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(54) **METHOD AND APPARATUS FOR IDENTIFYING A TRACK OF A ROTATING DISK USING EPR4 DATA EQUALIZATION AND DETECTION TECHNIQUES**

(75) Inventor: **Charles H. Sobey**, Plano, TX (US)

(73) Assignee: **Texas Instruments Incorporated**, Dallas, TX (US)

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(52) **U.S. Cl.** **360/49**; 360/65
(58) **Field of Search** 360/60, 46, 77.12, 360/75; 375/290, 291

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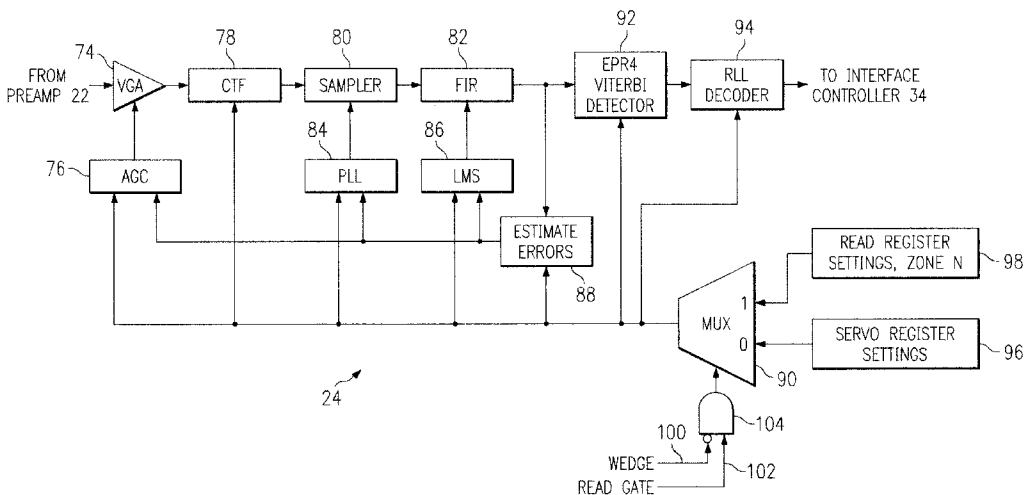
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Primary Examiner—David Hudspeth
Assistant Examiner—Glenda Rodriguez
(74) Attorney, Agent, or Firm—W. Daniel Swayze, Jr.; W. James Brady; Frederick J. Telecky, Jr.

(57) **ABSTRACT**

According to a broad aspect of the invention, a method and apparatus are presented for identifying a track (**42**) of a rotating disk (**12**) of a mass data storage device (**10**), using EPR4 data detection techniques. The track identification indicia (**64**) may be written more densely than the track identification indicia would have been written without using EPR4 data equalization techniques, wherein track identification indicia pulses (**110–113**) may at least partially overlap. The identification indicia (**110–113**) is read from the disk (**12**) using a read head (**18**), and processed using EPR4 data equalization techniques in an EPR4 Viterbi detector (**92**). The Viterbi detector (**92**) may be used also to detect data pulses (**64**) by switching its mode of operation from a track identification mode to a data detection mode.
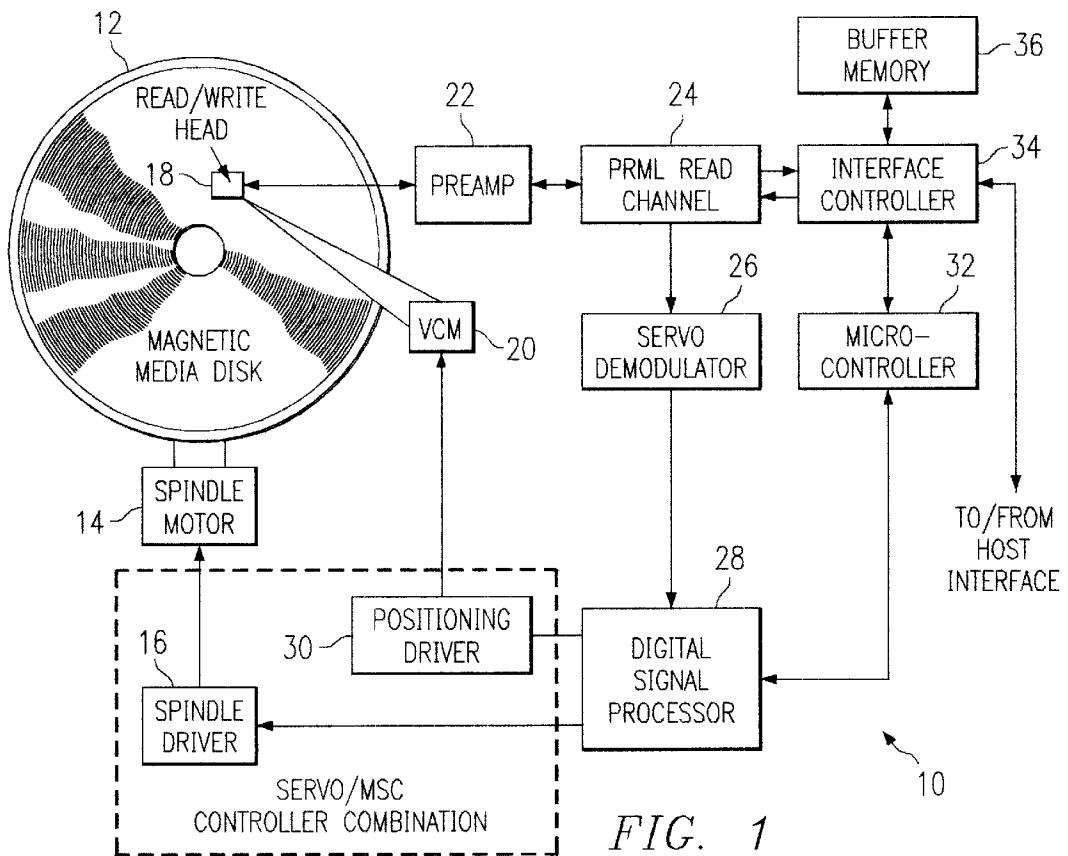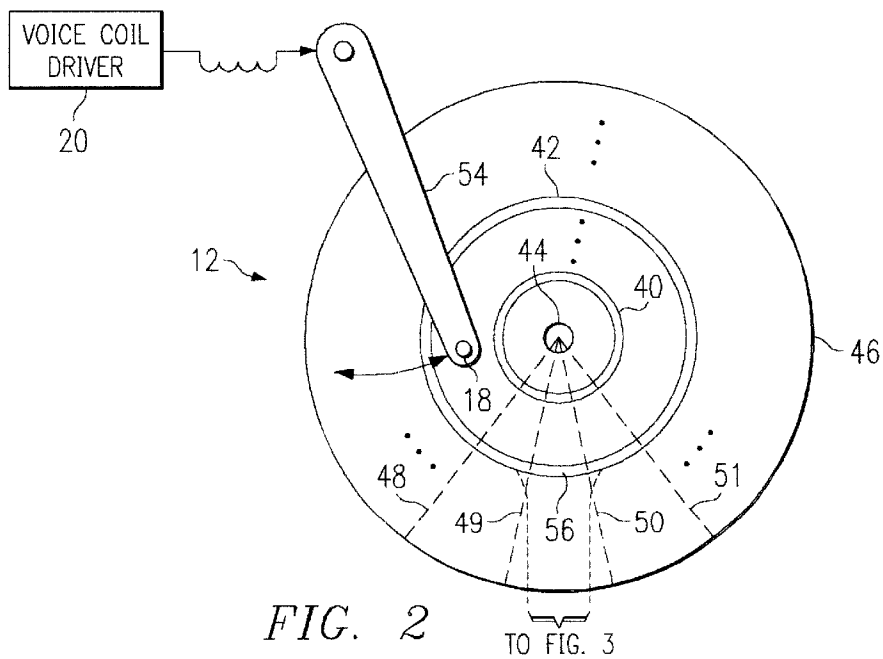
20 Claims, 8 Drawing Sheets

12

READ/WRITE
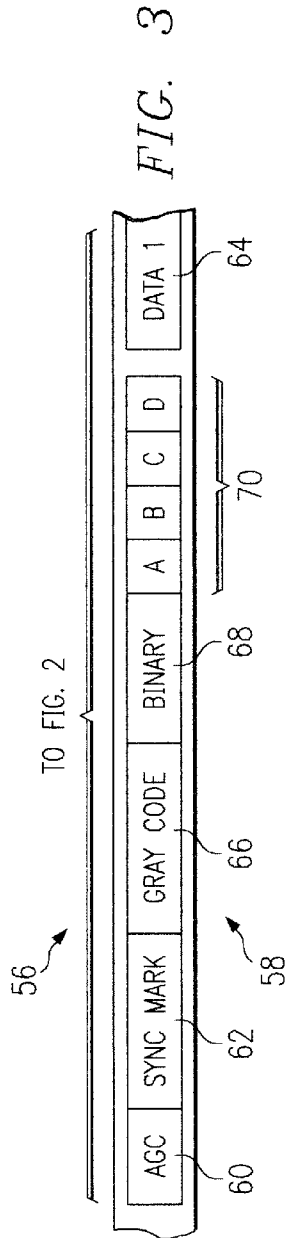HEAD

18

MAGNETIC
MEDIA DISK

VCM —20

14 — SPINDLE
MOTOR

22

PREAMP

24

PRML READ
CHANNEL

26

SERVO
DEMODULATOR

BUFFER
MEMORY —36

INTERFACE
CONTROLLER —34

32

MICRO-
CONTROLLER

TO/FROM
HOST
INTERFACE

30 — POSITIONING
DRIVER

16

SPINDLE
DRIVER

28

DIGITAL
SIGNAL
PROCESSOR

SERVO/MSC
CONTROLLER COMBINATION

10

FIG. 1

VOICE COIL
DRIVER

20

54

42

44

40

18

46

48

49

56

50

51

12

FIG. 2

TO FIG. 3

FIG. 3

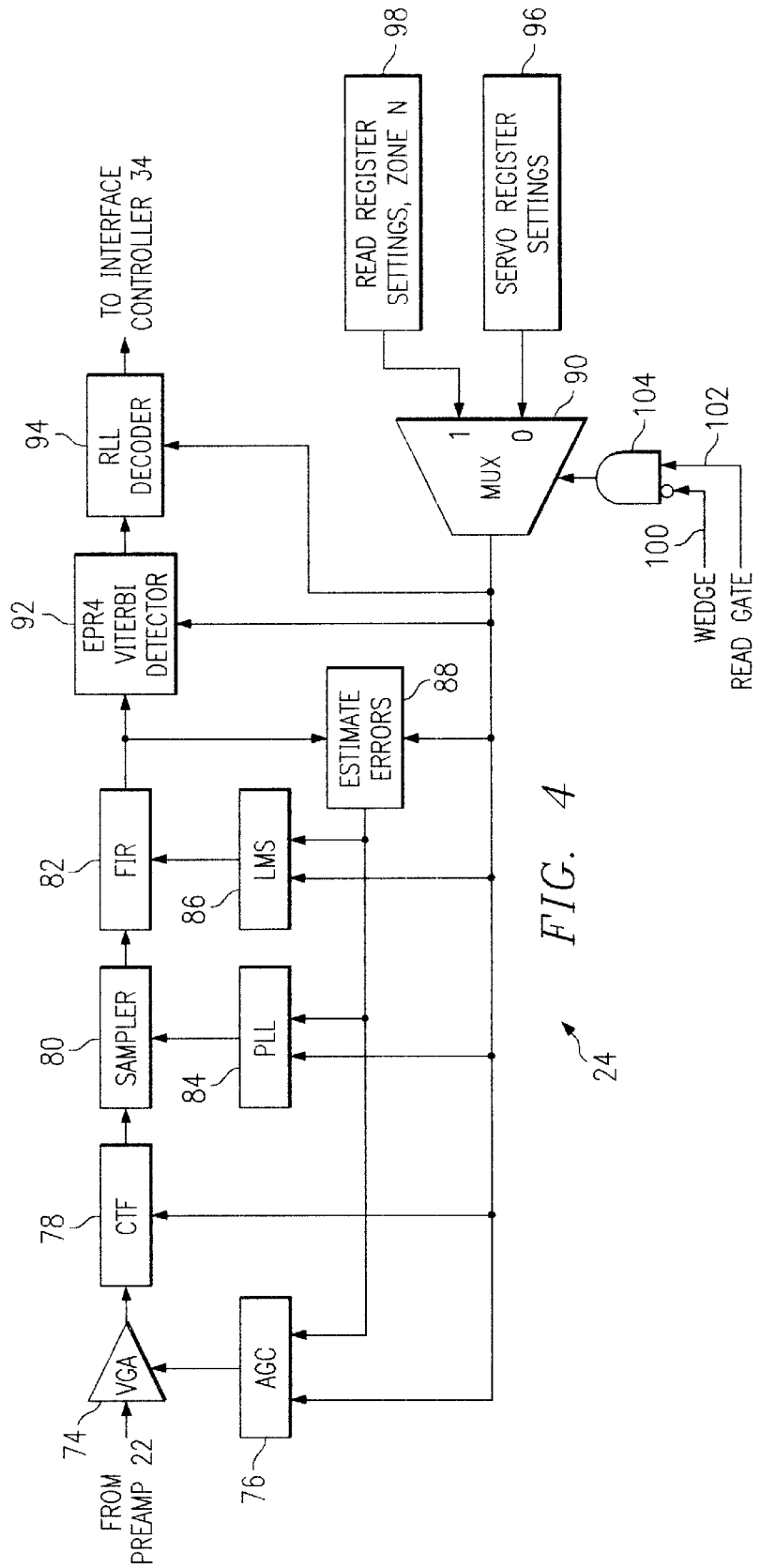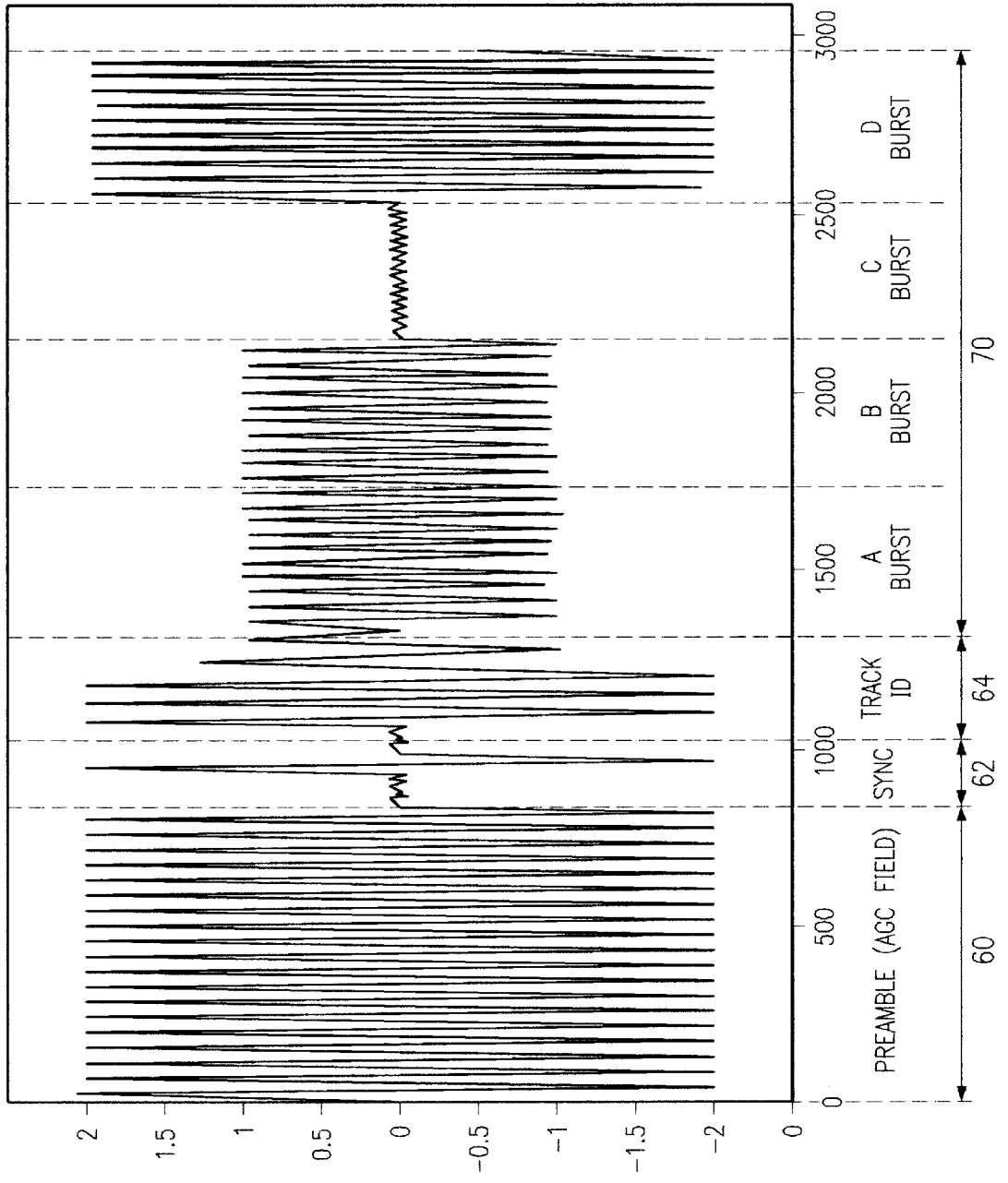| AGC	SYNC MARK	GRAY CODE	BINARY	A	B	C	D	DATA 1

60   62   66   68   70   64
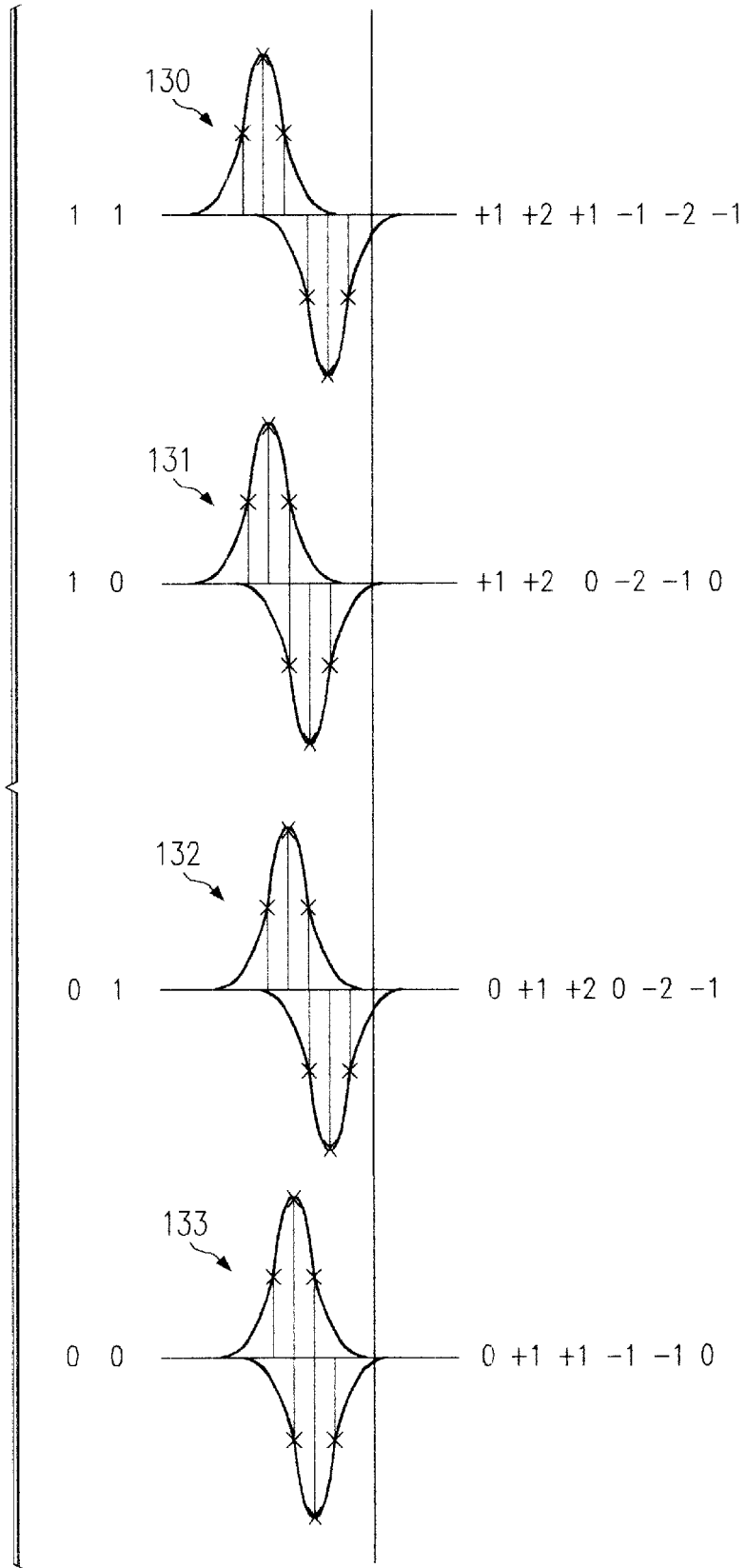
56   58

TO FIG. 2

FIG. 4

FIG. 5

FIG. 6

FIG. 7

FIG. 8

FIG. 9

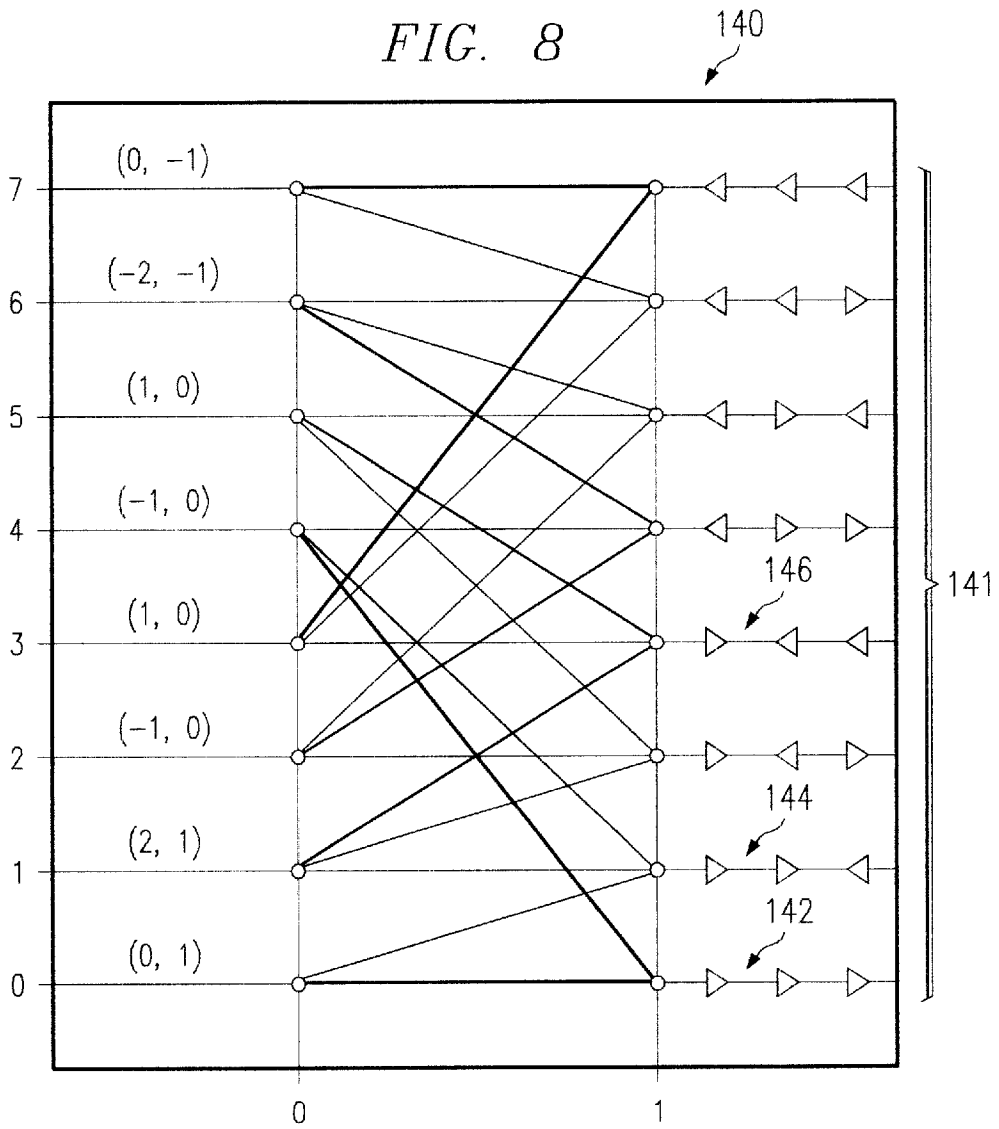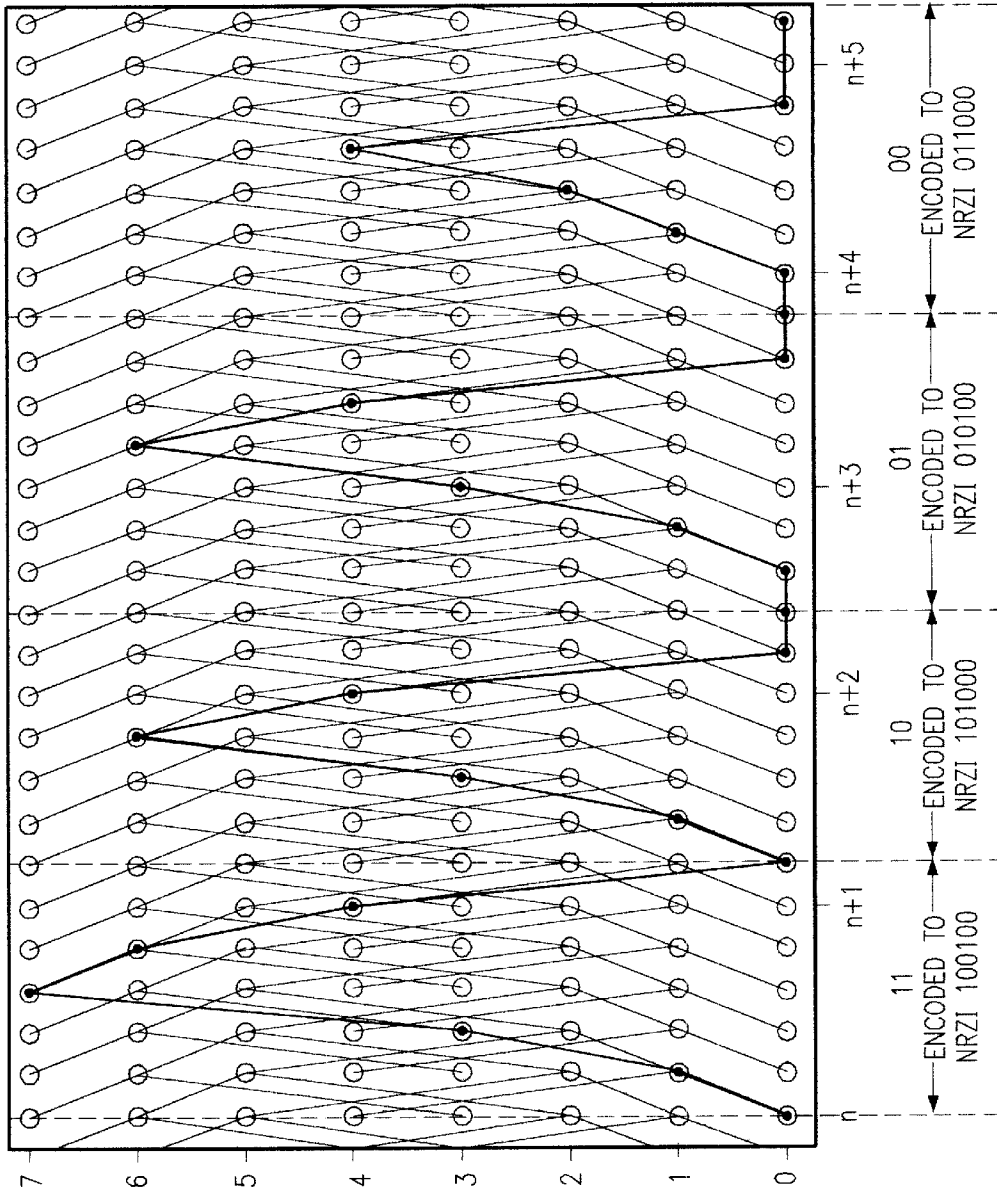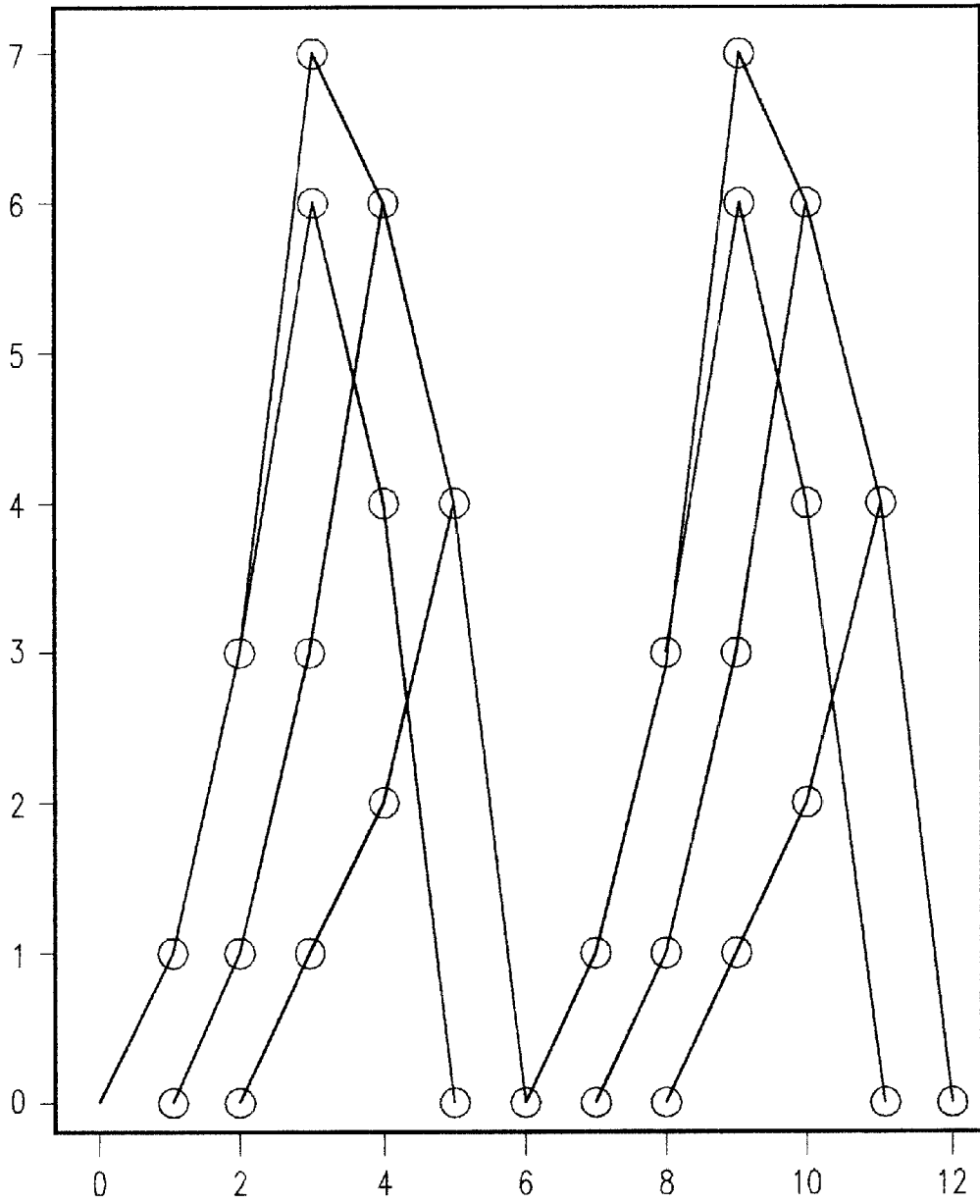*FIG. 10*

METHOD AND APPARATUS FOR IDENTIFYING A TRACK OF A ROTATING DISK USING EPR4 DATA EQUALIZATION AND DETECTION TECHNIQUES

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to improvements in mass data storage devices and methods for processing data in a read channel thereof, and more particularly to improvements in apparatuses and methods for detecting track identification indicia in accessing the data tracks of the device.

2. Relevant Background

Mass data storage devices include well known hard disk drives that have one or more spinning magnetic disks or platters onto which data is recorded for storage and subsequent retrieval. Hard disk drives may be used in many applications, including personal computers, set top boxes, video and television applications, audio applications, or some mix thereof. Many applications are still being developed. Applications for hard disk drives are increasing in number, and are expected to further increase in the future. Mass data storage devices may also include optical disks in which the optical properties of a spinning disk are locally varied to provide a reflectivity gradient that can be detected by a laser transducer head, or the like. Optical disks may be used, for example, to contain data, music, or other information.

In the past, typically the track identification pulses are well separated from each other to enable them to be properly detected. However, there has been considerable recent pressure on disk drive manufacturers to increase the density of the data written to a disk to increase the capacity of the drive. Much effort has been directed to data detection techniques to increase the density of the data that can be contained on the disk. For example, maximum likelihood sequence detection (MLSD) and partial response (PR) filtering techniques have been developed that allow adjacent data pulses to at least partially overlap and still be properly detected. Moreover, EPR4 filtering techniques and Viterbi algorithms have been developed that efficiently implement MLSD and enable the data to be written more closely.

However, to the best of my knowledge, such EPR4 techniques have not been applied to the detection of track identification information.

BRIEF DESCRIPTION OF THE DRAWINGS

A preferred embodiment of the invention is shown in the accompanying drawings, in which:

FIG. 1 is a block diagram of a disk drive system, illustrating the environment in which the invention may be practiced.

FIG. 2 is a diagram showing a typical arrangement of selectable radial tracks of the disk of FIG. 1.

FIG. 3 is an expanded diagram showing a wedge portion of one of the rings or tracks within one of the tracks of FIG. 2, showing the various data areas therein.

FIG. 4 is a block diagram of the read channel of FIG. 1, showing an embodiment in which the Viterbi detector thereof is selectively switchable from a track identification mode to a data detection mode.

FIG. 5 is a graph showing the various signals of the wedge portion of FIG. 3.

FIG. 6 is a time-expanded view of the preamble, sync and track ID portions of the graph of FIG. 5.

FIG. 7 is a set of graphs showing dibit signals to which the track identification information may be encoded, to enable subsequent detection using EPR4 detection techniques, according to a preferred embodiment of the invention.

FIG. 8 is a state diagram of a particular EPR4 scheme for decoding the various NRZI track identification indicia combinations of FIG. 7, according to a preferred embodiment of the invention.

FIG. 9 is an NRZI trellis diagram that shows the detected paths that result from the decoding scheme of FIG. 8 for respective NRZI encoded data combinations, according to a preferred embodiment of the invention.

FIG. 10 is a diagram showing a time varying trellis structure for an eight-state EPR4 Viterbi detector, that can detect NRZI encoded track identification data combinations, with paths removed that do not correspond to valid coded di-bit sequences, according to another preferred embodiment of the invention.

In the various figures of the drawings, like reference numerals are used to denote like or similar parts.

SUMMARY OF THE INVENTION

According to a broad aspect of the invention, a method is presented for identifying a track of a rotating disk of a mass data storage device. The track identification indicia may be written more densely than the track identification indicia would have been written without using the EPR4 data equalization techniques, wherein track identification indicia pulses may at least partially overlap, for example to an extent beyond 30%, or more. The method includes reading track identification indicia recorded on the disk, and processing the read back track identification indicia using EPR4 data equalization techniques. Processing the detected track identification indicia may be performed using a Viterbi detector. The Viterbi may be used also to detect data pulses.

According to another broad aspect of the invention, a mass data storage device is presented. The track identification indicia of the device may partially overlap on a rotating disk of the device. The mass data storage device includes a read head selectively positionable to detect the track identification indicia and an EPR4 processor to process the detected track identification indicia. The EPR4 processor may be, for example, a Viterbi detector. The Viterbi detector may be configured, if desired, to include a trellis configured to detect only four possible basic data combinations or sub-sequences. The Viterbi may also be used, if desired, to detect data pulses.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 is a block diagram of a disk drive system 10, which represents the environment in which the invention may be practiced. The system includes a magnetic media disk 12 that is rotated by a spindle motor 14 and spindle driver circuit 16. A data transducer or head 18 is selectably radially locatable by a voice coil motor (VCM) 20 to track along circumferential tracks of the disk, illustrated in FIG. 2, described below.

The tracks may contain magnetic states that contain information about the tracks, such as track identification data, location information, synchronization data, as well as user data, and so forth. The head 28 may be used both to record user data to and read user data back from the disk 12.

The head **28** also may be used to detect signals that identify the tracks and sectors at which data is written, and to detect servo bursts that enable the head to be properly laterally aligned with the tracks of the disk, as below described.

Analog electrical signals that are generated by the head **18** and preamplifier **22** combination in response to the magnetic signals recorded on the disk **12**. These signals are preamplified for delivery to PRML (Partial Response Maximum Likelihood) read channel circuitry **24**, details of which are described below with reference to FIG. **4**. Servo signals, below described in detail, are detected and demodulated by one or more servo demodulator circuits **26** and processed by a digital signal processor (DSP) **28** to control the position of the head **18** via a positioning driver circuit **30**. The servo data that is read and processed may be analog data that is interpreted by the DSP **28** for positioning the head **18**.

A microcontroller **32** is typically provided to control the DSP **28**, as well as an interface controller **34** to enable data to be passed to and from a host interface (not shown) in known manner. A data memory **36** may be provided, if desired, to buffer data being written to and read from the disk **12**.

The data rings of the disk **12** of FIG. **1** are illustrated in FIG. **2**. The disk may be coated with a magnetic material to which data and other information are written in a number of concentrically located tracks or rings **40** . . . **42** . . . . The tracks typically contain user data sectors and servo sectors arranged in concentric cascading rings from the inside diameter **44** of the disk at the hub to the outside diameter **46** of the disk at the edge. Evenly spaced radial lines **48–51** are also shown emanating from the hub **44** to the edge **46**. (The lines **48–51** do not actually exist in a physical device, but are shown for purposes of illustrating the alignment of the fields of the tracks, as described below.) The lines **48–51** correspond to the location of the servo sectors at each respective intersection of the lines **48–51** with the rings **40** . . . **42**. . . . Generally, there are two or more data sectors per servo sector.

A servo sector exists at the junction of each of the radial lines and its respective track. It should be noted that servo sectors are written by the disk drive manufacturer by a device known as a servo writer. These servo sectors are never re-written, in normal drive operation.

The read/write head is positioned by an arm **54** that is pivotally attached to allow the read/write head **18** to be radially moved inwardly and outwardly to selected radial distances of the disk **12** to tracks **40** . . . **42** . . . identified by the desired track identification number. The radial position of the read/write head arm is controlled in a known manner by the "voice coil" motor **20** that receives positioning signals from the positioning driver circuit **30**.

The layout **56** of one of the rings or tracks within one of the sectors, is shown in FIG. **3**, details of which are shown in FIG. **5** below. The sector portion may be identical to other sector portions that repeat continuously around the ring, and includes a number of servo sectors that separate respective user data sector regions. Each user data sector region may include a number of data sectors.

More particularly, each track has one or more servo sectors **58** located at spaced locations along the track. Each servo sector **58** has a number of fields, each for providing information for location or control of the head. Typically, for example, each servo sector includes a field that contains a preamble field **60**, which, when read, enables AGC and timing circuitry associated with the disk to automatically adjust the gain in the head amplifiers and acquire the proper

timing to enable the following data to be properly detected. The preamble field also is used to ensure that the trellis of the Viterbi detector starts in the correct state. Typically following the preamble burst is a field **62** that contains one or more sync marks so that the longitudinal position of the head relative to the track of interest can be determined. The sync marks **62** may be used, for example, to enable subsequent fields, such as the user data sectors **64** to be located by counting a predetermined elapsed time from the time that the sync marks are detected.

A Gray code field **66** may follow the sync mark field **62** in the servo sector **58**. The Gray code field **66** may contain Gray code data from which the identification of the particular radial track over which the head is positioned can be established. Following the Gray code field **66** is a field **68** containing binary data, for example, to contain longitudinal track identification information, so that the identity of each track region between adjacent servo sectors can be established. The Gray code and the track identification information are referred to herein as "track identification pulses" or "track identification indicia." After the binary data field **68**, a number, typically four, of burst fields **70** are presented for more precision alignment of the head laterally with respect to the selected track.

According to a preferred embodiment of the invention, a method is presented for identifying a track of a rotating disk of a mass data storage device. The tracks of the disk are identified by track identification indicia that are written onto the disk during manufacture using standard servo writing apparatuses, and, according to the invention, may be written with at least some of said track identification indicia pulses at least partially overlapping.

The track identification indicia that are recorded on the disk are read using the read head. Since the track identification indicia may partially overlap, merely using an amplitude peak detector may not properly discern between adjacent indicia. Thus, the signals that are developed by the read head are processed using EPR4 data equalization techniques. The EPR4 data equalization techniques enable the partially overlapping signals to be separated and decoded.

Thus, to practice the method of the invention, the track identification indicia or pulses do not have to be specially coded. Instead, they are merely written closer together than heretofore permitted using peak detection schemes. The indicia may be decoded by a Viterbi detector, preferably the same Viterbi detector that is used to decode the data that is contained on the track. However, since the track identification information can be contained in only four possible basic data combinations or sub-sequences, the Viterbi can be configured in track identification operation to detect only the necessary four sub-sequences. If additional sequences are required in normal operation, additional trellis states can be employed in the Viterbi. Of course, the track identification indicia are typically encoded with a Gray code to facilitate track seek operation. This invention does not change this; that is, the track identification information may still be encoded as it was in the past, and recorded more densely on the disk.

To detect the track identification indicia, as well as the user data in the track being read, the read channel **24** may be configured in the manner shown in FIG. **4**, to which reference is now additionally made. A variable gain amplifier (VGA) **74** of the read channel **24** receives input signals from the preamplifier **22**, shown in FIG. **3**. The variable gain amplifier **74** is in a feedback circuit that includes an automatic gain control circuit (AGC) **76** to control the amplitude

of the detected signal to enable the remaining read channel circuitry to properly process it. The output from the VGA **74** is filtered, first with a continuous time filter (CTF) **78**, then after being sampled by a sampler circuit **80**, by a finite impulse response (FIR) filter **82**. The output of the FIR filter **82** is fed back to the AGC **76** to control the gain of the VGA **74**, but is also used to control the timing of the sampler **80** via phase locked loop circuit **84** and to control the coefficients of the FIR filter **82** via least means squared (LMS) adaptation circuit **86**. Those skilled in the art will appreciate that there are other possible arrangements of these blocks. A circuit **88**, denoted estimate errors, is used to modify the feedback signal in dependence upon the values produced at the output of the FIR filter **82** and the output of a multiplexer (MUX) **90**, as below described.

The output from the FIR filter **82** is detected by an EPR4 Viterbi detector **92**, details of which are also below described. The output from the EPR4 Viterbi detector **92** are then run-length-limited (RLL) decoded by an RLL decoder **94**, to deliver the read channel output to the interface controller **34** (FIG. **1**) and to the host (not shown).

According to one embodiment of the invention, the read channel circuitry of FIG. **4** can be switchably used to detect either the track identification indicia read from the disk **12** or the user data read therefrom. This is accomplished by the MUX **90**, which has as one input the servo register settings **96**, and which has another input the read register settings **98** for any particular zone, denoted "zone N". (A zone is a group of consecutive tracks that have the same data rate.) The output from the multiplexer controls the AGC **76**, PLL **84** and LMS **86** feedback elements, as well as the EPR4 Viterbi detector **82** and RLL decoder **94**. The selection between the servo register settings **96** and the read register settings **98** is controlled by whether a "wedge" signal **100** and a "read gate signal" **102** are applied to the MUX input via an AND gate **104**.

In operation, when the "wedge" signal **100** is not applied and the read gate signal **102** is applied, the read register settings are applied to the MUX **90** to configure the circuitry of the read channel **24** to read the data from the disk **12**, in normal fashion. On the other hand, when the "wedge" signal **100** is applied, the MUX **90** is configured to apply the servo register settings **96** to configure the read channel circuitry, and, in particular, the settings of the trellis of the Viterbi detector **92**, to read and detect the track identification indicia read from the disk **12**.

With reference now additionally to FIG. **5**, the waveforms of the various fields of a servo "wedge" are shown. The binary field **68** of FIG. **2** has been omitted, for clarity. (It is noted that in many applications, various ones of the wedge fields may be rearranged or omitted, depending upon the particular setup of the drive on which the fields are used.) The waveforms of FIG. **5** are shown with an expanded horizontal time scale in FIG. **6**, to which reference is now additionally made.

As mentioned, according to the invention, the waveforms of the track identification indicia **64** may be compressed and detected using EPR4 processing techniques. Thus, each of the NRZI (Non-Return-to-Zero Inverse) dibit encoded track indicia **110–113** are compressed from their normal width, indicated by vertical start time lines **115–118** to compressed time formats, shown by the respective stop time lines **122–125**. This may, of course, result in overlap of dibit information, as shown by the waveforms **130–133** of FIG. **7**, but which can nevertheless be discriminated and detected using EPR4 techniques. The waveforms **130–133** represent,

respectively, the four data sub-combinations "11", "10", "01", and "00". It can be seen that the sample values for the di-bit waveforms shown are respectively "+1+2+1−1−2−1", "+1+20−2−10", "0+1+20−2−1" and "0+1+1−1−10".

The construction of the EPR4 Viterbi detector **92** to be enabled to detect the track identification indicia includes the modification of a standard EPR4 Viterbi detector that can detect any possible binary sequence, can be modified to selectively detects only those subsequences that represent track identification information.

A state diagram **140** of a particular EPR4 scheme for decoding the various NRZI track identification indicia combinations of FIG. **7**, according to a preferred embodiment of the invention, is shown in FIG. **8**, to which reference is now additionally made. The magnetic domains that are written on the disk are represented by the arrows **141** on the right side of the diagram **140**. The arrows are directed either to the right or left, depending upon the manner in which the encoded data was originally written, in known manner, and the various domain orientations correspond to the various states of the diagram. The domains are decoded in sets of three, beginning with zero, and shifting to the right one position as each additional domain from the disk is read.

For example, if the track identification data combination of "11", which is represented by NRZI 100100, has been recorded on the disk, the manner by which it is decoded is as follows. The state diagram **140** starts in state **0**, in which the domain arrows **142** representing the history of the domains all point to the right. When the first domain of the NRZI sequence is read, it represents a domain change, corresponding the NRZI "1". Thus, the domain sequence becomes arrows **144** that now have the first two pointing right and the third pointing left. This corresponds to state **1**. The next magnetic domain that is read shows no change in direction. This is seen in the diagram by arrows **146**. No change in magnetic domain direction corresponds to an NRZI "0", and corresponds to state **3** in the diagram. This process is continued as the remaining magnetic domains are read and the NRZI code "100100" is decoded following the states of the state diagram **140**.

The sample values corresponding to each state transition are determined by the number pairs on the left side of the state diagram **140**. A zero NRZI value corresponds to the value on the left, and a one NRZI value corresponds to the value on the right. For example, following the decoded states of NRZI data representing a data combination "00", which is "011000", the sample values 0+1+1−1−10 result.

The state paths defined for each defined sequence are shown in the NRZI trellis diagram of FIG. **9**, to which reference is now additionally made. Thus, the Viterbi trellis paths are outlined by the basic data combinations or sequences of the four possible track identification indicia, namely, 11, 10, 01, and 00. The track identification indicia are NRZI encoded, respectively, to 100100, 101000, 010100, and 011000. Each of these indicia can be developed from the state diagram **140**, in the manner described above. As can be seen, state **0** is three magnets to the right (−1−1−1) and state **7** is three magnets to the left +1+1+1). Thus, the basic pairs of track identification information described above provide the basic building block from which an entire detector can be constructed. The four combinations correspond specifically to target value sequences.

FIG. **10**, to which reference is now additionally made, is a diagram showing a time varying trellis structure for an eight-state EPR4 Viterbi detector, which can optionally be implemented to detect NRZI encoded track identification

data combinations. The shapes of the various possible paths will be recognized to correspond to the shapes of the basic data combinations "11", "10", "01" and "00" described above with respect to FIGS. 8 and 9. In the trellis structure of FIG. 10, the di-bit sequences or paths that do not correspond to valid coded di-bit sequences are removed. Every sixth bit is forced to go through state 0. Thus, the six-sample structure shown repeats every 6th bit throughout the track identification.

It will be appreciated that the EPR4 Viterbi detector used to detect track identification may be the same detector as used to detect data in normal operation. For example, in the trellis diagram of FIG. 9, all of the trellis states are present, and a Viterbi constructed to implement the trellis illustrated will detect the abbreviated track identification data as well. Preferably, however, the detector may be modified so that only the paths that will be encountered in the abbreviated track identification coding are used. This has a number of advantages; for example, in power savings, detection error reduction, and so forth.

The manner by which the EPR4 Viterbi detector may be switched to remove the unused paths in track identification mode preferably is by turning off the non-used paths of the Viterbi, or by adjusting the path weights of the Viterbi so that the non-allowed paths in a four-state embodiment do not occur. Of course, as will be apparent to those skilled in the art, other Viterbi trellis arrangements may be used.

It should be noted that although the invention has been described with specific reference to EPR4 techniques, it need not be limited strictly thereto. Thus, for example, the target values of EPR4 may have a 2:1 ratio between the absolute value of the smallest and largest non-zero sample values. However, a generalized target may also be used, which does not keep an integer relationship between the target values. For instance, a pulse defined over a fixed number of sample values, such as three, may be used. The sample values may be "A", "B", and "C". In EPR4, "A" may equal 1, "B" may equal 2, and "C" may equal 1. Moreover, the negative portion of the pulse may still have different values, for example, "D", "E" and "F", where "D", "E", and "F" may, but not necessarily equal "-A", "-B", and "-C". This is referred to herein as "generalized EPR4," or "generalized eight-state" trellis decoding.

Although the invention has been described and illustrated with a certain degree of particularity, it is understood that the present disclosure has been made only by way of example, and that numerous changes in the combination and arrangement of parts can be resorted to by those skilled in the art without departing from the spirit and scope of the invention, as hereinafter claimed.

What is claimed is:

1. A method for identifying a track of a rotating disk of a mass data storage device, comprising:

detecting track identification indicia recorded on said disk using a read head; and

processing said detected track identification indicia using a data equalization technique having at least three positive and three negative target values,

wherein said three positive target values are normalized to 1, 2, and 1, and said three negative target values are normalized to −1, −2, and −3.

2. The method of claim 1 wherein said processing said detected track identification indicia comprises processing said detected track identification indicia using a Viterbi detector.

3. A method for identifying a track of a rotating disk of a mass data storage device, comprising:

detecting track identification indicia recorded on said disk using a read head; and

processing said detected track identification indicia using a data equalization technique having at least three positive and three negative target values,

wherein said three positive target values are other than 1, 2, and 1, and said three negative target values are other than −1, −2, and −3.

4. A method for identifying a track of a rotating disk of a mass data storage device, comprising:

detecting track identification indicia recorded on said disk using a read head; and

processing said detected track identification Indicia using EPR4 data equalization techniques,

wherein said processing said detected track identification indicia comprises processing said detected track identification indicia using a Viterbi detector, and

wherein a trellis of said Viterbi detector is configured to detect only four possible information sequences.

5. The method of claim 4 wherein said Viterbi detector is also usable to detect data pulses.

6. The method of claim 5 herein said Viterbi detector is switchable to selectively detect either data pulses or track identification indicia.

7. The method of claim 5 wherein said Viterbi detector is time variable to include a repeating track identification trellis for detecting track identification indicia.

8. The method of claim 5 wherein said repeating track identification trellis has only allowed trellis states.

9. The method of claim 4 further comprising writing the track identification indicia more densely than said track identification indicia would have been written without using said EPR4 data equalization techniques.

10. The method of claim 4 further comprising writing the track identification indicia wherein track identification indicia pulses at least partially overlap.

11. The method of claim 9 wherein tracks of adjacent tracks are coded with a Gray code.

12. The method of claim 10 wherein tracks of adjacent tracks are coded with a Gray code.

13. A method for identifying a track of a rotating disk of a mass data storage device, comprising:

writing track identification indicia onto said disk with at least some of said track identification indicia pulses at least partially overlapping;

detecting said track identification indicia; and processing said detected track identification indicia using EPR4 data equalization techniques,

wherein said processing said detected track Identification Indicia comprises processing said detected track identification indicia using a Viterbi detector, and

wherein said Viterbi comprises a trellis configured to detect only four possible information sequences.

14. The method of claim 13 wherein said Viterbi detector is also usable to detect data pulses.

15. The method of claim 13 wherein tracks of adjacent tracks are coded with a Gray code.

16. The method of claim 14 wherein said Viterbi detector is switchable to selectively detect either detect data pulses or track identification indicia.

17. A mass data storage device, comprising:

partially overlapping track Identification indida on a rotating disk of said device;

a read head selectively positionable to detect said track identification indicia; and an EPR4 processor to process said detected track identification indicia,

wherein said EPR4 processor comprises a Viterbi detector which includes a trellis configured to detect only four possible information sequences.

18. The mass data storage device of claim **17** wherein said EPR4 processor is also used to detect data pulses.

19. The mass data storage device of claim **17** wherein tracks of adjacent tracks are coded with a Gray code.

20. The mass data storage device of claim **18** wherein said Viterbi detector is switchable to selectively detect either data pulses or track identification indicia.

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