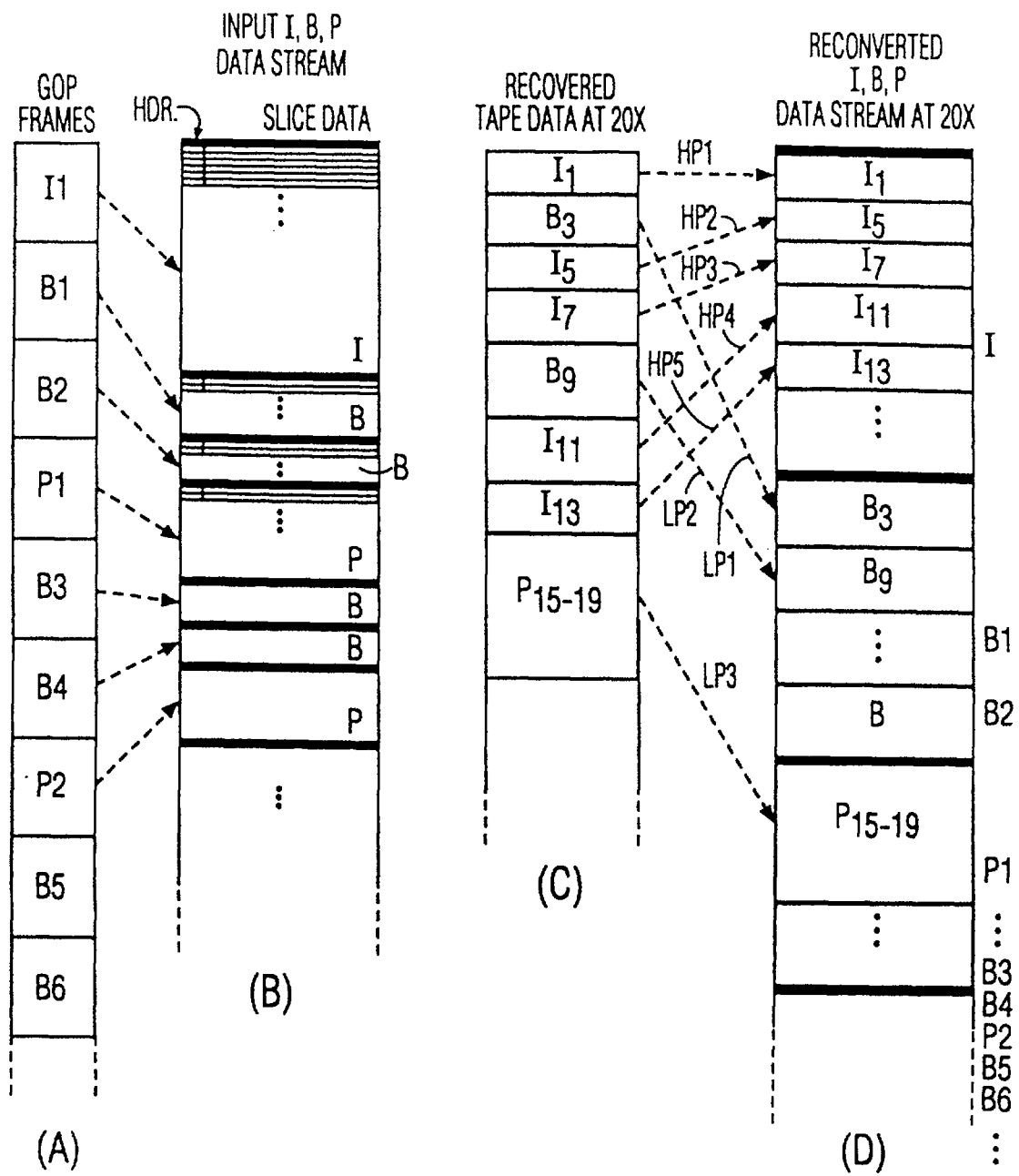


FIG. 7

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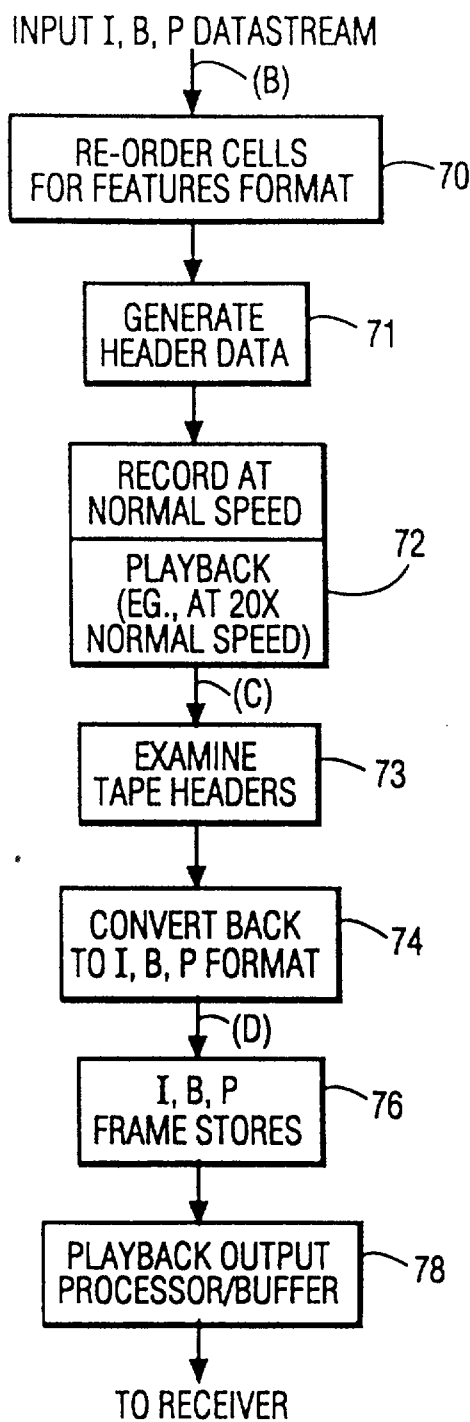


FIG. 7A

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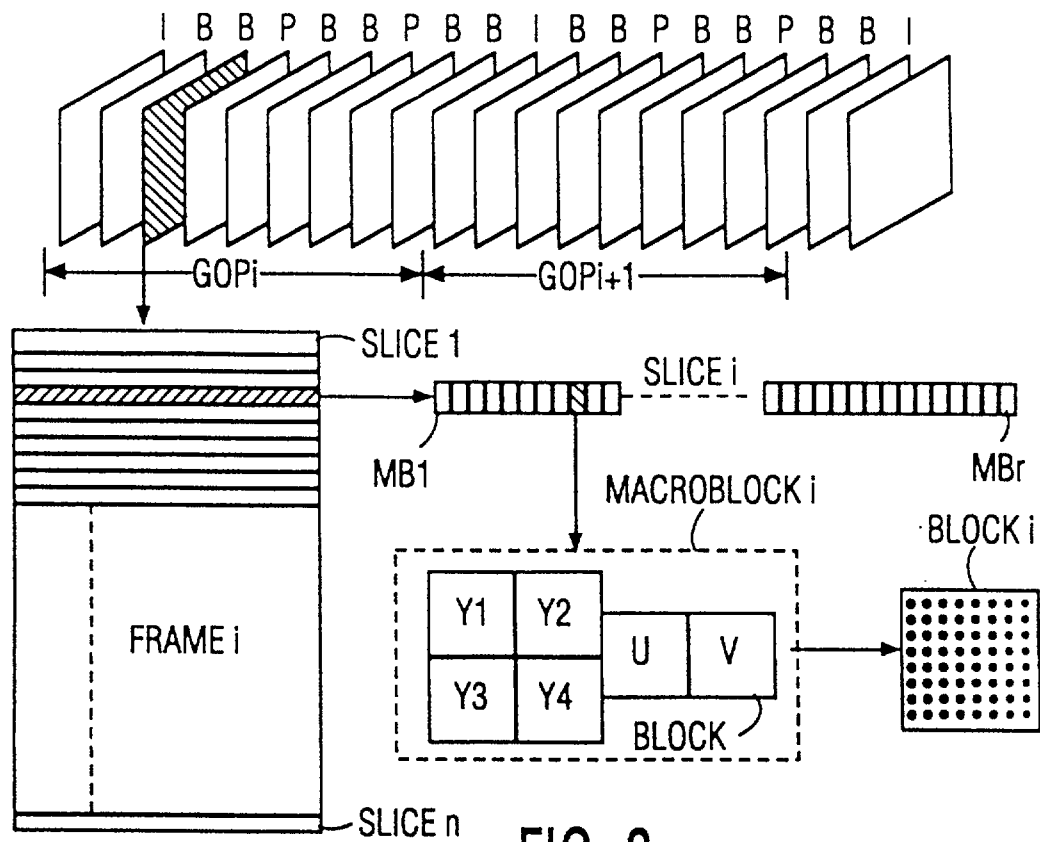


FIG. 8

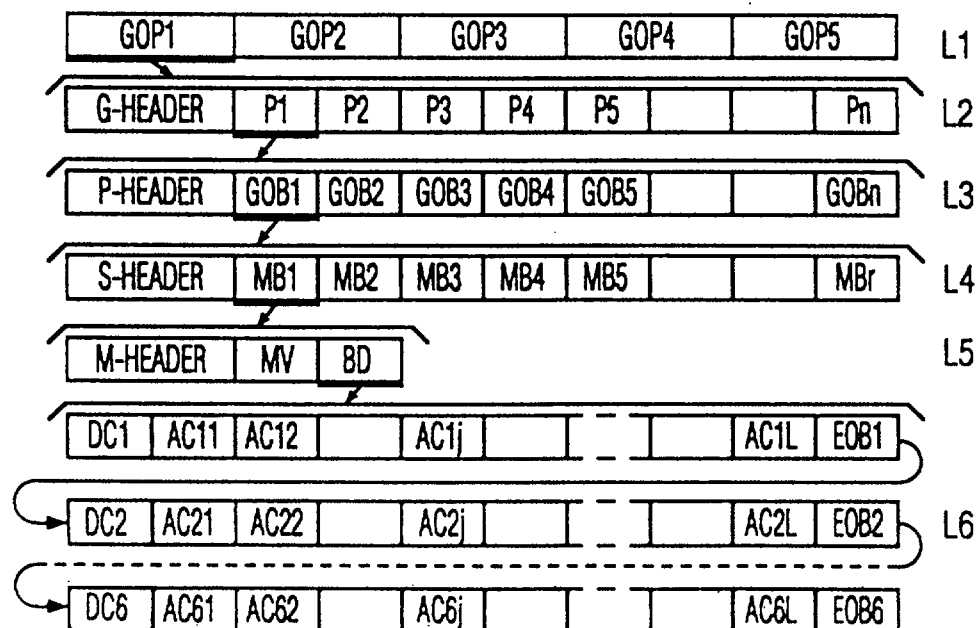


FIG. 9

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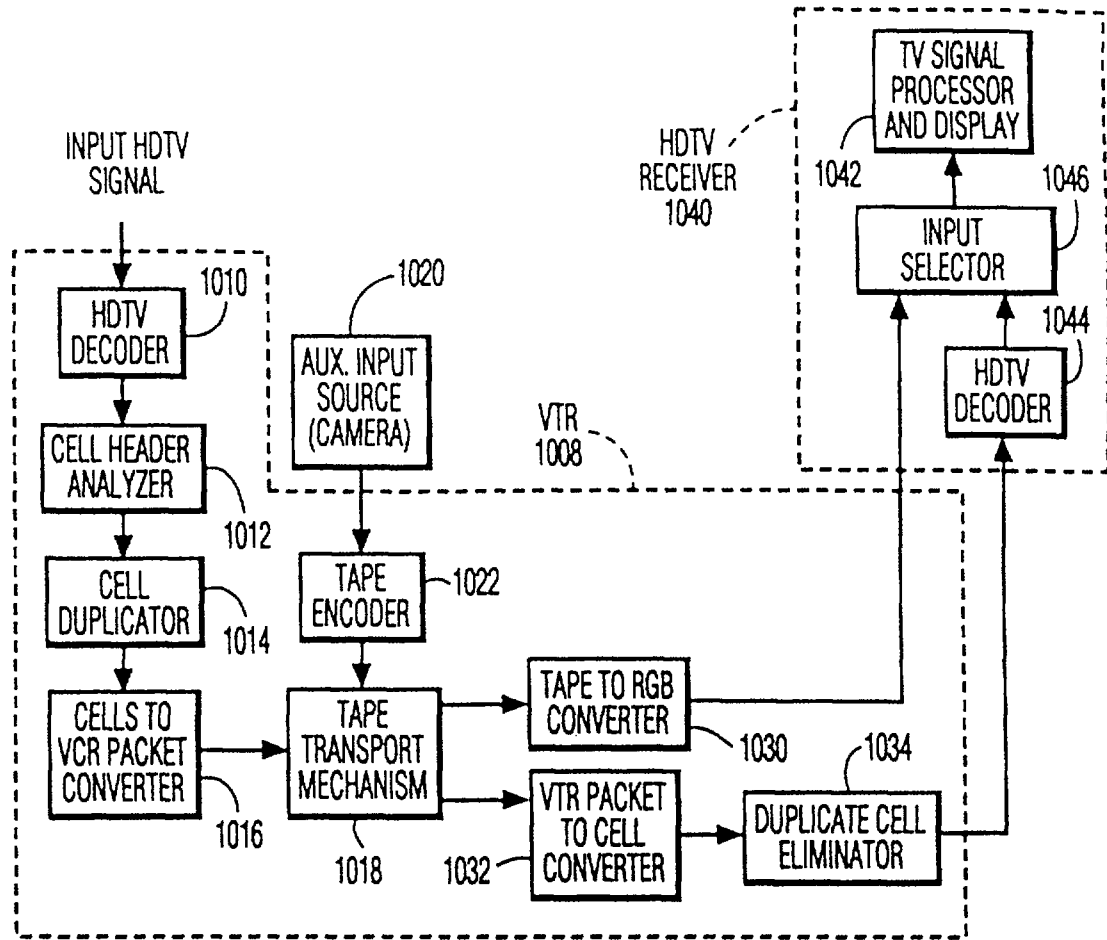


FIG. 10

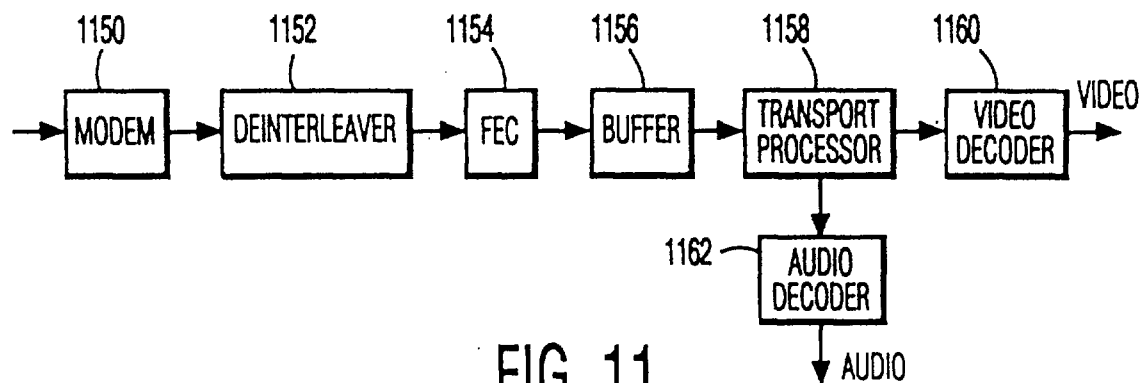
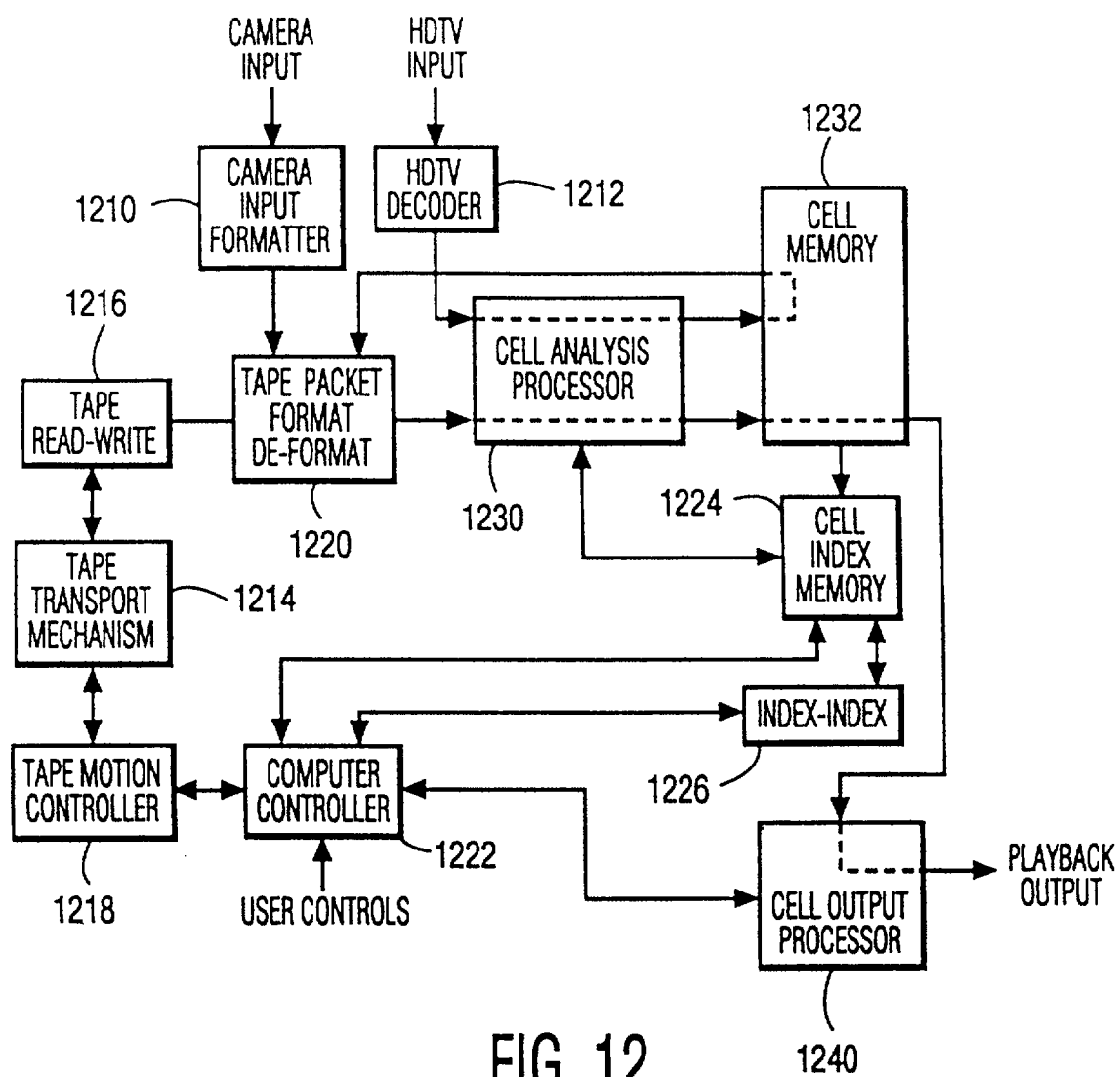


FIG. 11

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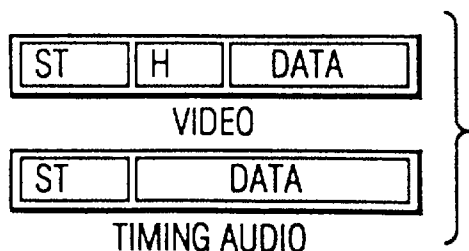


FIG. 13

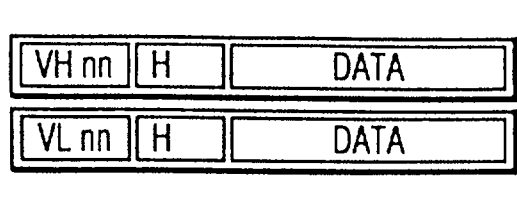


FIG. 14

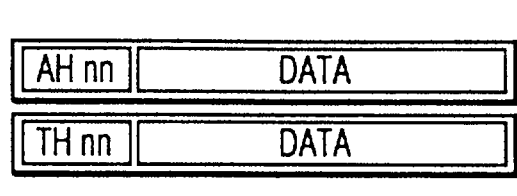


FIG. 15

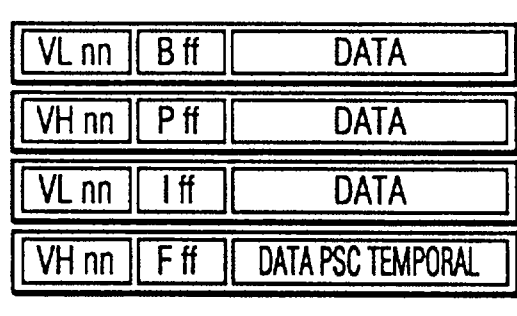


FIG. 16

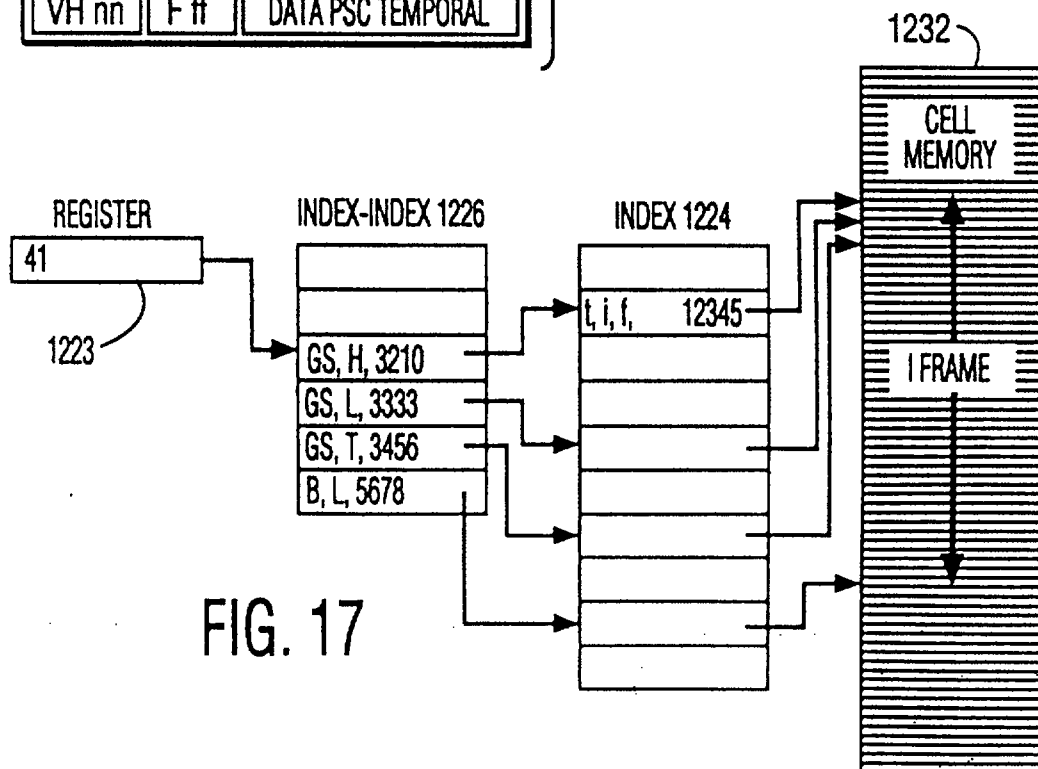


FIG. 17

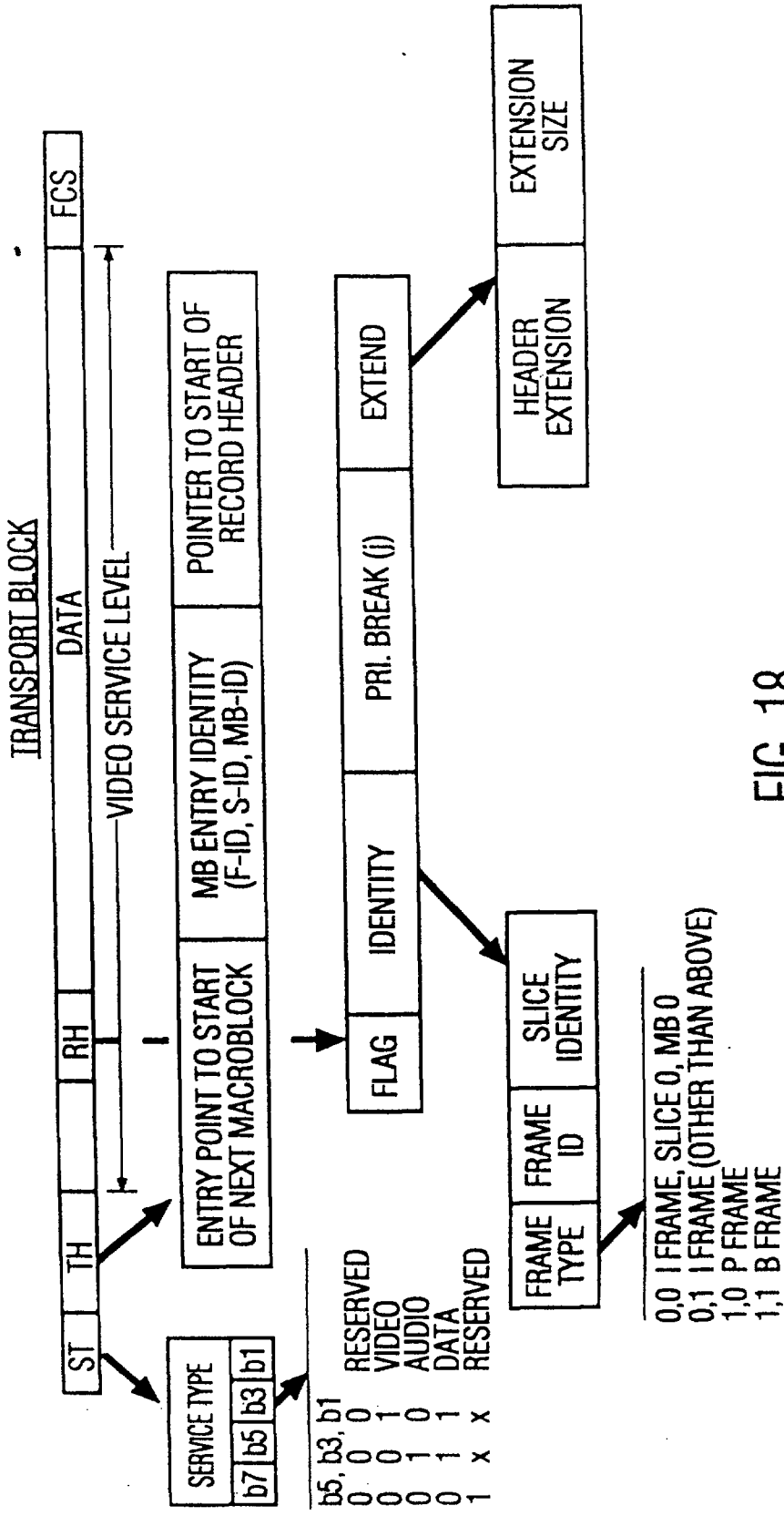


FIG. 18

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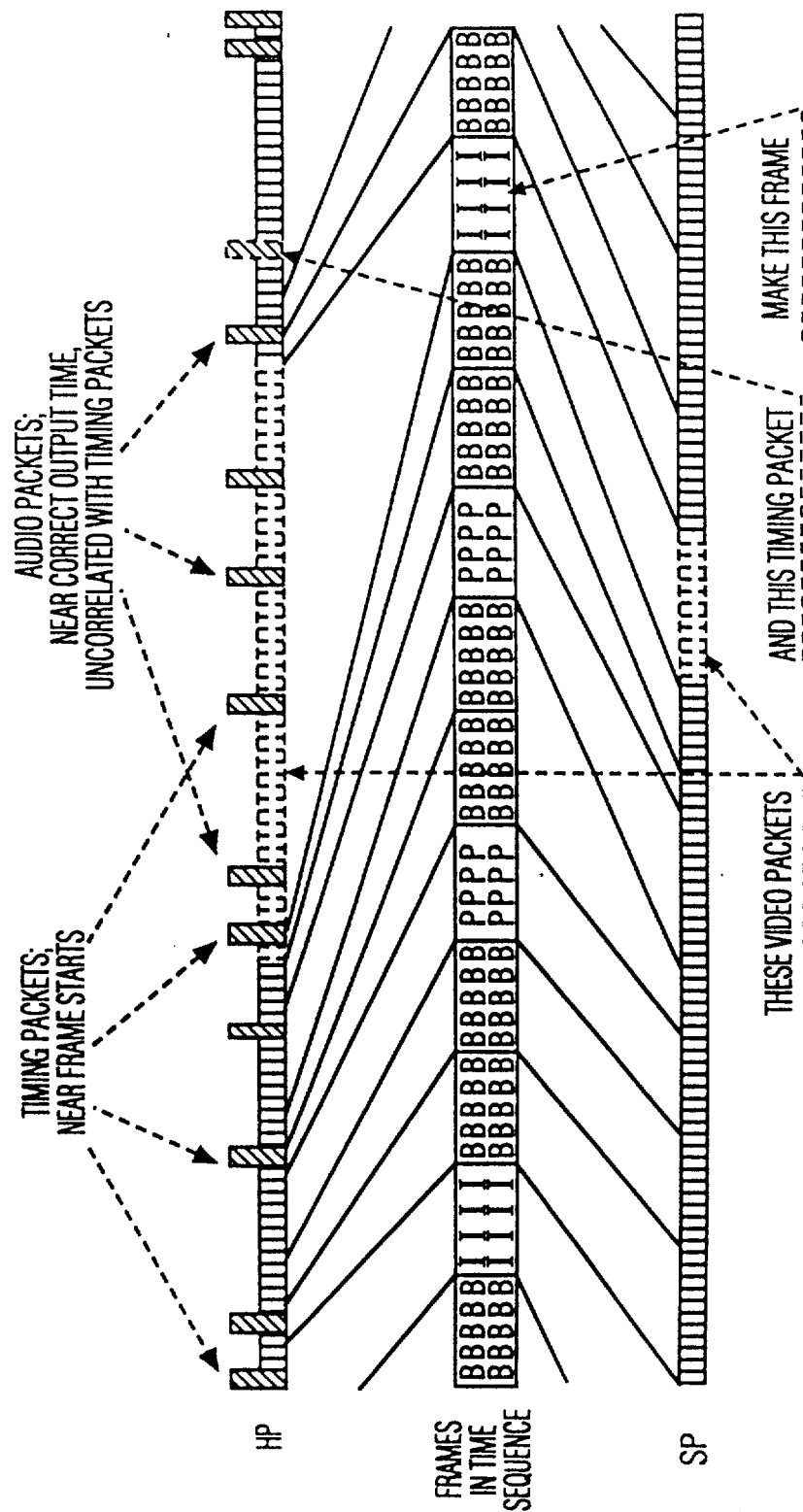


FIG. 19

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FRAME TYPE	I	B	B	P	B	B	I	B	B	P	B	B	P	B	B	P	B	B
TRANSMISSION ORDER	0	-2	-1	3	1	2	6	4	5	9	7	8	12	10	11	15	13	14
DISPLAYED FRAME										6	7	8	9	10	11	12	13	14
GOING FORWARD							RM			•								
							RM			R	•							
							RM			R		•						
										R			•					
										R			R	•				
										R			R		•			
										R			R			•		
													R			R	•	
													R			R		•
GOING BACKWARD	R3			R6			R			•								
	R3			R6			R			R	•							
	R3			R6			R			R		•						
										R			•					
										R			R	•				
										R			R		•			
										R			R			•		
										R			R			RM	•	
										R			R			RM		•

LEGEND: • REQUESTED FRAME R REQUIRED TO MAKE REQUESTED FRAME RM REQUIRED, BUT ALREADY IN MEMORY Rn REQUIRED TO MAKE FRAME n

FIG. 20

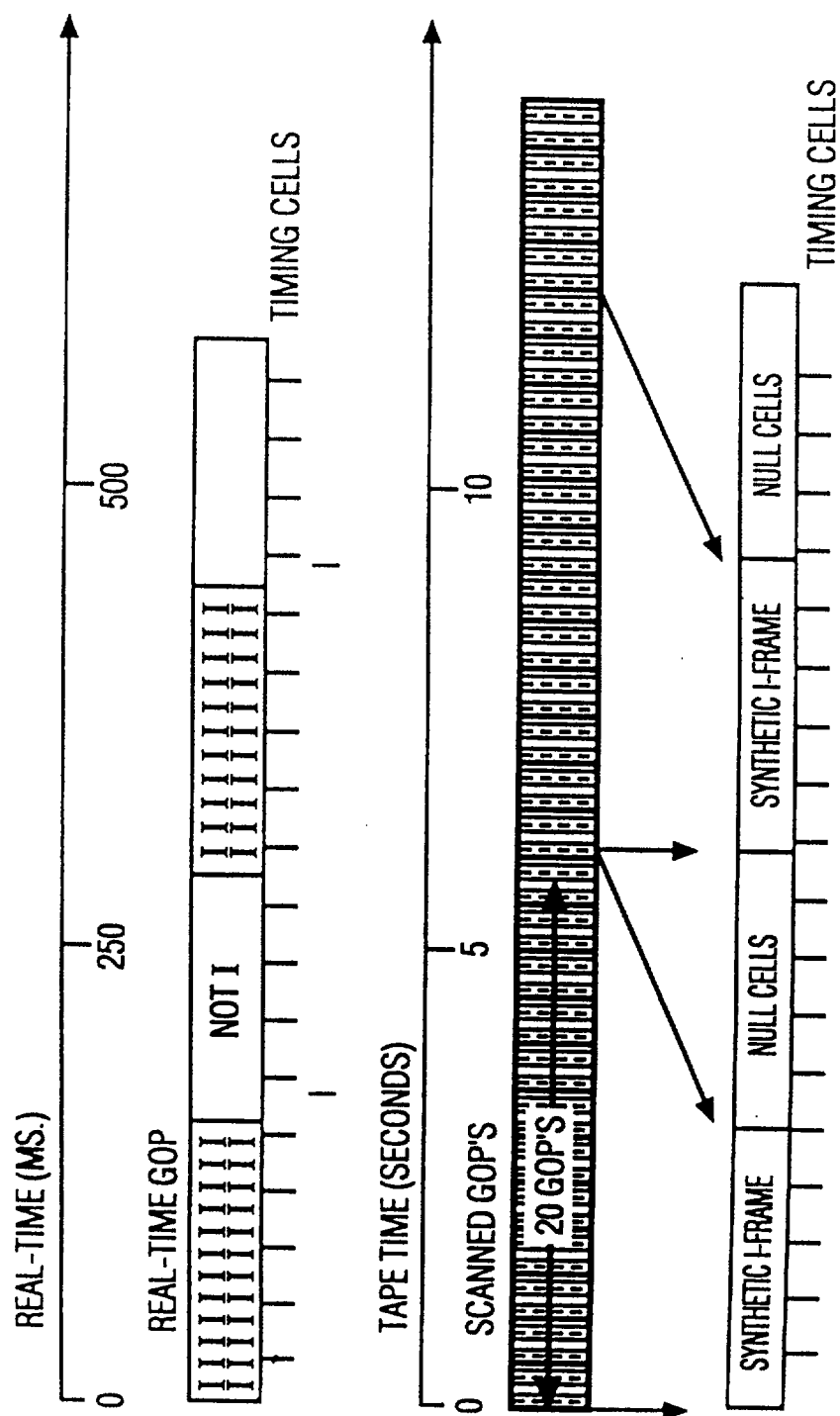


FIG. 21

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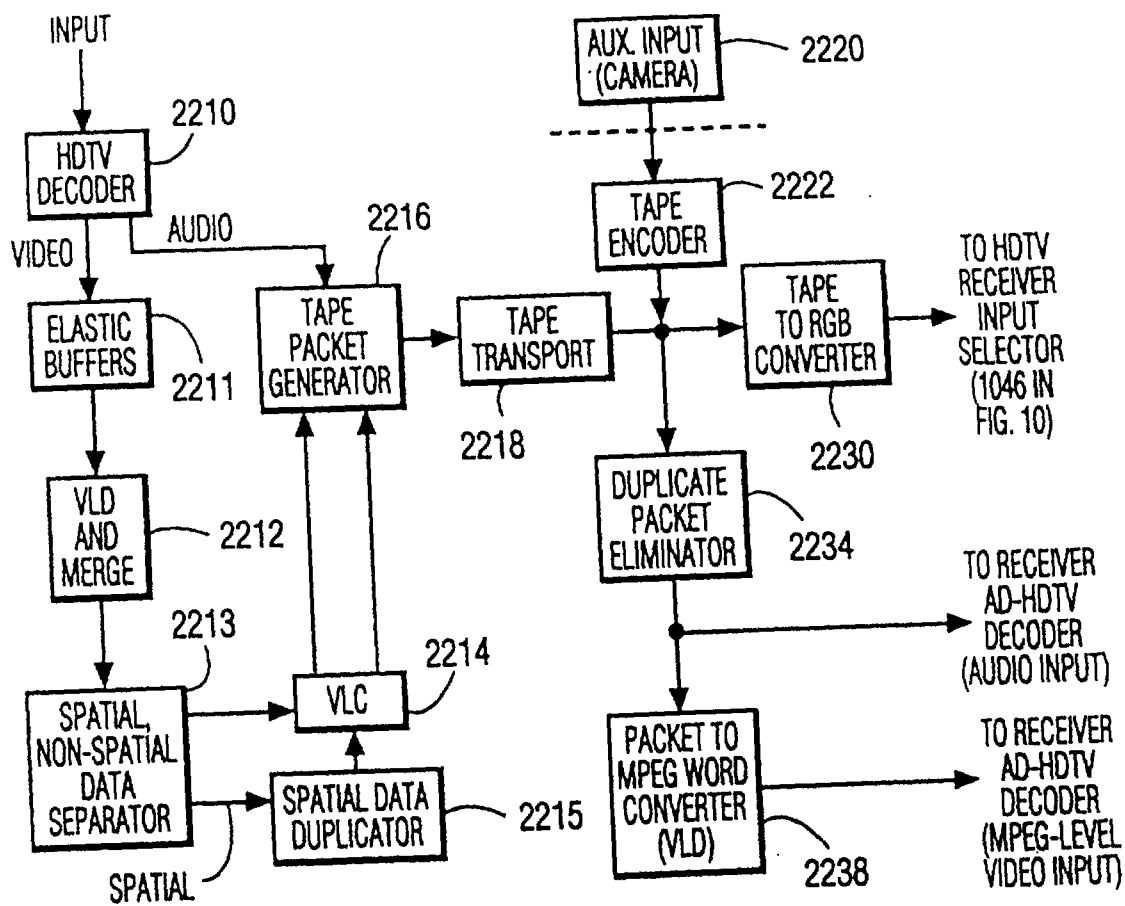


FIG. 22

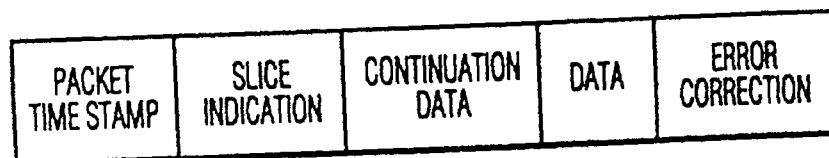


FIG. 24

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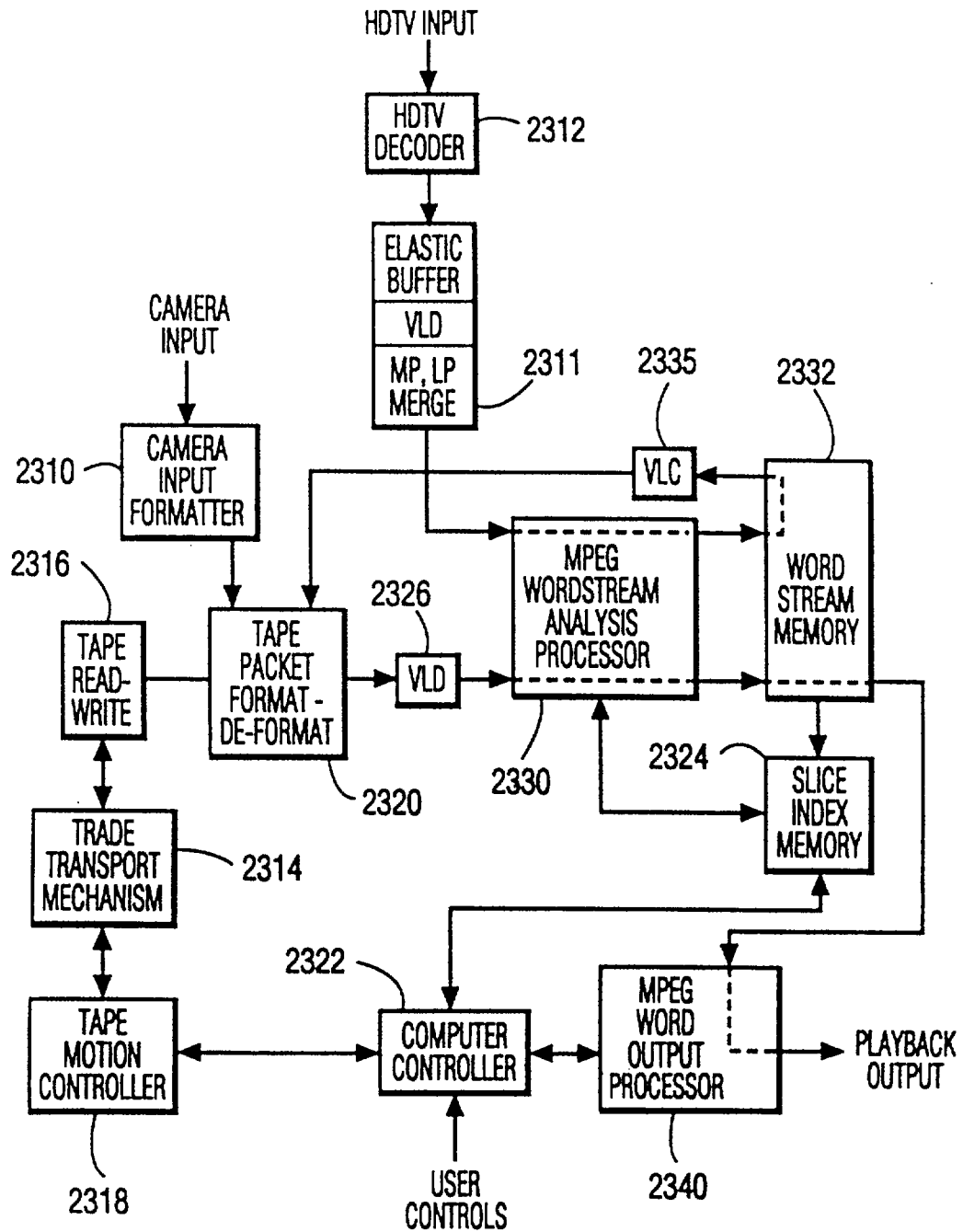


FIG. 23