US006601104B1

(12) **United States Patent**
Fallon

(10) **Patent No.:** **US 6,601,104 B1**
(45) **Date of Patent:** **Jul. 29, 2003**

(54) **SYSTEM AND METHODS FOR ACCELERATED DATA STORAGE AND RETRIEVAL**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/266,394**

(22) Filed: **Mar. 11, 1999**

(51) **Int. Cl.**[7] **G06F 13/00**

(52) **U.S. Cl.** **709/231**

(58) **Field of Search** 709/231, 233

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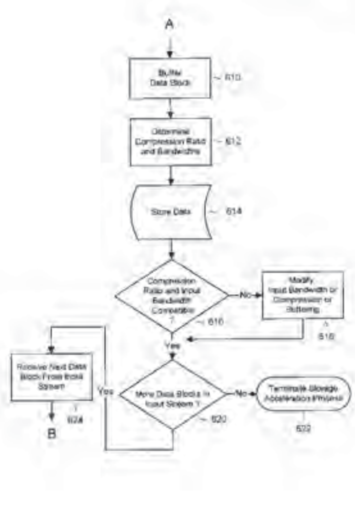
(57) **ABSTRACT**

Systems and methods for providing accelerated data storage and retrieval utilizing lossless data compression and decompression. A data storage accelerator includes one or a plurality of high speed data compression encoders that are configured to simultaneously or sequentially losslessly compress data at a rate equivalent to or faster than the transmission rate of an input data stream. The compressed data is subsequently stored in a target memory or other storage device whose input data storage bandwidth is lower than the original input data stream bandwidth. Similarly, a data retrieval accelerator includes one or a plurality of high speed data decompression decoders that are configured to simultaneously or sequentially losslessly decompress data at a rate equivalent to or faster than the input data stream from the target memory or storage device. The decompressed data is then output at rate data that is greater than the output rate from the target memory or data storage device. The data storage and retrieval accelerator method and system may employed: in a disk storage adapter to reduce the time required to store and retrieve data from computer to disk; in conjunction with random access memory to reduce the time required to store and retrieve data from random access memory; in a display controller to reduce the time required to send display data to the display controller or processor; and/or in an input/output controller to reduce the time required to store, retrieve, or transmit data.

35 Claims, 20 Drawing Sheets



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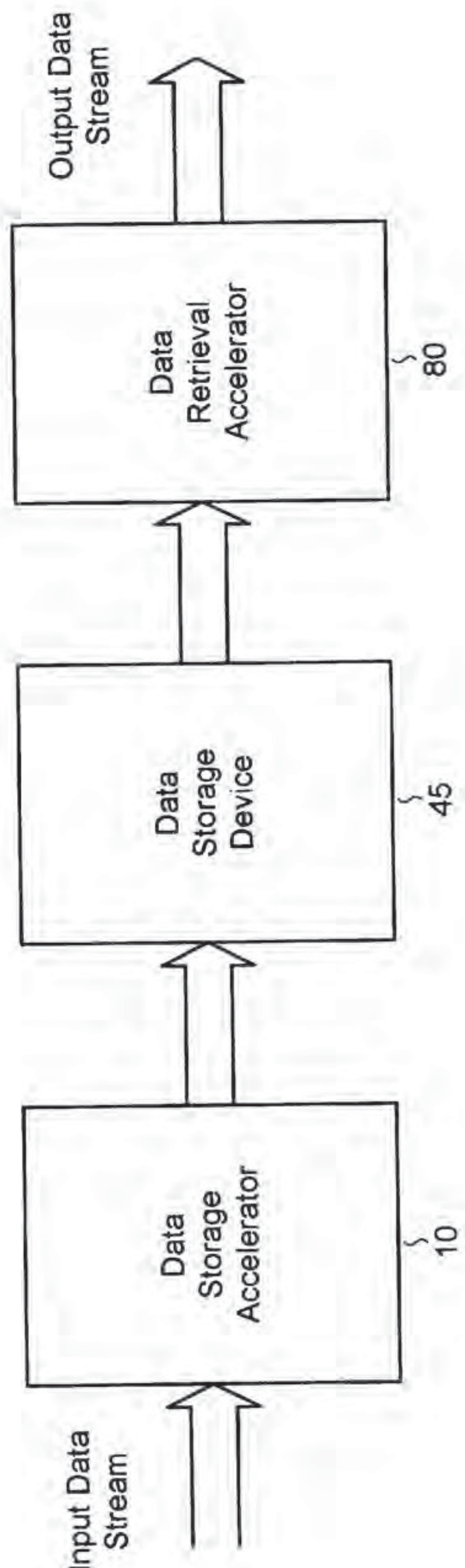

Output Data Stream
Data Retrieval Accelerator
80
Data Storage Device
45
Data Storage Accelerator
10
Input Data Stream

FIGURE 1

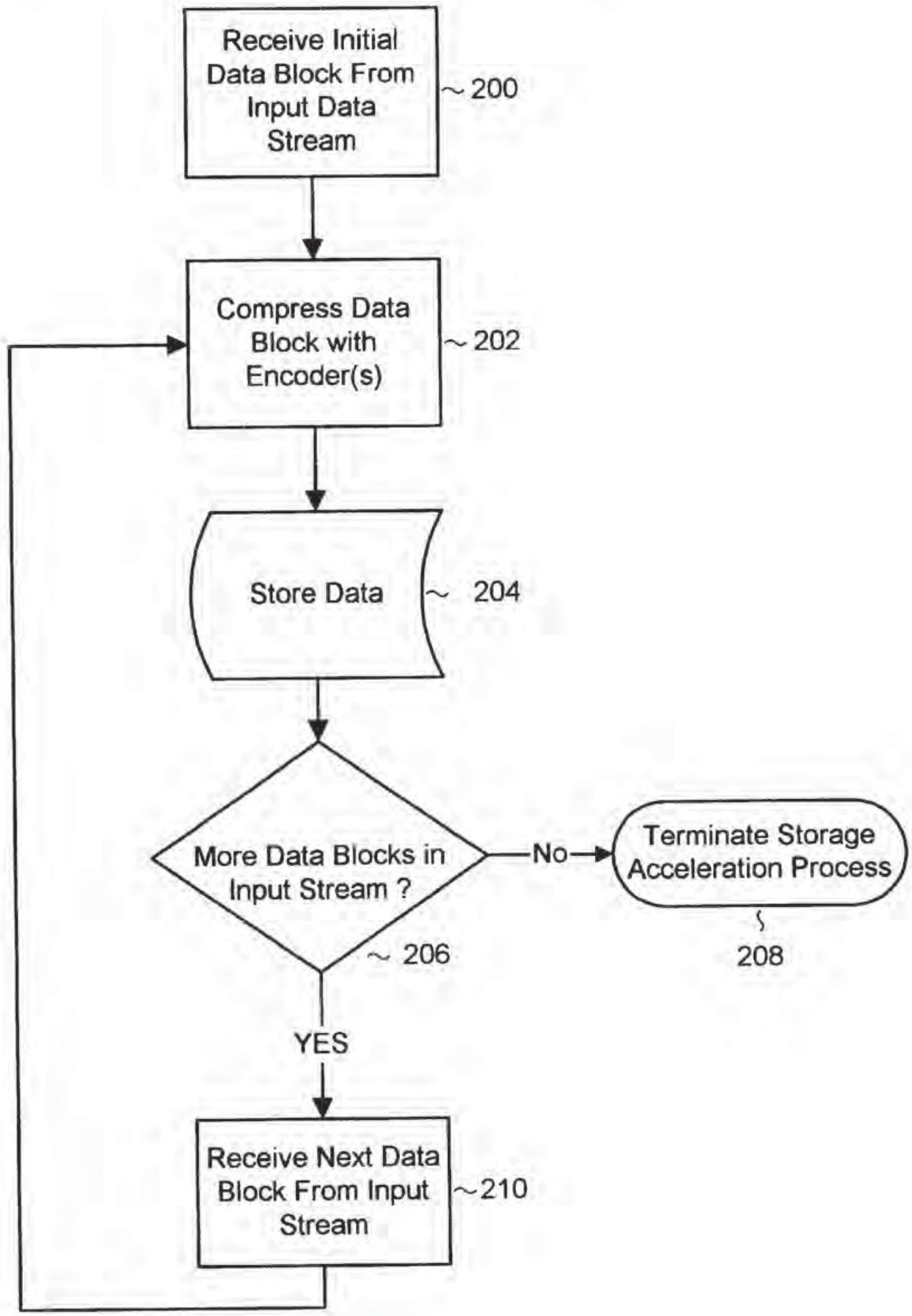

Receive Initial Data Block From Input Data Stream
200
Compress Data Block with Encoder(s)
202
Store Data
204
More Data Blocks in Input Stream ?
206
No
Terminate Storage Acceleration Process
208
YES
Receive Next Data Block From Input Stream
210

FIGURE 2

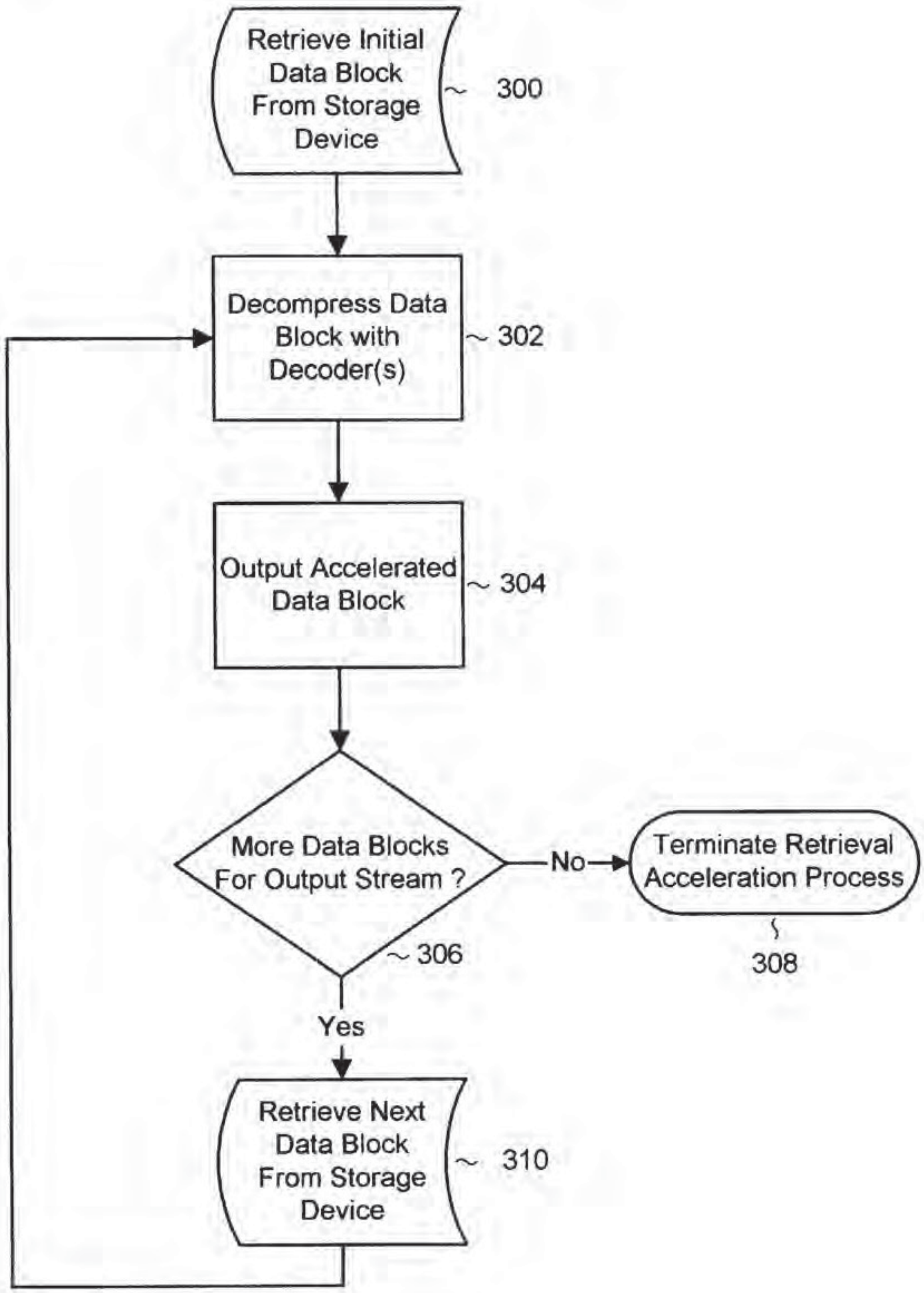

Retrieve Initial Data Block From Storage Device
300
Decompress Data Block with Decoder(s)
302
Output Accelerated Data Block
304
More Data Blocks For Output Stream ?
306
No
Terminate Retrieval Acceleration Process
308
Yes
Retrieve Next Data Block From Storage Device
310

FIGURE 3

Time Interval	T1	T2	T3	T4	Ti
Receive Data Block	Receive Data Block 1	Receive Data Block 2	Receive Data Block 3	Receive Data Block 4	Receive Data Block i
METHOD 1					
Compress Data Block	Compress Data Block 1	Compress Data Block 2	Compress Data Block 3	Compress Data Block 4	Compress Data Block i
Store Encoded Data Block	Store Encoded Data Block 1	Store Encoded Data Block 2	Store Encoded Data Block 3	Store Encoded Data Block 4	Store Encoded Data Block i
METHOD 2					
Compress Data Block		Compress Data Block 1	Compress Data Block 2	Compress Data Block 3	Compress Data Block (i-1)
Store Encoded Data Block			Store Encoded Data Block 1	Store Encoded Data Block 2	Store Encoded Data Block (i-2)

FIGURE 4a

Time Interval	T(i+1)	T(i+2)	Tn	T(n+1)	T(n+2)
Receive Data Block	Receive Data Block (i+1)	Receive Data Block (i+2)	Receive Data Block n		
METHOD 1					
Compress Data Block	Compress Data Block (i+1)	Compress Data Block (i+2)	Compress Data Block n		
Store Encoded Data Block	Store Encoded Data Block (i+1)	Store Encoded Data Block (i+2)	Store Encoded Data Block n		
METHOD 2					
Compress Data Block	Compress Data Block i	Compress Data Block (i+1)	Compress Data Block (n-1)	Compress Data Block n	
Store Encoded Data Block	Store Encoded Data Block (i-1)	Store Encoded Data Block i	Store Encoded Data Block (n-2)	Store Encoded Data Block (n-1)	Store Encoded Data Block n

FIGURE 4b

Time Interval	T1	T2	T3	T4	Ti
Retrieve Data Block	Retrieve Data Block 1	Retrieve Data Block 2	Retrieve Data Block 3	Retrieve Data Block 4	Retrieve Data Block i
METHOD 1					
Decompress Data Block	Decompress Data Block 1	Decompress Data Block 2	Decompress Data Block 3	Decompress Data Block 4	Decompress Data Block i
Output Decoded Data Block	Output Decoded Data Block 1	Output Decoded Data Block 2	Output Decoded Data Block 3	Output Decoded Data Block 4	Output Decoded Data Block i
METHOD 2					
Decompress Data Block		Decompress Data Block 1	Decompress Data Block 2	Decompress Data Block 3	Decompress Data Block (i-1)
Output Decoded Data Block			Output Decoded Data Block 1	Output Decoded Data Block 2	Output Decoded Data Block (i-2)

FIGURE 5a

Time Interval	T(i+1)	T(i+2)	Tn	T(n+1)	T(n+2)
Retrieve Data Block	Retrieve Data Block (i+1)	Retrieve Data Block (i+2)	Retrieve Data Block n		
<u>METHOD 1</u>					
Decompress Data Block	Decompress Data Block (i+1)	Decompress Data Block (i+2)	Decompress Data Block n		
Output Decoded Data Block	Output Decoded Data Block (i+1)	Output Decoded Data Block (i+2)	Output Decoded Data Block n		
<u>METHOD 2</u>					
Decompress Data Block	Decompress Data Block i	Decompress Data Block (i+1)	Decompress Data Block (n-1)	Decompress Data Block n	
Output Decoded Data Block	Output Decoded Data Block (i-1)	Output Decoded Data Block i	Output Decoded Data Block (n-2)	Output Decoded Data Block (n-1)	Output Decoded Data Block n

FIGURE 5b

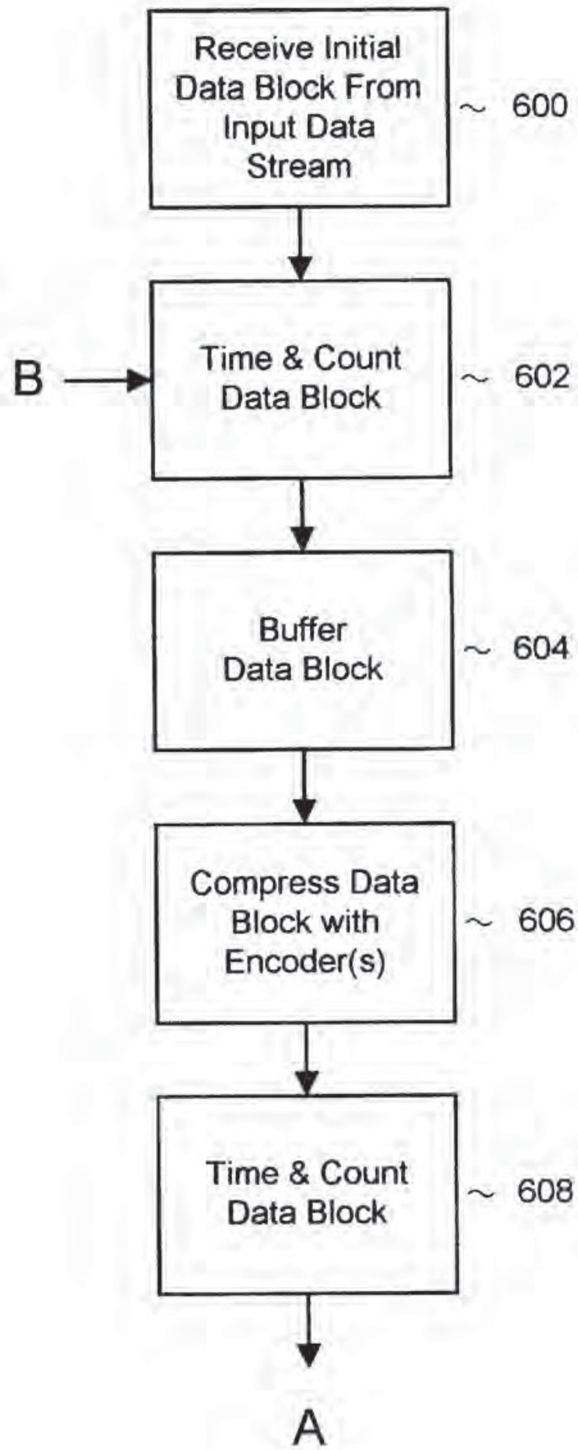

Receive Initial Data Block From Input Data Stream
600
Time & Count Data Block
602
B
Buffer Data Block
604
Compress Data Block with Encoder(s)
606
Time & Count Data Block
608
A

FIGURE 6a

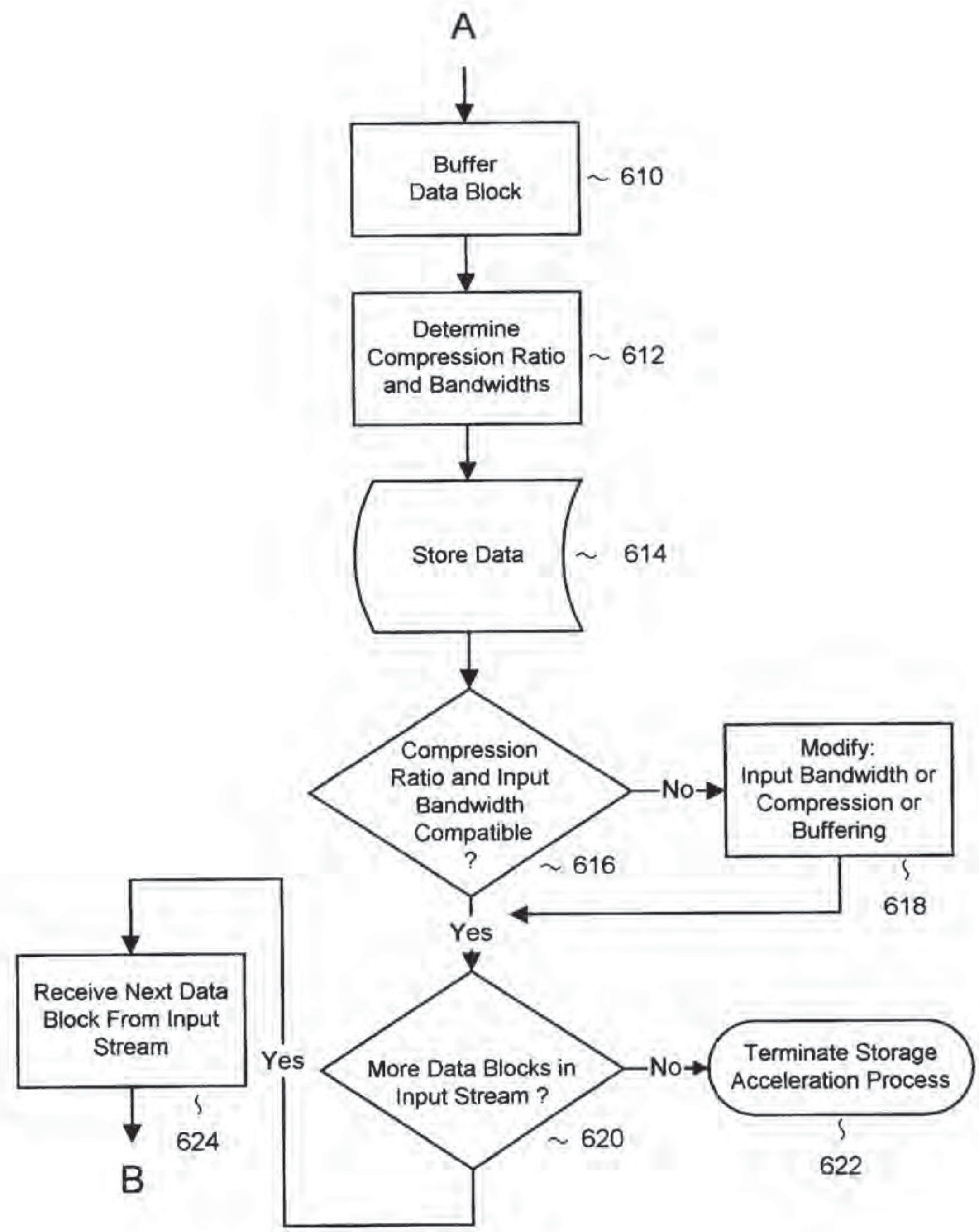

A
Buffer Data Block
610
Determine Compression Ratio and Bandwidths
612
Store Data
614
Compression Ratio and Input Bandwidth Compatible ?
616
No
Modify: Input Bandwidth or Compression or Buffering
618
Yes
Receive Next Data Block From Input Stream
624
B
Yes
More Data Blocks in Input Stream ?
620
No
Terminate Storage Acceleration Process
622

FIGURE 6b

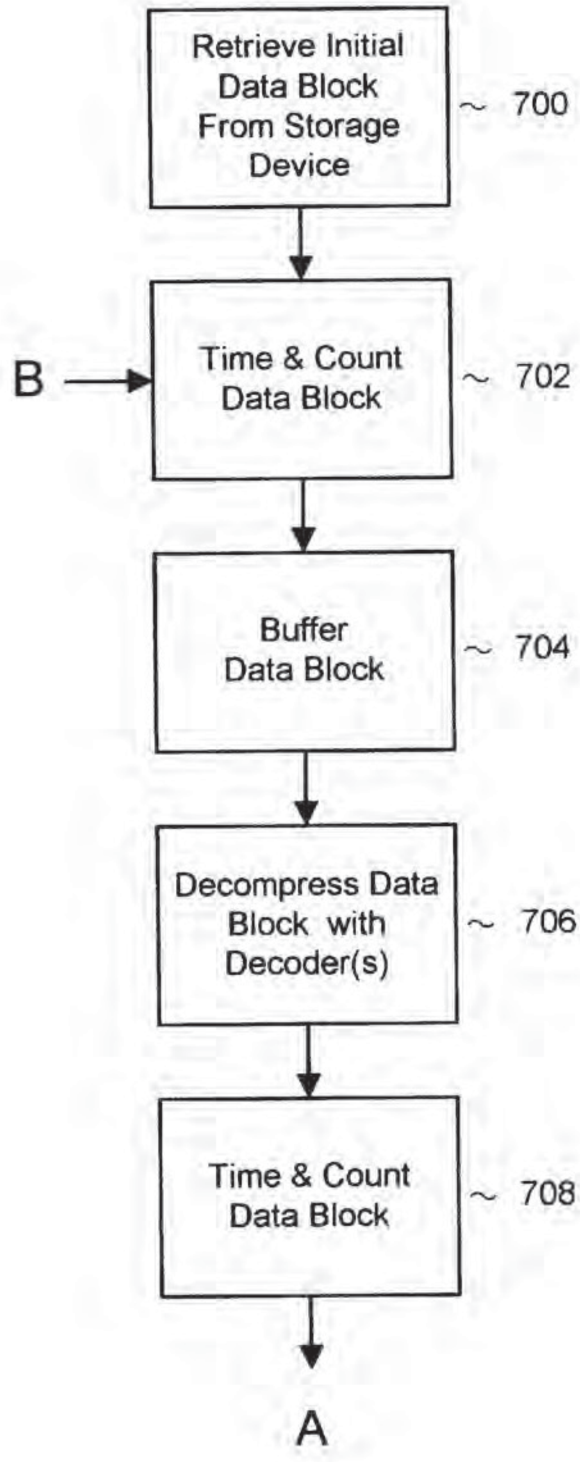

Retrieve Initial Data Block From Storage Device
700
B
Time & Count Data Block
702
Buffer Data Block
704
Decompress Data Block with Decoder(s)
706
Time & Count Data Block
708
A

FIGURE 7a

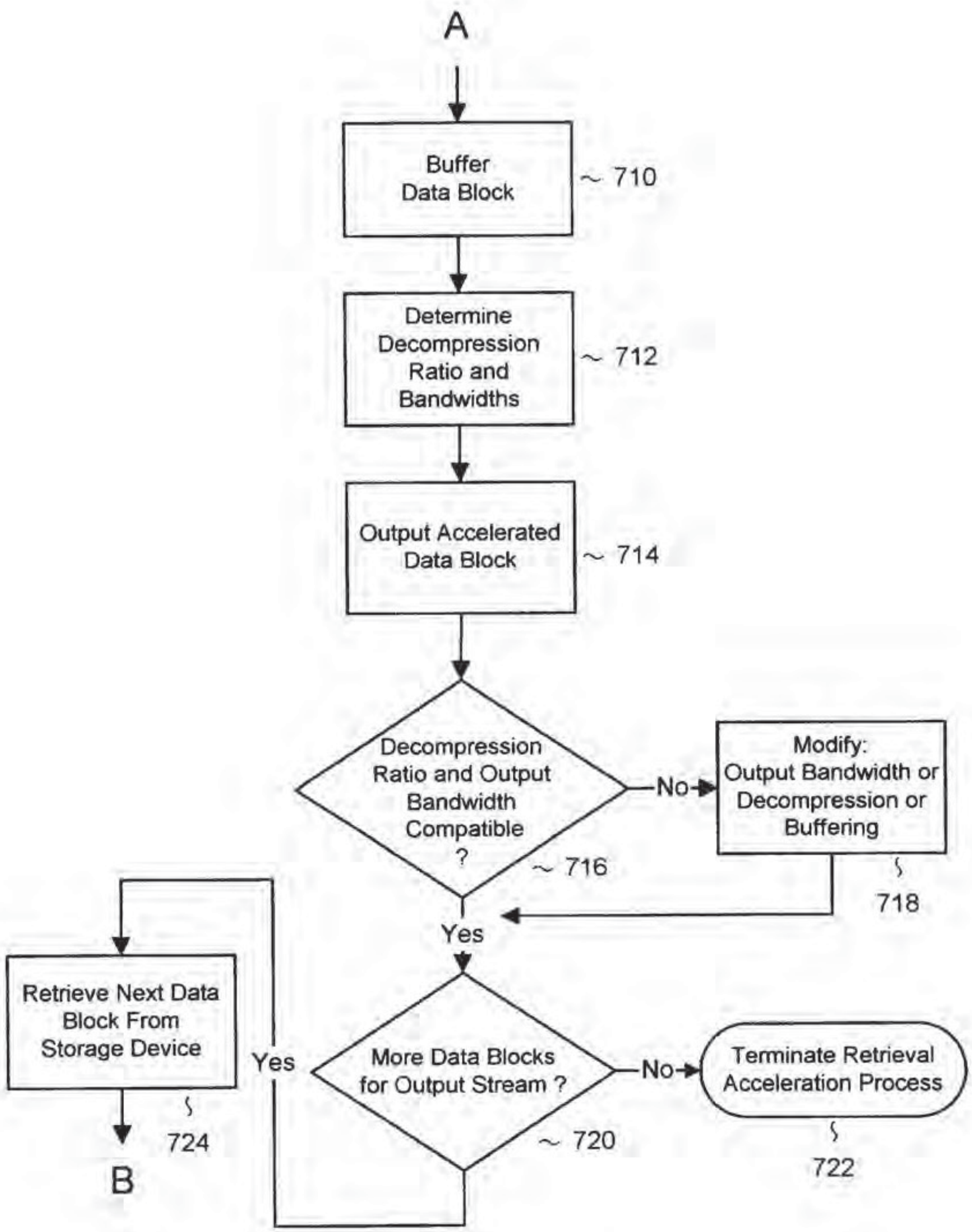
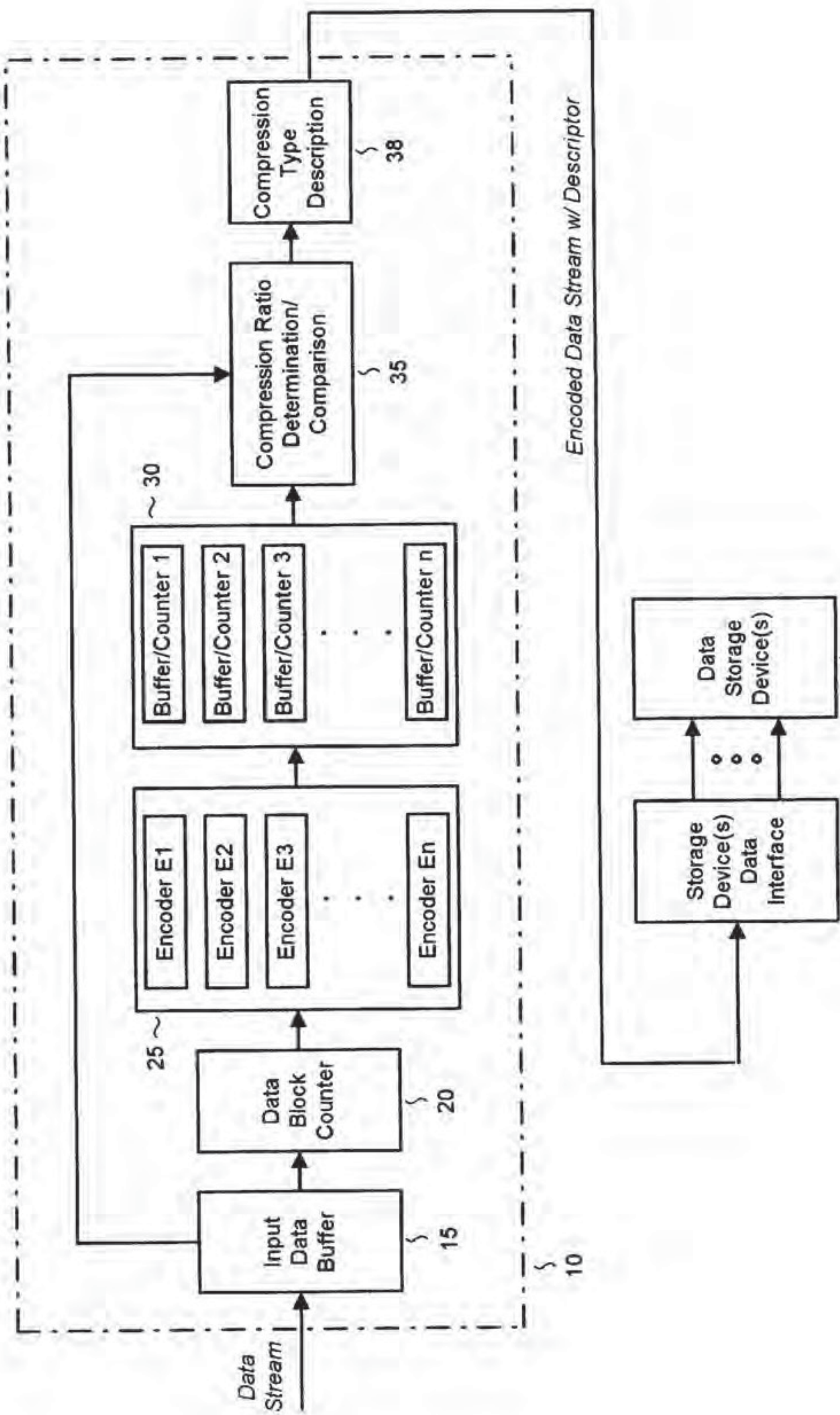

A
Buffer Data Block
710
Determine Decompression Ratio and Bandwidths
712
Output Accelerated Data Block
714
Decompression Ratio and Output Bandwidth Compatible ?
716
No
Modify: Output Bandwidth or Decompression or Buffering
718
Yes
More Data Blocks for Output Stream ?
720
No
Terminate Retrieval Acceleration Process
722
Yes
Retrieve Next Data Block From Storage Device
724
B

FIGURE 7b



Data Stream
Input Data Buffer
15
Data Block Counter
20
25
Encoder E1
Encoder E2
Encoder E3
Encoder En
30
Buffer/Counter 1
Buffer/Counter 2
Buffer/Counter 3
Buffer/Counter n
Compression Ratio Determination/ Comparison
35
Compression Type Description
38
10
Encoded Data Stream w/ Descriptor
Storage Device(s) Data Interface
40
Data Storage Device(s)
45

FIGURE 8

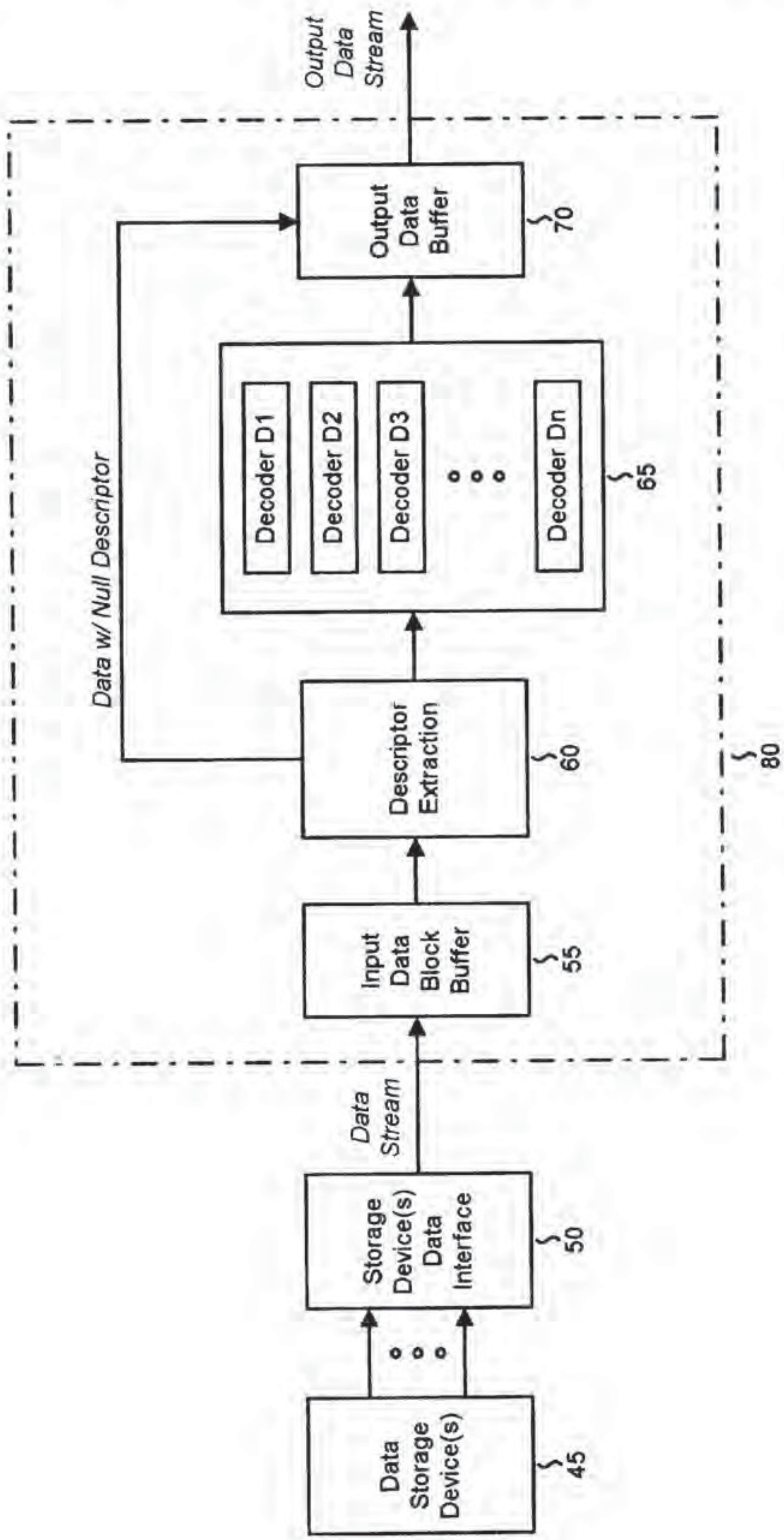

Data Storage Device(s)
45
Storage Device(s) Data Interface
50
Data Stream
Input Data Block Buffer
55
Descriptor Extraction
60
Data w/ Null Descriptor
Decoder D1
Decoder D2
Decoder D3
Decoder Dn
65
Output Data Buffer
70
Output Data Stream
80

FIGURE 9

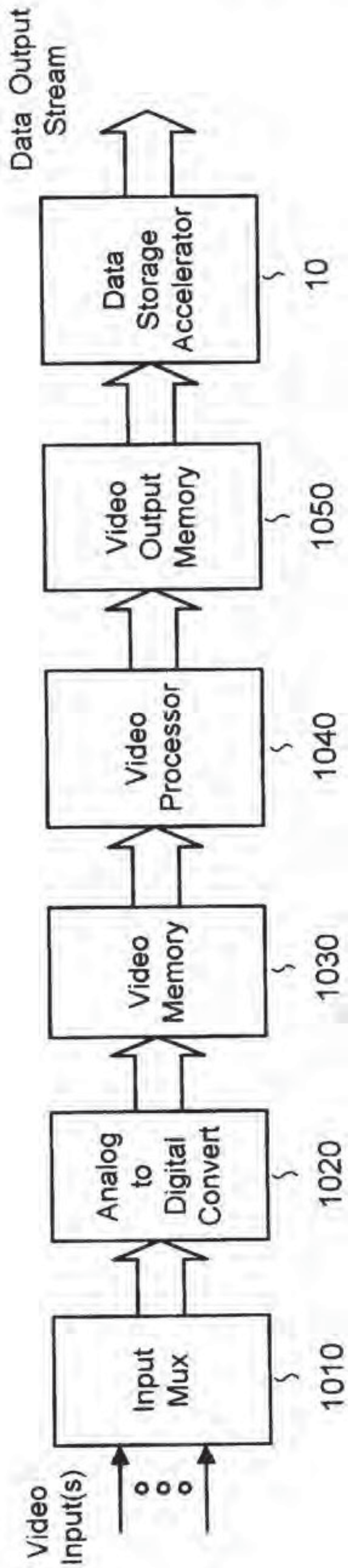

Video Input(s)
Input Mux
1010
Analog to Digital Convert
1020
Video Memory
1030
Video Processor
1040
Video Output Memory
1050
Data Storage Accelerator
10
Data Output Stream

FIGURE 10

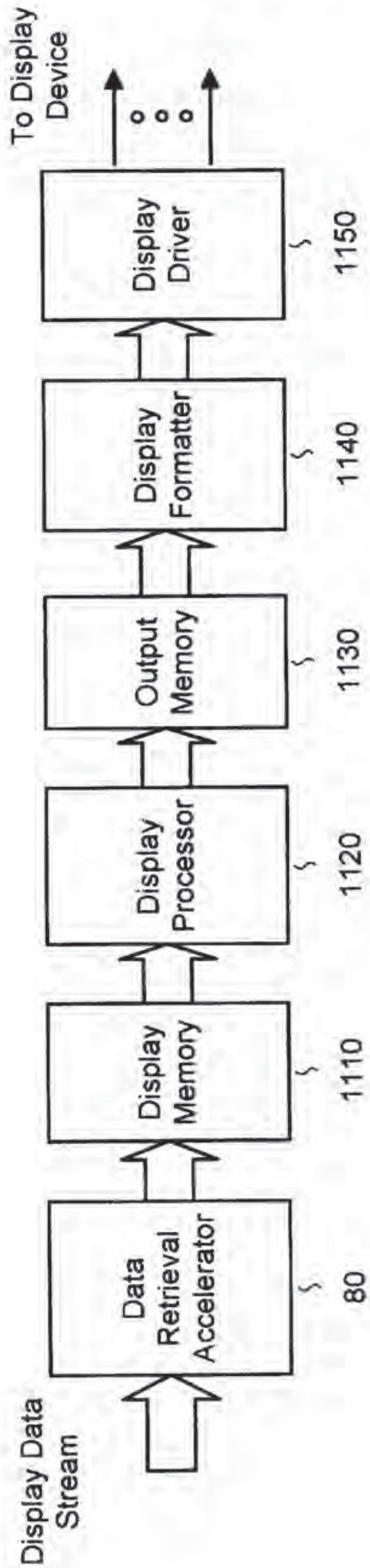

Display Data Stream
Data Retrieval Accelerator
80
Display Memory
1110
Display Processor
1120
Output Memory
1130
Display Formatter
1140
Display Driver
1150
To Display Device

FIGURE 11

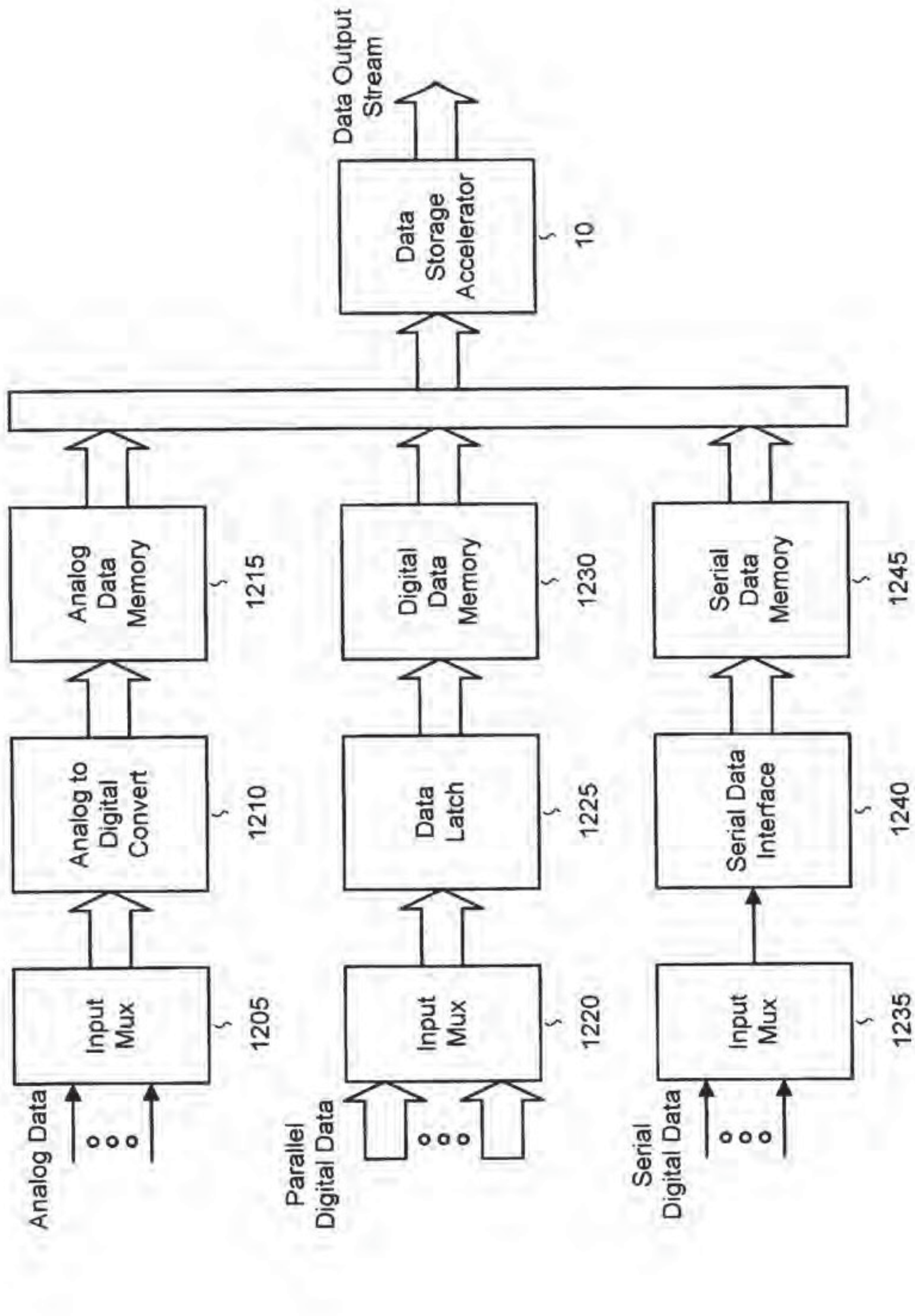
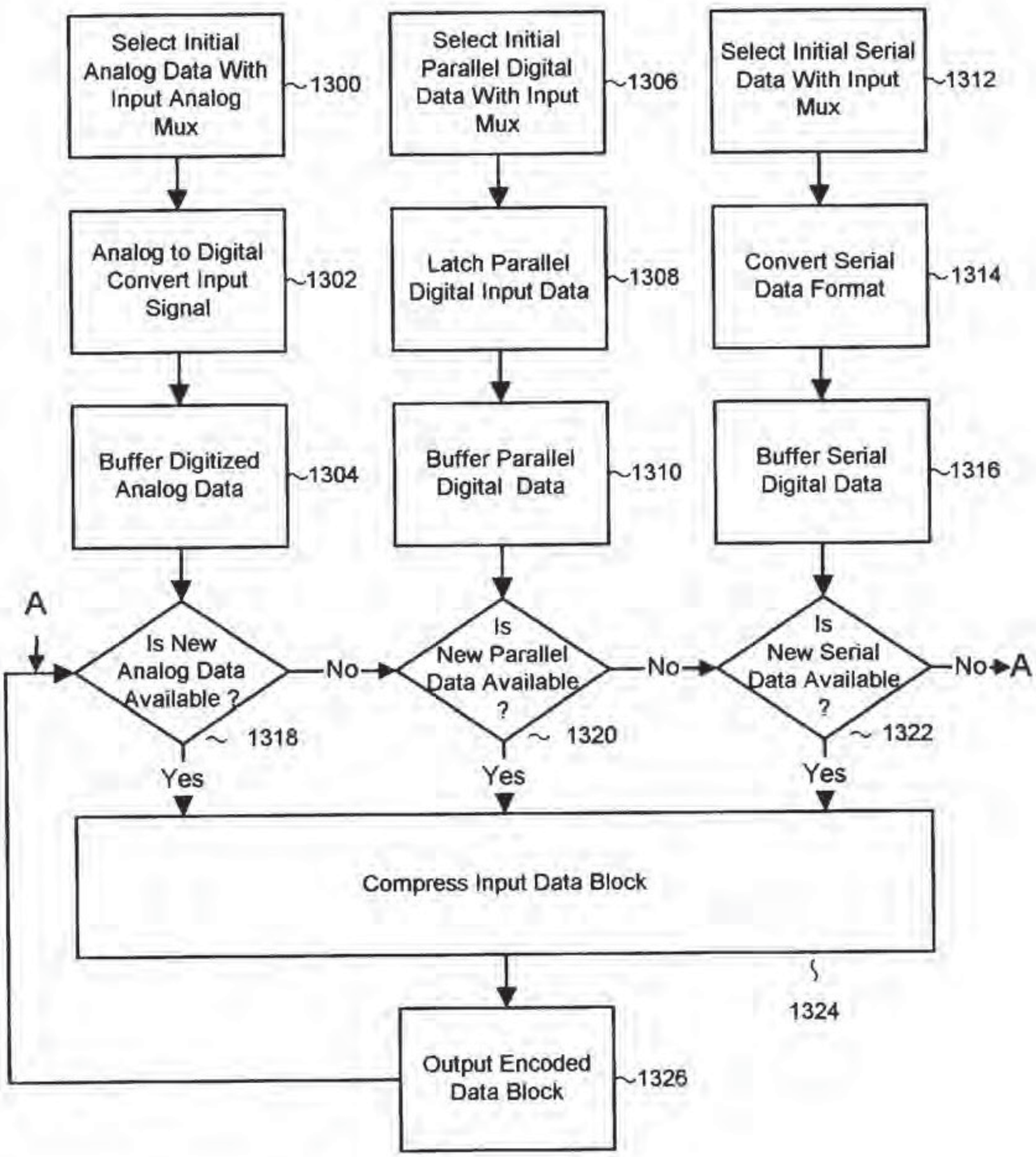

Analog Data
Input Mux
1205
Analog to Digital Convert
1210
Analog Data Memory
1215
Parallel Digital Data
Input Mux
1220
Data Latch
1225
Digital Data Memory
1230
Serial Digital Data
Input Mux
1235
Serial Data Interface
1240
Serial Data Memory
1245
Data Storage Accelerator
10
Data Output Stream

FIGURE 12



Select Initial Analog Data With Input Analog Mux
1300
Analog to Digital Convert Input Signal
1302
Buffer Digitized Analog Data
1304
Select Initial Parallel Digital Data With Input Mux
1306
Latch Parallel Digital Input Data
1308
Buffer Parallel Digital Data
1310
Select Initial Serial Data With Input Mux
1312
Convert Serial Data Format
1314
Buffer Serial Digital Data
1316
A
Is New Analog Data Available ?
1318
No
Is New Parallel Data Available ?
1320
No
Is New Serial Data Available ?
1322
No
A
Yes
Yes
Yes
Compress Input Data Block
1324
Output Encoded Data Block
1326

FIGURE 13

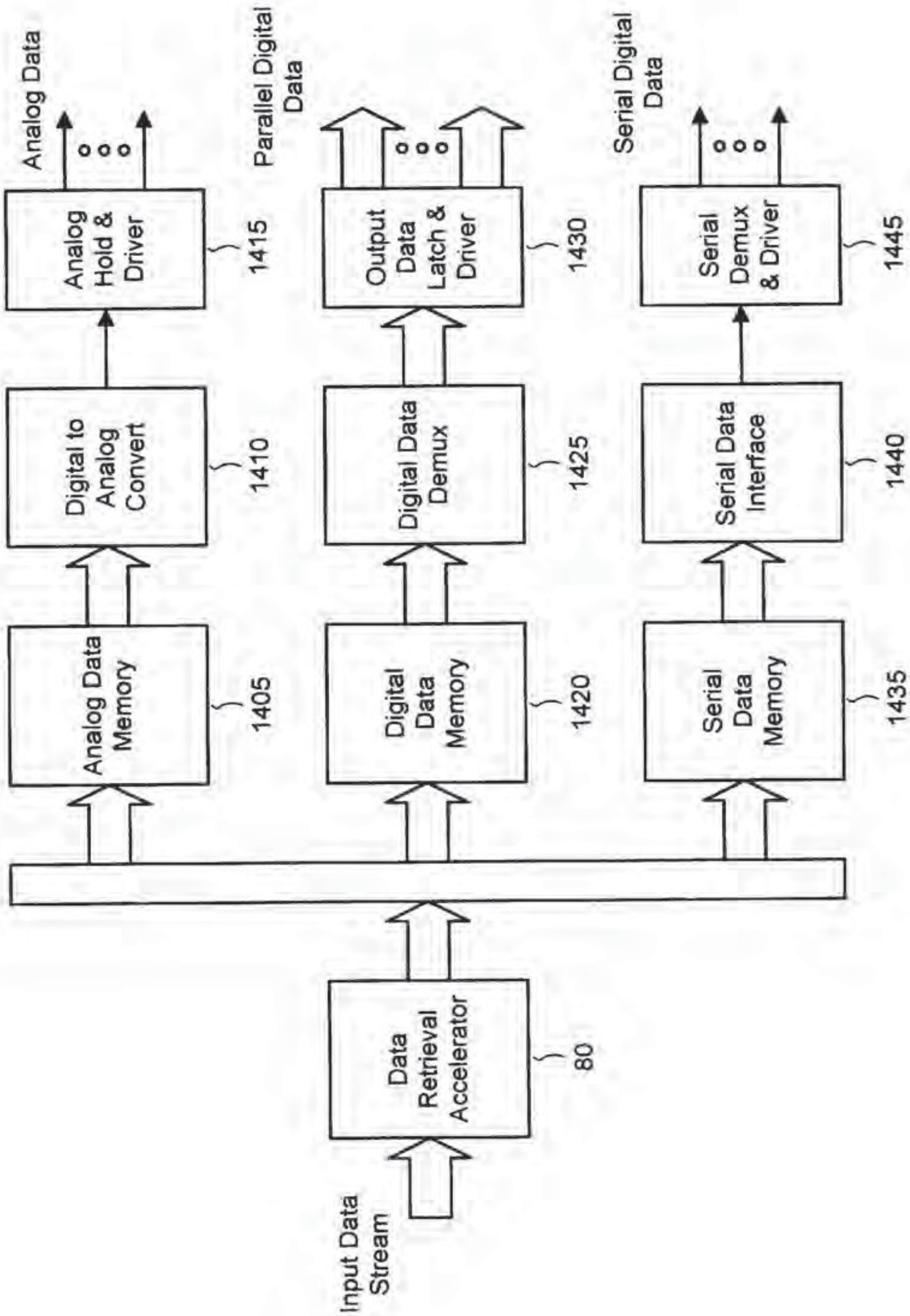

Input Data Stream
Data Retrieval Accelerator
80
Analog Data Memory
1405
Digital to Analog Convert
1410
Analog Hold & Driver
1415
Analog Data
Digital Data Memory
1420
Digital Data Demux
1425
Output Data Latch & Driver
1430
Parallel Digital Data
Serial Data Memory
1435
Serial Data Interface
1440
Serial Demux & Driver
1445
Serial Digital Data

FIGURE 14

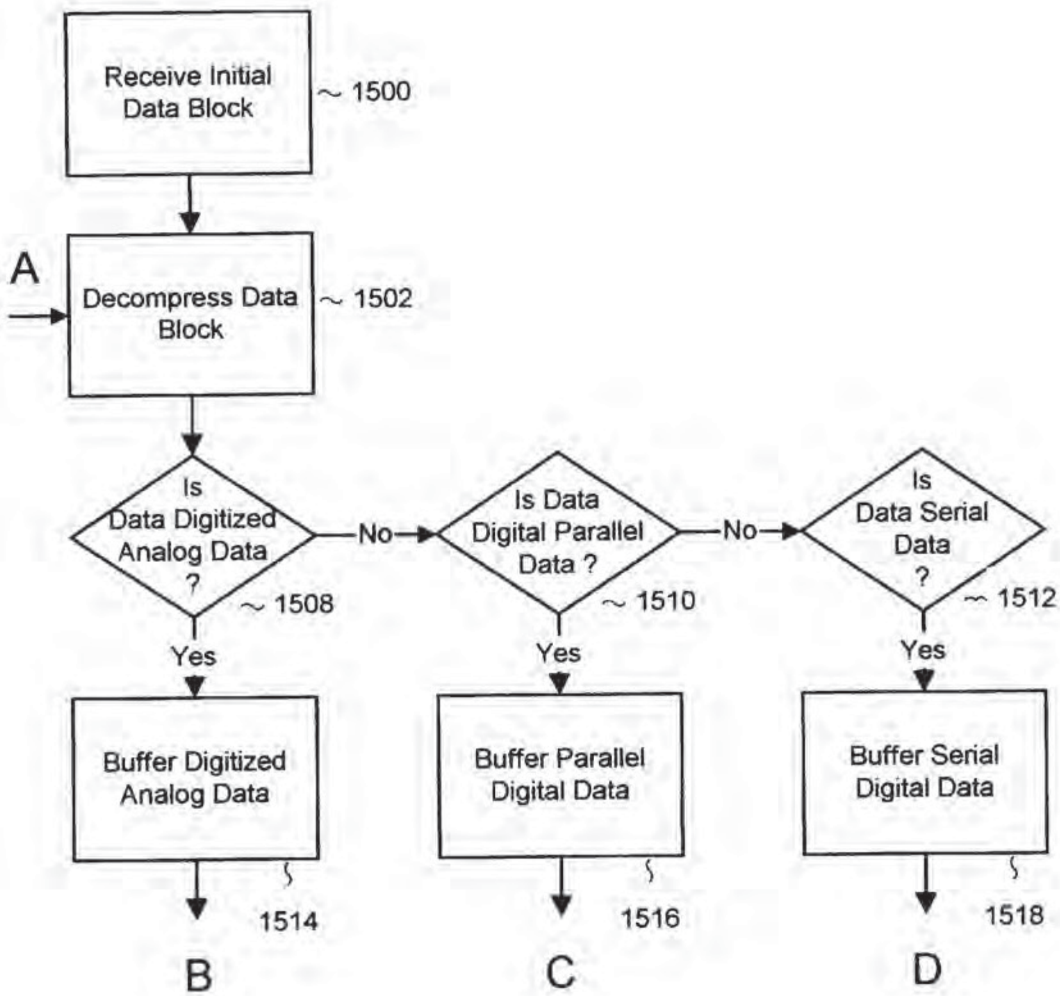

Receive Initial Data Block
1500
A
Decompress Data Block
1502
Is Data Digitized Analog Data ?
1508
No
Is Data Digital Parallel Data ?
1510
No
Is Data Serial Data ?
1512
Yes
Yes
Yes
Buffer Digitized Analog Data
Buffer Parallel Digital Data
Buffer Serial Digital Data
1514
1516
1518
B
C
D

FIGURE 15a

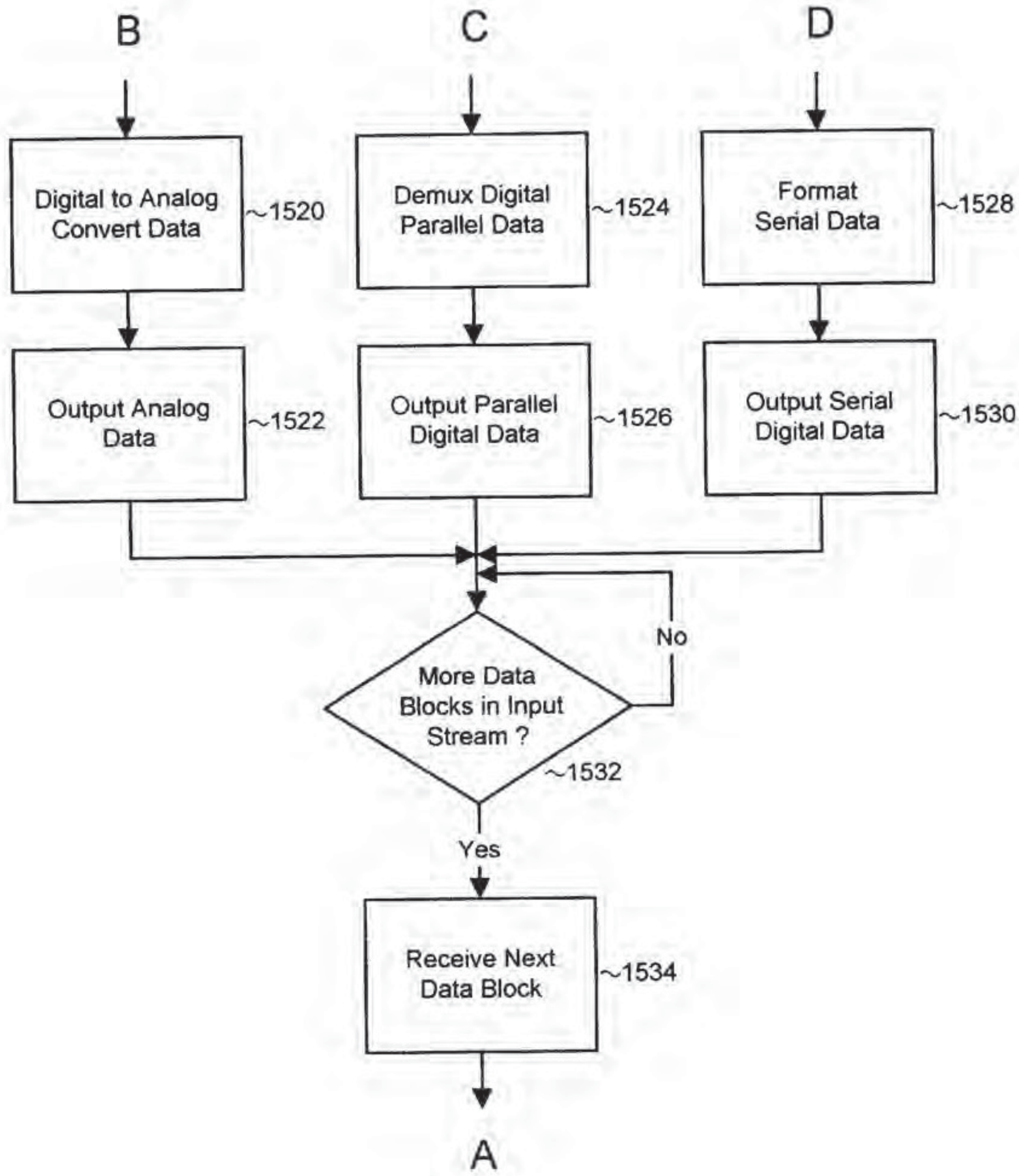

B
C
D
Digital to Analog Convert Data
1520
Demux Digital Parallel Data
1524
Format Serial Data
1528
Output Analog Data
1522
Output Parallel Digital Data
1526
Output Serial Digital Data
1530
No
More Data Blocks in Input Stream ?
1532
Yes
Receive Next Data Block
1534
A

FIGURE 15b

SYSTEM AND METHODS FOR ACCELERATED DATA STORAGE AND RETRIEVAL

BACKGROUND

1. Technical Field

The present invention relates generally to data storage and retrieval and, more particularly to systems and methods for improving data storage and retrieval bandwidth utilizing lossless data compression and decompression.

2. Description of the Related Art

Information may be represented in a variety of manners. Discrete information such as text and numbers are easily represented in digital data. This type of data representation is known as symbolic digital data. Symbolic digital data is thus an absolute representation of data such as a letter, figure, character, mark, machine code, or drawing.

Continuous information such as speech, music, audio, images and video frequently exists in the natural world as analog information. As is well-known to those skilled in the art, recent advances in very large scale integration (VLSI) digital computer technology have enabled both discrete and analog information to be represented with digital data. Continuous information represented as digital data is often referred to as diffuse data. Diffuse digital data is thus a representation of data that is of low information density and is typically not easily recognizable to humans in its native form.

There are many advantages associated with digital data representation. For instance, digital data is more readily processed, stored, and transmitted due to its inherently high noise immunity. In addition, the inclusion of redundancy in digital data representation enables error detection and/or correction. Error detection and/or correction capabilities are dependent upon the amount and type of data redundancy, available error detection and correction processing, and extent of data corruption.

One outcome of digital data representation is the continuing need for increased capacity in data processing, storage, and transmittal. This is especially true for diffuse data where increases in fidelity and resolution create exponentially greater quantities of data. Data compression is widely used to reduce the amount of data required to process, transmit, or store a given quantity of information. In general, there are two types of data compression techniques that may be utilized either separately or jointly to encode/decode data: lossy and lossless data compression.

Lossy data compression techniques provide for an inexact representation of the original uncompressed data such that the decoded (or reconstructed) data differs from the original unencoded/uncompressed data. Lossy data compression is also known as irreversible or noisy compression. Negentropy is defined as the quantity of information in a given set of data. Thus, one obvious advantage of lossy data compression is that the compression ratios can be larger than that dictated by the negentropy limit, all at the expense of information content. Many lossy data compression techniques seek to exploit various traits within the human senses to eliminate otherwise imperceptible data. For example, lossy data compression of visual imagery might seek to delete information content in excess of the display resolution or contrast ratio of the target display device.

On the other hand, lossless data compression techniques provide an exact representation of the original uncompressed data. Simply stated, the decoded (or reconstructed) data is identical to the original unencoded/uncompressed data. Lossless data compression is also known as reversible or noiseless compression. Thus, lossless data compression has, as its current limit, a minimum representation defined by the negentropy of a given data set.

It is well known within the current art that data compression provides several unique benefits. First, data compression can reduce the time to transmit data by more efficiently utilizing low bandwidth data links. Second, data compression economizes on data storage and allows more information to be stored for a fixed memory size by representing information more efficiently.

One problem with the current art is that existing memory storage devices severely limit the performance of consumer, entertainment, office, workstation, servers, and mainframe computers for all disk and memory intensive operations. For example, magnetic disk mass storage devices currently employed in a variety of home, business, and scientific computing applications suffer from significant seek-time access delays along with profound read/write data rate limitations. Currently the fastest available (10,000) rpm disk drives support only a 17.1 Megabyte per second data rate (MB/sec). This is in stark contrast to the modern Personal Computer's Peripheral Component Interconnect (PCI) Bus's input/output capability of 264 MB/sec and internal local bus capability of 800 MB/sec.

Another problem within the current art is that emergent high performance disk interface standards such as the Small Computer Systems Interface (SCSI-3) and Fibre Channel offer only the promise of higher data transfer rates through intermediate data buffering in random access memory. These interconnect strategies do not address the fundamental problem that all modern magnetic disk storage devices for the personal computer marketplace are still limited by the same physical media restriction of 17.1 MB/sec. Faster disk access data rates are only achieved by the high cost solution of simultaneously accessing multiple disk drives with a technique known within the art as data striping.

Additional problems with bandwidth limitations similarly occur within the art by all other forms of sequential, pseudo-random, and random access mass storage devices. Typically mass storage devices include magnetic and optical tape, magnetic and optical disks, and various solid-state mass storage devices. It should be noted that the present invention applies to all forms and manners of memory devices including storage devices utilizing magnetic, optical, and chemical techniques, or any combination thereof.

SUMMARY OF THE INVENTION

The present invention is directed to systems and methods for providing accelerated data storage and retrieval by utilizing lossless data compression and decompression. The present invention provides an effective increase of the data storage and retrieval bandwidth of a memory storage device. In one aspect of the present invention, a method for providing accelerated data storage and retrieval comprises the steps of:

receiving a data stream at an input data transmission rate which is greater than a data storage rate of a target storage device;

compressing the data stream at a compression ratio which provides a data compression rate that is greater than the data storage rate;

storing the compressed data stream in the target storage device;

retrieving the compressed data stream from the target storage device at a rate equal to a data access rate of the target storage device; and

decompressing the compressed data at a decompression ratio to provide an output data stream having an output transmission rate which is greater than the data access rate of the target storage device.

In another aspect of the present invention, the method for providing accelerated data storage and retrieval utilizes a compression ratio that is at least equal to the ratio of the input data transmission rate to the data storage rate so as to provide continuous storage of the input data stream at the input data transmission rate.

In another aspect of the present invention, the method for providing accelerated data storage and retrieval utilizes a decompression ratio which is equal to or greater than the ratio of the data access rate to a maximum accepted output data transmission rate so as to provide a continuous and optimal data output transmission rate.

In another aspect of the present invention the data storage and retrieval accelerator method and system is employed in a disk storage adapter to reduce the time required to store and retrieve data from computer to a disk memory device.

In another aspect of the present invention the data storage and retrieval accelerator method and system is employed in conjunction with random access memory to reduce the time required to store and retrieve data from random access memory.

In another aspect of the present invention a data storage and retrieval accelerator method and system is employed in a video data storage system to reduce the time required to store digital video data.

In another aspect of the present invention the data storage and retrieval accelerator method and system is employed in a display controller to reduce the time required to send display data to the display controller or processor.

In another aspect of the present invention the data storage and retrieval accelerator method and system is employed in an input/output controller to reduce the time required to store, retrieve, or transmit data various forms of data.

The present invention is realized due to recent improvements in processing speed, inclusive of dedicated analog and digital hardware circuits, central processing units, digital signal processors, dedicated finite state machines (and any hybrid combinations thereof), that, coupled with advanced data compression and decompression algorithms, are enabling of ultra high bandwidth data compression and decompression methods that enable improved data storage and retrieval bandwidth.

These and other aspects, features and advantages, of the present invention will become apparent from the following detailed description of preferred embodiments, that is to be read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a system for accelerated data storage and retrieval according to one embodiment of the present invention;

FIG. **2** is a flow diagram of a method for accelerated data storage in accordance with one aspect of the present invention;

FIG. **3** is a flow diagram of a method for accelerated data retrieval in accordance with one aspect of the present invention;

FIGS. **4***a* and **4***b* are timing diagrams of methods for accelerated data storage according to the present invention;

FIGS. **5***a* and **5***b* are timing diagrams of methods for accelerated data retrieval according to the present invention;

FIGS. **6***a* and **6***b* comprise a flow diagram of a method for accelerated data storage in accordance with a further aspect of the present invention;

FIGS. **7***a* and **7***b* comprise a flow diagram of a method for accelerated data retrieval in accordance with a further aspect of the present invention;

FIG. **8** is a detailed block diagram of a system for accelerated data storage according to a preferred embodiment of the present invention;

FIG. **9** is a detailed block diagram of a system for accelerated data retrieval according to a preferred embodiment of the present invention;

FIG. **10** is a block diagram of a system for accelerated video storage according to one embodiment of the present invention;

FIG. **11** is a block diagram of a system for accelerated retrieval of video data according to one embodiment of the present invention;

FIG. **12** is a block diagram of an input/output controller system for accelerated storage of analog, digital, and serial data according to one embodiment of the present invention;

FIG. **13** is a flow diagram of a method for accelerated storage of analog, digital, and serial data according to one aspect of the present invention;

FIG. **14** is a block diagram of an input/output system for accelerated retrieval of analog, digital, and serial data according to one embodiment of the present invention; and

FIGS. **15***a* and **15***b* comprise a flow diagram of method for accelerated retrieval of analog, digital, and serial data according to one aspect of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention is directed to systems and methods for providing improved data storage and retrieval bandwidth utilizing lossless data compression and decompression. In the following description, it is to be understood that system elements having equivalent or similar functionality are designated with the same reference numerals in the Figures. It is to be further understood that the present invention may be implemented in various forms of hardware, software, firmware, or a combination thereof. Preferably, the present invention is implemented on a computer platform including hardware such as one or more central processing units (CPU) or digital signal processors (DSP), a random access memory (RAM), and input/output (I/O) interface(s). The computer platform may also include an operating system, microinstruction code, and dedicated processing hardware utilizing combinatorial logic or finite state machines. The various processes and functions described herein may be either part of the hardware, microinstruction code or application programs that are executed via the operating system, or any combination thereof.

It is to be further understood that, because some of the constituent system components described herein are preferably implemented as software modules, the actual system connections shown in the Figures may differ depending upon the manner in that the systems are programmed. It is to be appreciated that special purpose microprocessors, digital signal processors, dedicated hardware, or and combination thereof may be employed to implement the present invention. Given the teachings herein, one of ordinary skill in the related art will be able to contemplate these and similar implementations or configurations of the present invention.

Referring now to FIG. **1**, a block diagram illustrates a system for accelerated data storage and retrieval in accordance with an embodiment of the present invention. The system includes a data storage accelerator **10**, operatively coupled to a data storage device **45**. The data storage accelerator operates to increase the effective data storage rate of the data storage device **45**. It is to be appreciated that the data storage device **45** may be any form of memory device including all forms of sequential, pseudo-random, and random access storage devices. The memory storage device **45** may be volatile or non-volatile in nature, or any combination thereof. Storage devices as known within the current art include all forms of random access memory, magnetic and optical tape, magnetic and optical disks, along with various other forms of solid-state mass storage devices. Thus it should be noted that the current invention applies to all forms and manners of memory devices including, but not limited to, storage devices utilizing magnetic, optical, and chemical techniques, or any combination thereof.

The data storage accelerator **10** receives and processes data blocks from an input data stream. The data blocks may range in size from individual bits through complete files or collections of multiple files, and the data block size may be fixed or variable. In order to achieve continuous data storage acceleration, the data storage accelerator **10** must be configured to compress a given input data block at a rate that is equal to or faster than receipt of the input data. Thus, to achieve optimum throughput, the rate that data blocks from the input data stream may be accepted by the data storage accelerator **10** is a function of the size of each input data block, the compression ratio achieved, and the bandwidth of the target storage device. For example, if the data storage device **45** (e.g., a typical target mass storage device) is capable of storing 20 megabytes per second and the data storage accelerator **10** is capable of providing an average compression ratio of 3:1, then 60 megabytes per second may be accepted as input and the data storage acceleration is precisely 3:1, equivalent to the average compression ratio.

It should be noted that it is not a requirement of the present invention to configure the storage accelerator **10** to compress a given input data block at a rate that is equal to or faster than receipt of the input data. Indeed, if the storage accelerator **10** compresses data at a rate that is less than the input data rate, buffering may be applied to accept data from the input data stream for subsequent compression.

Additionally, it is not a requirement that the data storage accelerator **10** utilize data compression with a ratio that is at least the ratio of the input data stream to the data storage access rate of the data storage device **45**. Indeed, if the compression ratio is less than this ratio, the input data stream may be periodically halted to effectively reduce the rate of the input data stream. Alternatively, the input data stream or the output of the data accelerator **10** may be buffered to temporarily accommodate the mismatch in data bandwidth. An additional alternative is to reduce the input data rate to rate that is equal to or slower than the ratio of the input data rate to the data storage device access rate by signaling the data input source and requesting a slower data input rate, if possible.

Referring again to FIG. **1**, a data retrieval accelerator **80** is operatively connected to and receives data from the data storage device **45**. The data retrieval accelerator **80** receives and processes compressed data from data storage device **45** in data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the input data block size may be fixed or variable. The data retrieval accelerator **80** is configured to decompress each compressed data block which is received from the data storage device **45**. In order to achieve continuous accelerated data retrieval, the data retrieval accelerator must decompress a given input data block at a rate that is equal to or faster than receipt of the input data.

In a manner analogous to the data storage accelerator **10**, achieving optimum throughput with the data retrieval accelerator **80** is a function of the rate that compressed data blocks are retrieved from the data storage device **45**, the size of each data block, the decompression ratio achieved, and the limitation on the bandwidth of the output data stream, if any. For example, if the data storage device **45** is capable of continuously supplying 20 megabytes per second and the data retrieval accelerator **80** is capable of providing an average decompression ratio of 1:3, then a 60 megabytes per second output data stream is achieved, and the corresponding data retrieval acceleration is precisely 1:3, equivalent to the average decompression ratio.

It is to be understood that it is not required that the data retrieval accelerator **80** utilize data decompression with a ratio that is at most equal to the ratio of the retrieval rate of the data storage device **45** to the maximum rate data output stream. Indeed, if the decompression ratio is greater than this ratio, retrieving data from the data storage device may be periodically halted to effectively reduce the rate of the output data stream to be at or below its maximum. Alternatively, the compressed data retrieved from the data storage device **45** or the output of the data decompressor may be buffered to temporarily accommodate the mismatch in data bandwidth. An additional alternative is to increase the output data rate by signaling or otherwise requesting the data output device (s) receiving the output data stream to accept a higher bandwidth, if possible.

Referring now to FIG. **2**, a flow diagram of a method for accelerated data storage according to one aspect of the present invention illustrates the operation of the data storage acceleration shown in FIG. **1**. As previously stated above, data compression is performed on a per data block basis. Accordingly, the initial input data block in the input data stream (step **200**) is input into and compressed by the data storage accelerator **10** (step **202**). Upon completion of the encoding of the input data block, the encoded data block is then stored in the data storage device **45** (step **204**). A check or other form of test is performed to see if there are additional data blocks available in the input stream (step **206**). If no more data blocks are available, the storage acceleration process is terminated (step **208**). If more data blocks are available in the input data stream, the next data block is received (step **210**) and the process repeats beginning with data compression (step **202**).

Referring now to FIG. **3**, a flow diagram of a method for accelerated data retrieval according to one aspect of the present invention illustrates the operation of the data retrieval accelerator **80** shown in FIG. **1**. Data decompression is also performed on a per data block basis. The initial compressed data block is retrieved from the storage device **45** (step **300**) and is decompressed by the data retrieval accelerator **80** (step **302**). Upon completion of the decoding of the initial data block, the decoded data block is then output for subsequent processing, storage, or transmittal (step **304**). A check or other form of test is performed to see if additional data blocks available from the data storage device (step **306**). If no more data blocks are available, the data retrieval acceleration process is terminated (step **308**). If more data blocks are available from the data storage device, the next data block is retrieved (step **310**) and the process repeats beginning with data decompression (step **302**).

Referring now to FIGS. **4***a* and **4***b*, a timing diagram illustrates methods for accelerated data storage utilizing data compression in accordance with the present invention. Successive time intervals of equal duration are represented as T1 through T(n+2). Data block **1** is received from an input stream of one or more data blocks. Similarly, data block **2** through data block n are received during time intervals T2 through Tn, respectively. For the purposes of discussion, FIG. **4***a* and **4***b* demonstrate one embodiment of the data storage utilizing a stream of n data blocks. As previously stated, the input data stream is comprised of one or more data blocks data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the input data block size may be fixed or variable.

In accordance with Method 1, compression of data block **1** and subsequent storage of the encoded data block **1** occurs within time interval T1. Similarly, the compression and storage of each successive data block occurs within the time interval the data block is received. Specifically, data blocks **2** . . . n are compressed in time intervals T2 . . . Tn, respectively, and the corresponding encoded data blocks **2** . . . n are stored during the time intervals T2 . . . Tn, respectively. It is to be understood that Method 1 relies on data compression and encoding techniques that process data as a contiguous stream, i e., are not block oriented. It is well known within the current art that certain data compression techniques including, but not limited to, dictionary compression, run length encoding, null suppression and arithmetic compression are capable of encoding data when received. Method 1 possesses the advantage of introducing a minimum delay in the time from receipt of input to storage of encoded data blocks.

Referring again to FIGS. **4***a* and **4***b*, Method 2 illustrates compressing and storing data utilizing pipelined data processing. For Method 2, successive time intervals of equal duration are represented as T1 through T(n+2). Data block **1** is received from an input stream of one or more data blocks during time interval T1. Similarly, data block **2** through data block n are received during time intervals T2 through Tn, respectively. Compression of data block **1** occurs during time interval T2 and the storage of encoded data block **1** occurs during time interval T3. As shown by Method 2, compression of each successive data block occurs within the next time interval after the data block is received and data storage of the corresponding encoded data block occur in the next time interval after completion of data compression.

The pipelining of Method 2, as shown, utilizes successive single time interval delays for data compression and data storage. Within the current invention, it is permissible to have increased pipelining to facilitate additional data processing or storage delays. For example, data compression processing for a single input data block may utilize more than one time interval. Accommodating more than one time interval for data compression requires additional data compressors to process successive data blocks, e.g., data compression processing of a single data block through three successive time intervals requires three data compressors, each processing a successive input data block. Due to the principle of causality, encoded data blocks are output only after compression encoding.

Method 2 provides for block oriented processing of the input data blocks. Within the current art, block oriented data compression techniques provide the opportunity for increased data compression ratios. The disadvantage of Method 2 is increased delay from receipt of input data block to storage of encoded data. Depending on factors such as the size of input data blocks, the rate that they are received, the time required for data compression processing, the data compression ratio achieved, the bandwidth of the data storage device, and the intended application, the delay may or may not be significant. For example, in a modern database system, recording data for archival purposes, the opportunity for increased data compression may far outweigh the need for minimum delay. Conversely, in systems such as a military real-time video targeting system, minimizing delay is often of the essence. It should be noted that Method 1 and Method 2 are not mutually exclusive, and may be utilized in any combination.

Referring now to FIGS. **5***a* and **5***b*, a timing diagram illustrates methods for accelerated data retrieval utilizing data decompression in accordance the present invention shown. Successive time intervals of equal duration are represented as T1 through T(n+2). Data block **1** is retrieved or otherwise accepted as input from one or more compressed data blocks retrieved from a data storage device. As shown, data block **2** through data block n are retrieved during time intervals T2 through Tn, respectively. For the purposes of discussion, FIGS. **5***a* and **5***b* demonstrate one embodiment of the data retrieval accelerator utilizing a stream of n data blocks. Once again, the retrieved data stream is comprised of one or more data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the retrieved data block size may be fixed or variable.

In accordance with Method 1, decompression of data block **1** and subsequent outputting of the decoded data block **1** occurs within time interval T1. Similarly, decompression and outputting of each successive data block occurs within the time intervals they are retrieved. In particular, data block **2** through data block n are decompressed and decoded data block **2** through decoded data block n are output during time intervals T2 . . . Tn, respectively. It is to be understood that Method 1 relies on data decompression and decoding techniques that process compressed data as a contiguous stream, i.e., are not block oriented. It is well known within the current art that certain data decompression techniques including, but not limited to , dictionary compression, run length encoding, null suppression and arithmetic compression are capable of decoding data when received. Method 1 possesses the advantage of introducing a minimum delay in the time from retrieval of compressed data to output of decoded data blocks.

Referring again to FIGS. **5***a* and **5***b*, Method 2 involves decompressing and outputting data utilizing pipelined data processing. For Method 2 , successive time intervals of equal duration are represented as T1 through T(n+2). Data block **1** through data block n are retrieved or otherwise accepted as input from a data storage device during time intervals T1 through Tn, respectively. Decompression of data block **1** occurs during time interval T2 and the decoded data block **1** is output during time interval T3. Similarly, decompression of each successive data block occurs within the next time interval after the data block is retrieved and the outputting of the decoded data block occurs during the next time interval after completion of data decompression.

The pipelining of Method 2 , utilizes successive single time interval delays for data decompression and data output. Within the current invention, it is permissible to have increased pipelining to facilitate additional data retrieval or data decompression processing delays. For example, data decompression processing for a single input data block may utilize more than one time interval. Accommodating more than one time interval for data compression requires additional data decompressors to process successive compressed data blocks, e.g., data decompression processing of a single data block through three successive time intervals requires three data decompressors, each processing a successive input data block. Due to the principle of causality, decoded data blocks are only output after decompression decoding.

As before, Method 2 provides for block oriented processing of the retrieved data blocks. Within the current art, block oriented data decompression techniques provide the opportunity to utilize data compression encoders that increase data compression ratios. The disadvantage of method 2 is increased delay from retrieval of compressed data block to output of decompressed data. As previously discussed for data storage acceleration, depending on the size of retrieved data blocks, the rate that they are retrieved, the time required for data decompression processing, the data decompression ratio achieved, the bandwidth of the data output, and the intended application, the delay may or may not be significant.

Referring now to FIGS. **6***a* and **6***b*, a flow diagram illustrates a method for accelerated data storage according to a further aspect of the present invention. With this method, the data compression rate of the storage accelerator **10** is not required to be equal to or greater than the ratio of the input data rate to the data storage access rate. As previously stated above, data compression is performed on a per data block basis. Accordingly, the initial input data block in the input data stream is received (step **600**) and then timed and counted (step **602**). Timing and counting enables determination of the bandwidth of the input data stream. The input data block is then buffered (step **604**) and compressed by the data storage accelerator **10** (step **606**). During and after the encoding of the input data block, the encoded data block is then timed and counted (step **608**), thus enabling determination of the compression ratio and compression bandwidth. The compressed, timed and counted data block is then buffered (step **610**). The compression ratio and bandwidths of the input data stream and the encoder are then determined (step **612**). The compressed data block is then stored in the data storage device **45** (step **614**). Checks or other forms of testing are applied to ensure that the data bandwidths of the input data stream, data compressor, and data storage device are compatible (step **616**). If the bandwidths are not compatible, then one or more system parameters may be modified to make the bandwidths compatible (step **618**). For instance, the input bandwidth may be adjusted by either not accepting input data requests, lowering the duty cycle of input data requests, or by signaling one or more of the data sources that transmit the input data stream to request or mandate a lower data rate. In addition, the data compression ratio of the data storage accelerator **10** may be adjusted by applying a different type of encoding process such as employing a single encoder, multiple parallel or sequential encoders, or any combination thereof. Furthermore, additional temporary buffering of either the input data stream or the compressed data stream (or both) may be utilized.

By way of example, assuming the input data rate is 90 MB/sec and the data storage accelerator **10** provides a compression ration of 3:1, then the output of the data storage accelerator **10** would be 30 MB/sec. If the maximum data storage rate of the data storage device **45** is 20MB/sec (which is less than the data rate output from the data storage accelerator **10**), data congestion and backup would occur at the output of the data storage accelerator **10**. This problem may be solved by adjusting any one of the system parameters as discussed above, e.g., by adjusting the compression ratio to provide a data output rate from the data storage accelerator **10** to be equal to the data storage rate of the data storage device **45**.

On the other hand, if the bandwidths are compatible (or made compatible by adjusting one or more of the system parameters), then a check or other form of test is performed to determine if there are additional data blocks available in the input stream (step **620**). If no more data blocks are available, the storage acceleration process is terminated (step **622**). If more data blocks are available in the input data stream, the next data block is received (step **624**) and the process repeats beginning with timing and counting of the input data block (step **602**).

Referring now to FIGS. **7***a* and **7***b*, a flow diagram illustrates a method for accelerated data retrieval according to one aspect of the present invention. With this method, the data decompression ratio is not required to be less than or equal to the ratio of the data retrieval access rate to the maximum output data rate. As previously stated above, data decompression is performed on a per data block basis. Accordingly, the initial input data block is retrieved from the storage device (step **700**) and is timed and counted (step **702**). Timing and counting enables determination of the bandwidth of data retrieval. The retrieved data block is then buffered (step **704**) and decompressed by the data retrieval accelerator **80** (step **706**). During and after the decoding of the input data block, the decoded data block is then timed and counted (step **708**), thus enabling determination of the decompression ratio and decompression bandwidth. The decompressed, timed and counted data block is then buffered (step **710**). The decompression ratio and bandwidths of the retrieved data and the decoder are then determined (step **712**). The decompressed data block is then output (step **714**). Checks or other forms of testing are applied to ensure that the data bandwidths of the retrieved data, data decompressor, and data output are compatible (step **716**). If the bandwidths are not compatible, then one or more system parameters may be modified to make the bandwidths compatible (step **718**). For instance, the data retrieval bandwidth may be adjusted either not accepting (continuously) data blocks retrieved from the data storage device or lowering the duty cycle of data blocks retrieved from the data storage device. In addition, one or more of the output data devices that receive the output data stream may be signaled or otherwise requested to accept a higher data rate. Moreover, a different type of decoding process may be applied to adjust the data decompression rate by applying, for example, a single decoder, multiple parallel or sequential decoders, or any combination thereof. Also, additional temporary buffering of either the retrieved or output data or both may be utilized.

By way of example, assuming the data storage device **45** has a data retrieval rate of 20 MB/sec and the data retrieval accelerator **80** provides a 1:4 decompression ratio, then the output of the data retrieval accelerator **80** would be 80 MB/sec. If the maximum output data transmission rate that can be accepted from the data retrieval accelerator **80** is 60 MB/sec (which is lower than the data output data rate of 80 MB/sec of the data retrieval accelerator **80**), data congestion and backup would occur at the output of the data retrieval accelerator **80**. This problem may be solved by adjusting any one of the system parameters as discussed above, e.g., by adjusting the decompression ratio to provide a data output rate from the data storage accelerator **80** to be equal to the maximum accepted output data transmission rate.

On the other hand, if the bandwidths are compatible (or made compatible by adjusting one or more system parameters), then a check or other form of test is performed to see if there are additional data blocks available from the data storage device (step **720**). If no more data blocks are available for output, the retrieval acceleration process is terminated (step **722**). If more data blocks are available to be retrieved from the data storage device, the next data block is retrieved (step **724**) and the process repeats beginning with timing and counting of the retrieved data block (return to step **702**).

It is to be understood that any conventional compression/decompression system and method (which comply with the above mentioned constraints) may be employed in the data storage accelerator **10** and data retrieval accelerator **80** for providing accelerated data storage and retrieval in accordance with the present invention. Preferably, the present invention employs the data compression/decompression techniques disclosed in U.S. Ser. No. 09/210,491 entitled "Content Independent Data Compression Method and System," filed on Dec. 11, 1998, which is commonly assigned and which is fully incorporated herein by reference. It is to be appreciated that the compression and decompression systems and methods disclosed in U.S. Ser. No. 09/210,491 are suitable for compressing and decompressing data at rates which provide accelerated data storage and retrieval.

Referring now to FIG. **8**, a detailed block diagram illustrates a preferred system for accelerated data storage which employs a compression system as disclosed in the above-incorporated U.S. Ser. No. 09/210,491. In this embodiment, the data storage accelerator **10** accepts data blocks from an input data stream and stores the input data block in an input buffer or cache **15**. It is to be understood that the system processes the input data stream in data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the input data block size may be fixed or variable. A counter **20** counts or otherwise enumerates the size of input data block in any convenient units including bits, bytes, words, double words. It should be noted that the input buffer **15** and counter **20** are not required elements of the present invention. The input data buffer **15** may be provided for buffering the input data stream in order to output an uncompressed data stream in the event that, as discussed in further detail below, every encoder fails to achieve a level of compression that exceeds an a priori specified minimum compression ratio threshold.

Data compression is performed by an encoder module **25** which may comprise a set of encoders **E1**, **E2**, **E3** . . . En. The encoder set **E1**, **E2**, **E3** . . . En may include any number "n" (where n may =1) of those lossless encoding techniques currently well known within the art such as run length, Huffman, Lempel-Ziv Dictionary Compression, arithmetic coding, data compaction, and data null suppression. It is to be understood that the encoding techniques are selected based upon their ability to effectively encode different types of input data. It is to be appreciated that a full complement of encoders are preferably selected to provide a broad coverage of existing and future data types.

The encoder module **25** successively receives as input each of the buffered input data blocks (or unbuffered input data blocks from the counter module **20**). Data compression is performed by the encoder module **25** wherein each of the encoders **E1** . . . En processes a given input data block and outputs a corresponding set of encoded data blocks. It is to be appreciated that the system affords a user the option to enable/disable any one or more of the encoders **E1** . . . En prior to operation. As is understood by those skilled in the art, such feature allows the user to tailor the operation of the data compression system for specific applications. It is to be further appreciated that the encoding process may be performed either in parallel or sequentially. In particular, the encoders **E1** through En of encoder module **25** may operate in parallel (i.e., simultaneously processing a given input data block by utilizing task multiplexing on a single central processor, via dedicated hardware, by executing on a plurality of processor or dedicated hardware systems, or any combination thereof). In addition, encoders **E1** through En may operate sequentially on a given unbuffered or buffered input data block. This process is intended to eliminate the complexity and additional processing overhead associated with multiplexing concurrent encoding techniques on a single central processor and/or dedicated hardware, set of central processors and/or dedicated hardware, or any achievable combination. It is to be further appreciated that encoders of the identical type may be applied in parallel to enhance encoding speed. For instance, encoder **E1** may comprise two parallel Huffman encoders for parallel processing of an input data block.

A buffer/counter module **30** is operatively connected to the encoder module **25** for buffering and counting the size of each of the encoded data blocks output from encoder module **25**. Specifically, the buffer/counter **30** comprises a plurality of buffer/counters **BC1**, **BC2**, **BC3** . . . BCn, each operatively associated with a corresponding one of the encoders **E1** . . . En. A compression ratio module **35**, operatively connected to the output buffer/counter **30**, determines the compression ratio obtained for each of the enabled encoders **E1** . . . En by taking the ratio of the size of the input data block to the size of the output data block stored in the corresponding buffer/counters **BC1** . . . BCn. In addition, the compression ratio module **35** compares each compression ratio with an a priori-specified compression ratio threshold limit to determine if at least one of the encoded data blocks output from the enabled encoders **E1** . . . En achieves a compression that exceeds an a priori-specified threshold. As is understood by those skilled in the art, the threshold limit may be specified as any value inclusive of data expansion, no data compression or expansion, or any arbitrarily desired compression limit. A description module **38**, operatively coupled to the compression ratio module **35**, appends a corresponding compression type descriptor to each encoded data block which is selected for output so as to indicate the type of compression format of the encoded data block. A data compression type descriptor is defined as any recognizable data token or descriptor that indicates which data encoding technique has been applied to the data. It is to be understood that, since encoders of the identical type may be applied in parallel to enhance encoding speed (as discussed above), the data compression type descriptor identifies the corresponding encoding technique applied to the encoded data block, not necessarily the specific encoder. The encoded data block having the greatest compression ratio along with its corresponding data compression type descriptor is then output for subsequent data processing, storage, or transmittal. If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit, then the original unencoded input data block is selected for output and a null data compression type descriptor is appended thereto. A null data compression type descriptor is defined as any recognizable data token or descriptor that indicates no data encoding has been applied to the input data block. Accordingly, the unencoded input data block with its corresponding null data compression type descriptor is then output for subsequent data processing, storage, or transmittal.

The data storage acceleration device **10** is connected to a data storage device interface **40**. The function of the data storage interface **40** is to facilitate the formatting and transfer of data to one or more data storage devices **45**. The data storage interface may be any of the data interfaces known to those skilled in the art such as SCSI (Small Computer Systems Interface), Fibre Channel, "Firewire", IEEE P1394, SSA (Serial Storage Architecture), IDE (Integrated Disk Electronics), and ATA/ATAPI interfaces. It should be noted that the storage device data interface **40** is not required for implementing the present invention. As before, the data storage device **45** may be any form of memory device including all forms of sequential, pseudo-random, and random access storage devices. The data storage device **45** may be volatile or non-volatile in nature, or any combination thereof. Storage devices as known within the current art include all forms of random access memory (RAM), magnetic and optical tape, magnetic and optical disks, along with various other forms of solid-state mass storage devices (e.g., ATA/ATAPI IDE disk). Thus it should be noted that the current invention applies to all forms and manners of memory devices including, but not limited to, storage devices utilizing magnetic, optical, and chemical techniques, or any combination thereof.

Again, it is to be understood that the embodiment of the data storage accelerator **10** of FIG. **8** is exemplary of a preferred compression system which may be implemented in the present invention, and that other compression systems and methods known to those skilled in the art may be employed for providing accelerated data storage in accordance with the teachings herein. Indeed, in another embodiment of the compression system disclosed in the above-incorporated U.S. Ser. No. 09/210,491, a timer is included to measure the time elapsed during the encoding process against an a priori-specified time limit. When the time limit expires, only the data output from those encoders (in the encoder module **25**) that have completed the present encoding cycle are compared to determine the encoded data with the highest compression ratio. The time limit ensures that the real-time or pseudo real-time nature of the data encoding is preserved. In addition, the results from each encoder in the encoder module **25** may be buffered to allow additional encoders to be sequentially applied to the output of the previous encoder, yielding a more optimal lossless data compression ratio. Such techniques are discussed in greater detail in the above-incorporated U.S. Ser. No. 09/210,491.

Referring now to FIG. **9**, a detailed block diagram illustrates a preferred system for accelerated data retrieval employing a decompression system as disclosed in the above-incorporated U.S. Ser. No. 09/210,491. In this embodiment, the data retrieval accelerator **80** retrieves or otherwise accepts data blocks from one or more data storage devices **45** and inputs the data via a data storage interface **50**. It is to be understood that the system processes the input data stream in data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the input data block size may be fixed or variable. As stated above, the memory storage device **45** may be volatile or non-volatile in nature, or any combination thereof. Storage devices as known within the current art include all forms of random access memory, magnetic and optical tape, magnetic and optical disks, along with various other forms of solid-state mass storage devices. Thus it should be noted that the current invention applies to all forms and manners of memory devices including storage devices utilizing magnetic, optical, and chemical techniques, or any combination thereof. The data storage device interface **50** converts the input data from the storage device format to a format useful for data decompression.

The storage device data interface **50** is operatively connected to the data retrieval accelerator **80** which is utilized for decoding the stored (compressed) data, thus providing accelerated retrieval of stored data. In this embodiment, the data retrieval accelerator **80** comprises an input buffer **55** which receives as input an uncompressed or compressed data stream comprising one or more data blocks. The data blocks may range in size from individual bits through complete files or collections of multiple files. Additionally, the data block size may be fixed or variable. The input data buffer **55** is preferably included (not required) to provide storage of input data for various hardware implementations. A descriptor extraction module **60** receives the buffered (or unbuffered) input data block and then parses, lexically, syntactically, or otherwise analyzes the input data block using methods known by those skilled in the art to extract the data compression type descriptor associated with the data block. The data compression type descriptor may possess values corresponding to null (no encoding applied), a single applied encoding technique, or multiple encoding techniques applied in a specific or random order (in accordance with the data compression system embodiments and methods discussed above).

A decoder module **65** includes one or more decoders **D1** . . . Dn for decoding the input data block using a decoder, set of decoders, or a sequential set of decoders corresponding to the extracted compression type descriptor. The decoders D1 . . . Dn may include those lossless encoding techniques currently well known within the art, including: run length, Huffman, Lempel-Ziv Dictionary Compression, arithmetic coding, data compaction, and data null suppression. Decoding techniques are selected based upon their ability to effectively decode the various different types of encoded input data generated by the data compression systems described above or originating from any other desired source.

As with the data compression systems discussed in U.S. application Ser. No. 09/210,491, the decoder module **65** may include multiple decoders of the same type applied in parallel so as to reduce the data decoding time. The data retrieval accelerator **80** also includes an output data buffer or cache **70** for buffering the decoded data block output from the decoder module **65**. The output buffer **70** then provides data to the output data stream. It is to be appreciated by those skilled in the art that the data retrieval accelerator **80** may also include an input data counter and output data counter operatively coupled to the input and output, respectively, of the decoder module **65**. In this manner, the compressed and corresponding decompressed data block may be counted to ensure that sufficient decompression is obtained for the input data block.

Again, it is to be understood that the embodiment of the data retrieval accelerator **80** of FIG. **9** is exemplary of a preferred decompression system and method which may be implemented in the present invention, and that other data decompression systems and methods known to those skilled in the art may be employed for providing accelerated data retrieval in accordance with the teachings herein.

In accordance with another aspect of the present invention, the data storage and retrieval accelerator system and method may be employed in for increasing the storage rate of video data. In particular, referring now to FIG. **10**, a block diagram illustrates a system for providing accelerated video data storage in accordance with one embodiment of the present invention. The video data storage acceleration system accepts as input one or more video data streams that are analog, digital, or any combination thereof in nature. The input multiplexer **1010** selects the initial video data stream for data compression and acceleration. The input multiplexer **1010** is operatively connected to an analog to digital converter **1020** which converts analog video inputs to digital format of desired resolution. The analog to digital converter **1020** may also include functions to strip video data synchronization to perform other data formatting functions. It should be noted that the analog to digital conversion process is not required for digital video inputs. The analog to digital converter **1020** is operatively connected a video memory **1030** that is, in turn, operatively connected to a video processor **1040**. The video processor **1040** performs manipulation of the digital video data in accordance with any user desired processing functions. The video processor **1040** is operatively coupled to a video output memory **1050**, that is operatively connected to a data storage accelerator **10** which compresses the video data to provide accelerated video data to the output data stream for subsequent data processing, storage, or transmittal of the video data. This video data acceleration process is repeated for all data blocks in the input data stream. If more video data blocks are available in the input data stream, the video multiplexer selects the next block of video for accelerated processing. Again, it is to be understood that the data storage accelerator **10** may employ any compression system which is capable of compressing data at a rate suitable for providing accelerated video data storage in accordance with the teachings herein.

In accordance with another aspect of the present invention, the accelerated data storage and retrieval system may be employed in a display controller to reduce the time required to send display data to a display controller or processor. In particular, referring now to FIG. **11**, a block diagram illustrates a display accelerator system in accordance with one embodiment of the present invention. The video display accelerator accepts as input one or more digital display data blocks from an input display data stream. It is to be understood that the system processes the input data stream in data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the input video data block size may be fixed or variable. The input data blocks are processed by a data retrieval accelerator **80** which employs a data decompression system in accordance with the teachings herein. Upon completion of data decompression, the decompressed data block is then output to a display memory **1110** that provides data to a display processor **1120**. The display processor **1120** performs any user desired processing function. It is well known within the current art that display data is often provided in one or more symbolic formats such as Open Graphics Language (Open GL) or another display or image language. The display processor **1120** is operatively connected an output memory buffer **1130**. The output memory **1130** supplies data to a display formatter **1140** that converts the data to a format compatible with the output display device or devices. Data from the display formatter **1140** is provided to the display driver **1150** that outputs data in appropriate format and drive signal levels to one or more display devices. It should be noted that the display memory **1110**, display processor **1120**, output memory **1130**, display formatter **1140**, and display driver **1150** are not required elements of the present invention.

In accordance with yet another aspect of the present invention, the data storage and retrieval accelerator system and method may be employed in an I/O controller to reduce the time for storing, retrieving or transmitting parallel data streams. In particular, referring now to FIG. **12**, a block diagram illustrates a system for accelerated data storage of analog, digital, and serial data in accordance with one embodiment of the present invention. The data storage accelerator **10** is capable of accepting one or more simultaneous analog, parallel digital, and serial data inputs. An analog input multiplexer **1205** selects the initial analog data for data compression and acceleration. The analog input multiplexer **1205** is operatively connected to an analog to digital converter **1210** that converts the analog input signal to digital data of the desired resolution. The digitized data output of the analog to digital converter **1210** is stored in an analog data memory buffer **1215** for subsequent data storage acceleration. Similarly, a parallel digital data input multiplexer **1220** selects the initial parallel digital data for data compression and acceleration. The parallel digital data input multiplexer **1220** is operatively connected to an input data latch **1225** that holds the input parallel digital data. The parallel digital data is then stored in digital data memory buffer **1245** for subsequent data storage acceleration. In addition, a serial digital data input multiplexer **1235** selects the initial serial digital data for data compression and acceleration. The serial digital data input multiplexer **1235** is operatively connected to a serial data interface **1240** that converts the serial data stream to a format useful for data acceleration. The formatted serial digital data is then stored in serial data memory buffer **1245** for subsequent data acceleration. The analog data memory **1215**, parallel digital data memory **1230**, and serial data memory **1245** are operatively connected to the data storage accelerator device **10**. Data is selected from each data memory subsystem based upon a user defined algorithm or other selection criteria. It should be noted that the analog input multiplexer **1205**, analog to digital converter **1210**, analog data memory **1215**, parallel data input multiplexer **1220**, data latch **1225**, digital data memory **1230**, serial data input multiplexer **1235**, serial data interface **1240**, serial data memory **1245**, and counter **20** are not required elements of the present invention. As stated above, the data storage accelerator **10** employs any of the data compression methods disclosed in the above-incorporated U.S. Ser. No. 09/210,491, or any conventional data compression method suitable for compressing data at a rate necessary for obtaining accelerated data storage. The data storage accelerator supplies accelerated data to the output data stream for subsequent data processing, storage, or transmittal.

Referring now to FIG. **13**, a flow diagram illustrates a method for accelerated data storage of analog, digital, and serial data according to one aspect of the present invention. The analog input multiplexer selects the initial analog data for data compression and acceleration (step **1300**). The analog input multiplexer provides analog data to the analog to digital converter that converts the analog input signal to digital data of the desired resolution (step **1302**). The digitized data output of the analog to digital converter is then buffered in the analog data memory buffer (step **1304**) for subsequent data acceleration. Similarly, the parallel digital data multiplexer selects the initial parallel digital data for data compression and acceleration (step **1306**). The parallel digital data multiplexer provides data to the input data latch that then holds the input parallel digital data (step **1308**). The parallel digital data is then stored in digital data memory buffer for subsequent data acceleration (step **1310**). The serial digital data input multiplexer selects the initial serial digital data for data compression and acceleration (step **1312**). The serial digital data input multiplexer provides serial data to the serial data interface that converts the serial data stream to a format useful for data acceleration (step **1314**). The formatted serial digital data is then stored in the serial data memory buffer for subsequent data acceleration (step **1316**). A test or other check is performed to see if new analog data is available (step **1318**). If no new analog data is available a second check is performed to see if new parallel data is available (step **1320**). If no new parallel data is available, a third test is performed to see if new serial data is available (step **1322**). If no new serial data is available (step **1322**) the test sequence repeats with the test for new analog data (step **1318**). If new analog data block is available (step **1318**), or if new parallel data block is available (step **1320**), or if new serial data block is available (step **1322**), the input data block is compressed by the data storage accelerator (step **1324**) utilizing any compression method suitable for providing accelerated data storage in accordance with the teachings herein. After data compression is complete, the compressed data block is then output subsequent accelerated data processing, storage, or transmittal (step **1326**). After outputting data the process repeats beginning with a test for new analog data (return to step **1318**).

Referring now to FIG. **14**, a block diagram illustrates a system for accelerated retrieval of analog, digital, and serial data in accordance with one embodiment of the present invention. A data retrieval accelerator **80** receives data from an input data stream. It is to be understood that the system processes the input data stream in data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the input data block size may be fixed or variable. The data retrieval accelerator **80** decompresses the input data utilizing any of the decompression methods suitable for providing accelerated data retrieval in accordance with the teachings herein. The data retrieval accelerator **80** is operatively connected to analog data memory **1405**, digital data memory **1420**, and serial data memory **1435**. Dependent upon the type of input data block, the decoded data block is stored in the appropriate analog **1405**, digital **1420**, or serial **1435** data memory.

The analog data memory **1405** is operatively connected to a digital to analog converter **1410** that converts the decompressed digital data block into an analog signal. The digital to analog converter **1410** is further operatively connected to an analog hold and output driver **1415**. The analog hold and output driver **1415** demultiplexes the analog signal output from the digital to analog converter **1410**, samples and holds the analog data, and buffers the output analog data.

In a similar manner, the digital data memory **1420** is operatively connected to a digital data demultiplexer **1425** that routes the decompressed parallel digital data to the output data latch and driver **1430**. The output latch and driver **1430** holds the digital data and buffers the parallel digital output.

Likewise, the serial data memory **1435** is operatively connected to a serial data interface **1440** that converts the decompressed data block to an output serial data stream. The serial data interface **1440** is further operatively connected to the serial demultiplexer and driver **1445** that routes the serial digital data to the appropriate output and buffers the serial data output.

Referring now to FIGS. **15***a* and **15***b*, a flow diagram illustrates a method for accelerated retrieval of analog, digital, and serial data according to one aspect of the present invention. An initial data block is received (step **1500**) and then decompressed by the data storage retrieval accelerator (step **1502**). Upon completion of data decompression, a test or other check is performed to see if the data block is digitized analog data (step **1508**). If the data block is not digitized analog data, a second check is performed to see if the data block is parallel digital data (step **1510**). If the data block is not parallel digital data, a third test is performed to see if the data block serial data (step **1512**). The result of at least one of the three tests will be affirmative.

If the data block is comprised of digitized analog data, the decoded data block is buffered in an "analog" digital data memory (step **1514**). The decoded data block is then converted to an analog signal by a digital to analog converter (step **1520**). The analog signal is then output (step **1522**).

If the data block is comprised of parallel digital data, the decoded data block is buffered in a "parallel" digital data memory (step **1516**). The decoded data block is then demultiplexed (step **1524**) and routed to the appropriate the output data latch and driver. The output latch and driver then holds the digital data and buffers the parallel digital output (step **1526**).

If the data block is comprised of serial data, the decoded data block is buffered in "serial" digital data memory (step **1518**). The decoded data is then formatted to a serial data format (step **1528**). The serial data is then demultiplexed, routed to the appropriate output, and output to a buffer (step **1530**).

Upon output of analog data (step **1522**), parallel digital data (step **1526**), or serial digital data (step **1530**), a test or other form of check is performed for more data blocks in the input stream (step **1532**). If no more data blocks are available, the test repeats (return to step **1532**). If a data block is available, the next data block is received (step **1534**) and the process repeats beginning with step **1502**.

Although illustrative embodiments have been described herein with reference to the accompanying drawings, it is to be understood that the present invention is not limited to those precise embodiments, and that various other changes and modifications may be affected therein by one skilled in the art without departing from the scope or spirit of the invention. All such changes and modifications are intended to be included within the scope of the invention as defined by the appended claims.

What is claimed is:

1. A program storage device readable by machine, tangibly embodying a program of instructions executable by the machine to perform method steps for providing accelerated data storage and retrieval, said method steps comprising:

receiving a data stream at an input data transmission rate which is greater than a data storage rate of a target storage device;

compressing the data stream at a compression rate that increases the effective data storage rate of the data storage device; and

storing the compressed data stream in the target storage device.

2. The program storage device of claim **1**, wherein the compression rate is at least equal to the ratio of the input data transmission rate to the data storage rate so as to provide continuous storage of the input data stream at the input data transmission rate.

3. The program storage device of claim **1**, further including instructions for performing the steps of:

determining the input data transmission rate and the data compression rate;

comparing the input data transmission rate, the data compression rate and the data storage rate to determine if they are compatible; and

adjusting one or more parameters to obtain compatibility between the input data transmission rate, the data compression rate and the data storage rate, if they are determined to be incompatible.

4. The program storage device of claim 3, wherein the instructions for performing the adjusting step include instructions for performing one of adjusting the input data transmission rate, adjusting the compression rate and a combination thereof.

5. The program storage device of claim 4, wherein the instructions for performing the adjusting step further include instructions for temporarily buffering one of the input data stream, the compressed data stream, and a combination thereof.

6. The program storage device of claim 1, further including instructions for performing the steps of:

retrieving the compressed data stream from the target storage device at a rate equal to a data access rate of the target storage device; and

decompressing the compressed data at a decompression rate that increases the effective data access rate of the target storage device.

7. The program storage device of claim 6, wherein the decompression rate is equal to the ratio of the data access rate to the input data transmission rate so as to obtain an output data transmission rate which is equal to the input data transmission rate.

8. The program storage device of claim 6, wherein the decompression rate is equal to or greater than the ratio of the data access rate to a maximum accepted output data transmission.

9. The program storage device of claim 6, further including instructions for performing the steps of:

determining the data retrieval rate and the data decompression rate;

comparing the data retrieval rate, the data decompression rate and the output data transmission rate to determine if they are compatible; and

adjusting one or more parameters to obtain compatibility between the data retrieval rate, the data decompression rate and the output data transmission rate if they are determined to be incompatible.

10. The program storage device of claim 9, wherein the instructions for performing the adjusting step include instructions for performing one of adjusting the data retrieval rate, adjusting the decompression ratio, and a combination thereof.

11. The program storage device of claim 9, wherein the instructions for performing the adjusting step include instructions for temporarily buffering one of the retrieved data stream, the decompressed data stream, and a combination thereof.

12. The program storage device of claim 1, wherein the instructions for performing the step of compressing comprise instructions for performing lossless compression.

13. A system for accelerating the rate of data storage and retrieval of a data storage device, comprising:

means for receiving a data stream having an input data transmission rate which is greater than a data storage rate of the data storage device;

means for compressing the data stream at a compression rate that increases the effective data storage rate of the data storage device; and

means for storing the compressed data stream in the data storage device.

14. The system of claim 13, wherein the compression rate is at least equal to the ratio of the input data transmission rate to the data storage rate so as to provide continuous storage of the input data stream at the input data transmission rate.

15. The system of claim 13, further comprising:

means for receiving the compressed data stream from the storage device at a rate equal to a data access rate of the storage device; and

means for decompressing the compressed data at a decompression rate that increases the effective data access rate of the storage device.

16. The system of claim 15, wherein the decompression rate is equal to the ratio of the data access rate to the input data transmission rate so as to obtain an output data transmission rate which is equal to the input data transmission rate.

17. The system of claim 13, wherein the data storage device is random access memory (RAM) device.

18. The system of claim 13, wherein the data storage device is one of a magnetic disk mass storage device, an optical mass storage device, a chemical mass storage device, and a combination thereof.

19. The system of claim 15, further including a data storage interface device for converting the compressed data stream to a format suitable for storage in the storage device and for converting the stored compressed data to a format suitable for decompression.

20. The system of claim 13, wherein the input data stream is a video data stream received from a video data processing system operatively connected to the receiving means.

21. The system of claim 15, further including a display controller system operatively connected to the decompression means, wherein the output data stream comprises a video data stream for processing by the display controller system.

22. The system of claim 13, further including an input/output controller system having a plurality of input/output ports, operatively connected to the compression means, wherein the input data stream comprises one of serial digital data, parallel digital data, analog data, and a selected combination thereof.

23. The system of claim 15, further including an input/output controller system having a plurality of input/output ports, operatively connected to the decompression means, wherein the output data stream comprises one of serial digital data, parallel digital data, analog data, and a selected combination thereof.

24. The system of claim 13, wherein the means for compressing comprises means for performing lossless compression.

25. A method for providing accelerated data storage and retrieval, comprising the steps of:

receiving a data stream at an input data transmission rate which is greater than a data storage rate of a target storage device;

compressing the data stream at a compression rate that increases the effective data storage rate of the data storage device; and

storing the compressed data stream in the target storage device.

26. The method of claim 25, wherein the compression rate is at least equal to the ratio of the input data transmission rate to the data storage rate so as to provide continuous storage of the input data stream at the input data transmission rate.

27. The method of claim 25, further including the steps of:

determining the input data transmission rate and the data compression rate;

comparing the input data transmission rate, the data compression rate and the data storage rate to determine if they are compatible; and adjusting one or more parameters to obtain compatibility between the input data transmission rate, the data compression rate and the data storage rate, if they are determined to be incompatible.

28. The method of claim **27**, wherein the adjusting step includes one of adjusting the input data transmission rate, adjusting the compression rate, and a combination thereof.

29. The method of claim **27**, wherein the adjusting step includes temporarily buffering one of the input data stream, the compressed data stream, and a combination thereof.

30. The method of claim **25**, further including the steps of:

retrieving the compressed data stream from the target storage device at a rate equal to a data access rate of the target storage device; and

decompressing the compressed data at a decompression rate that increases the effective data access rate of the target storage device.

31. The method of claim **30**, wherein the decompression rate is equal to the ratio of the data access rate to the input data transmission rate so as to obtain an output data transmission rate which is equal to the input data transmission rate.

32. The method of claim **30**, wherein the decompression rate is equal to or greater than the ratio of the data access rate to a maximum accepted output data transmission rate so as to provide a continuous and optimal data output transmission rate.

33. The method of claim **30**, further including the steps of:

determining the data retrieval rate and the data decompression rate;

comparing the data retrieval rate, the data decompression rate and the output data transmission rate to determine if they are compatible; and

adjusting one or more parameters to obtain compatibility between the data retrieval rate, the data decompression rate and the output data transmission rate if they are determined to be incompatible.

34. The method of claim **33**, wherein the adjusting step includes one of adjusting the data retrieval rate, adjusting the decompression rate, and a combination thereof.

35. The method of claim **33**, wherein the adjusting step includes temporarily buffering one of the retrieved data stream, the decompressed data stream, and a combination thereof.

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US006601104C1

(12) EX PARTE REEXAMINATION CERTIFICATE (8871st)
United States Patent
Fallon

(10) Number: US 6,601,104 C1
(45) Certificate Issued: Feb. 28, 2012

(54) SYSTEM AND METHODS FOR ACCELERATED DATA STORAGE AND RETRIEVAL

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Reexamination Request:
No. 90/009,428, Apr. 7, 2009

Reexamination Certificate for:

Patent No.:	**6,601,104**
Issued:	**Jul. 29, 2003**
Appl. No.:	**09/266,394**
Filed:	**Mar. 11, 1999**

(51) **Int. Cl.**
G06F 13/00 (2006.01)
G06F 13/12 (2006.01)

(52) **U.S. Cl.** **709/231**
(58) **Field of Classification Search** .... None
See application file for complete search history.

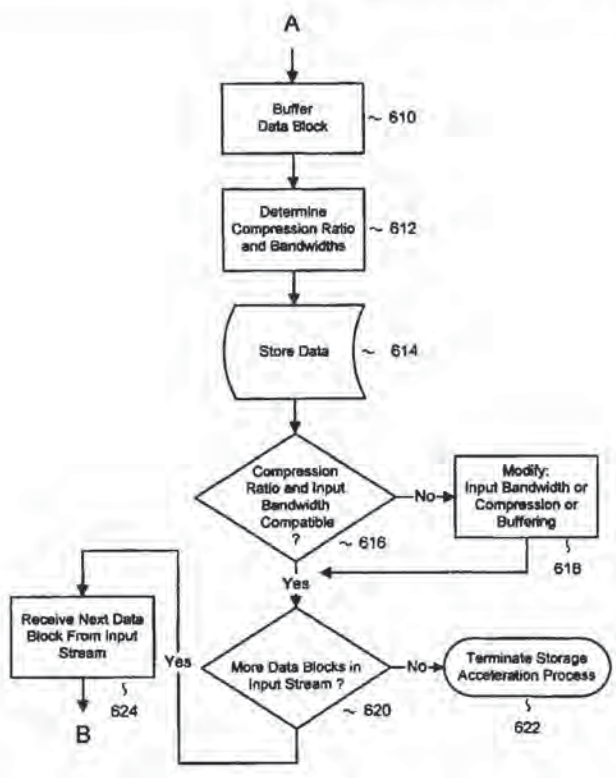
(56) **References Cited**

To view the complete listing of prior art documents cited during the proceeding for Reexamination Control Number 90/009,428, please refer to the USPTO's public Patent Application Information Retrieval (PAIR) system under the Display References tab.

Primary Examiner—Matthew Heneghan

(57) **ABSTRACT**

Systems and methods for providing accelerated data storage and retrieval utilizing lossless data compression and decompression. A data storage accelerator includes one or a plurality of high speed data compression encoders that are configured to simultaneously or sequentially losslessly compress data at a rate equivalent to or faster than the transmission rate of an input data stream. The compressed data is subsequently stored in a target memory or other storage device whose input data storage bandwidth is lower than the original input data stream bandwidth. Similarly, a data retrieval accelerator includes one or a plurality of high speed data decompression decoders that are configured to simultaneously or sequentially losslessly decompress data at a rate equivalent to or faster than the input data stream from the target memory or storage device. The decompressed data is then output at rate data that is greater than the output rate from the target memory or data storage device. The data storage and retrieval accelerator method and system may employed: in a disk storage adapter to reduce the time required to store and retrieve data from computer to disk; in conjunction with random access memory to reduce the time required to store and retrieve data from random access memory; in a display controller to reduce the time required to send display data to the display controller or processor; and/or in an input/output controller to reduce the time required to store, retrieve, or transmit data.



EX PARTE REEXAMINATION CERTIFICATE ISSUED UNDER 35 U.S.C. 307

THE PATENT IS HEREBY AMENDED AS INDICATED BELOW.

AS A RESULT OF REEXAMINATION, IT HAS BEEN DETERMINED THAT:

Claims **1**, **2**, **12**, **13**, **18**, **24** and **25** are cancelled.

Claims **3-11**, **14-17**, **19-23** and **26-35** were not reexamined.

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