(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
9 August 2007 (09.08.2007)

PCT

(10) International Publication Number
WO 2007/088139 A1

(51) International Patent Classification:
G11B 27/10 (2006.01) *G11B 20/10* (2006.01)

(21) International Application Number: PCT/EP2007/050772

(22) International Filing Date: 26 January 2007 (26.01.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
11/346,391 1 February 2006 (01.02.2006) US

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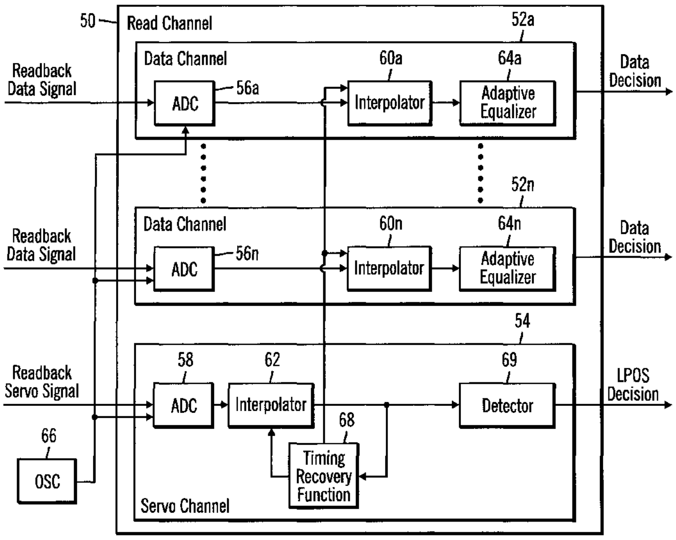
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH,

[Continued on next page]

(54) Title: USING AT LEAST ONE SERVO CHANNEL TO PROVIDE TIMING RECOVERY AND TIMING INFORMATION TO DATA CHANNELS



(57) Abstract: Provided is a read channel, storage drive, and method to process signals read from a storage medium. At least one data channel including an interpolator and equalizer and a servo channel includes an interpolator. A timing recovery function processes a timing error from the interpolator in the servo channel to calculate interpolation timing information used by the interpolator to interpolate a servo channel signal. A path is coupled to the timing recovery function and the interpolator in the at least one data channel to communicate the interpolation timing information to the interpolator in the at least one data channel. The interpolator in the at least one data channel is configured to use the interpolation timing information to interpolate an asynchronous data channel signal.

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GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

USING AT LEAST ONE SERVO CHANNEL TO PROVIDE TIMING RECOVERY AND TIMING INFORMATION TO DATA CHANNELS

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a system and device for using at least one servo channel to provide timing recovery and timing information to data channels.

Description of the Related Art

Magnetic tape cartridges include magnetic tape to store data to be saved and read back at a subsequent time. A magnetic tape drive writes the data to magnetic tape, typically as a set of parallel tracks, and subsequently a magnetic tape drive reads back the data. To read back the data, a magnetic tape drive typically comprises parallel read heads to read each of the parallel tracks, a drive system for moving a magnetic tape with respect to the read heads such that the read heads may detect magnetic signals on the magnetic tape, and a read channel for digitally sampling magnetic signals sensed by the read heads and providing digital samples of the magnetic signals sensed by the read heads. The digital samples are then decoded into data bits, and the data bits from the parallel tracks are combined to reproduce the data originally written on the storage medium. The read channel typically requires, among other signal processing functions, an equalizer for each of the read heads to compensate for the change in the signal characteristics due to the magnetic recording properties of the write head, the magnetic tape, and the read head. Magnetic tape cartridges may be interchanged between tape drives, such that a magnetic tape written on one tape drive will be read by another tape drive.

In recent years, the capacity and performance of tape storage systems has increased considerably, and the potential for further growth appears to be substantial. In order to achieve higher cartridge capacities and improved performance, advances in several technical areas are necessary. Areal density increase, i.e. increase in linear and/or track density is key to achieving higher storage capacities. Increases in linear density result in a decrease in the distance between adjacent bit cells, which leads to an increase in intersymbol-interference (ISI). Higher track density requiring narrower track width, narrower write/read heads and closer head spacing, leads to losses in signal-to-noise ratio (SNR). Also issues of intertrack-interference are of greater concern. With increasing areal densities, accurate timing recovery on all parallel data channels during tape operation is critical for achieving reliable data retrieval.

In current tape systems, two dedicated servo channels may be provided to derive longitudinal position (LPOS) information as well as a lateral position-error signal (PES). The timing-based track-following servo for linear tape systems has been adopted by the linear tape open (LTO) consortium as a standard for the so-called LTO tape drive systems.

In a read-channel architecture where the analog data channel signals are synchronously converted into the digital domain, an analog-to-digital converter (ADC) is driven by a variable frequency oscillator (VFO) that may be controlled by a digital timing-recovery unit such that the readback signal is sampled synchronously with respect to the boundaries of the write clock operating at the rate of 1/T, where T is the nominal interval between consecutive timing samples. Typically, the rate of the write clock is chosen such that a predetermined recording density is achieved. The synchronous signal samples are first equalized and then provided to the detection circuit. Timing information may be extracted from the equalized sample values and decisions provided by the detection circuit. This architecture in the context of tape systems comprising M parallel data tracks requires M analog VFOs and their associated feedback control loops.

In a read-channel architecture where the analog data channel signals are asynchronously converted into the digital domain, the ADC is driven by a fixed clock with rate 1/Ts and the sampling of the readback signal is done asynchronously with respect to the write clock boundaries. The synchronization of the signal samples is accomplished digitally using interpolative timing recovery (ITR). No analog feedback loops and associated VFOs are needed, making this approach attractive for multi-track tape systems.

In the latter architecture, the ITR function can take place after or before signal equalization, leading to asynchronous or synchronous equalization schemes, respectively. The asynchronous equalization scheme leads to a relatively short timing-loop delay since the equalizer is placed outside the timing loop. In a synchronous equalization scheme, the equalizer is within the timing loop and therefore introduces additional timing loop delay. However, because the equalizer operates, in this scheme, on signal samples for which synchronization has been accomplished, adaptive equalization may be easier to achieve than with asynchronous equalization. As an example of a synchronous equalization scheme, in optical storage systems two interpolators may generate two sequences of synchronous even-time and synchronous odd-time samples which are equalized by means of two 2T-spaced synchronous equalizers before sequence detection.

With the current systems, timing recovery is performed by timing-recovery loops within each data channel that employ the interpolator output signal to perform the timing recovery operation individually for each data channel. The timing-recovery algorithms typically use equalized signal samples to determine the time instants at which signal sampling must occur.

SUMMARY

In a first aspect, there is provided a read channel incorporated in a storage device to process signals read from a storage medium, comprising: at least one data channel including an interpolator and equalizer; and a servo channel including an interpolator; a timing recovery function for processing a timing error from the interpolator in the servo channel to calculate interpolation timing information used by the interpolator to interpolate a servo channel signal; and a path coupled to the timing recovery function and the interpolator in the at least one data channel to communicate the interpolation timing information to the interpolator in the at least one data channel, wherein the interpolator in the at least one data channel is configured to use the interpolation timing information to interpolate an asynchronous data channel signal.

Preferably, each data channel and the servo channel includes an analog-to-digital converter (ADC), further comprising: an oscillator for providing a clock signal to each ADC in each data channel and the servo channel.

Preferably, the timing recovery function is implemented in the servo channel, and wherein the asynchronous data channel signal is interpolated to a synchronous signal.

Preferably, the timing recovery function is further configured to calculate interpolation timing information by: using a timing error to calculate a timing correction to adjust an interpolation interval between two samples generated by the interpolator, wherein a new interpolation instant is used to determine coefficients used by the interpolator to interpolate the servo channel signal.

Preferably, the timing recovery function implements a loop filter of a second order loop to generate the timing correction from the timing error.

Preferably, the interpolation timing information communicated on the path to each data channel comprises the timing corrections, and wherein each data channel is configured to calculate the coefficients used by the interpolator from the timing corrections.

Preferably, the servo channel comprises a first servo channel, wherein the interpolator in the servo channel comprises a first interpolator, and wherein the timing recovery function comprises a first timing recovery function included in the first servo channel, and wherein the path comprises a first path, further comprising: a second servo channel including: a second interpolator; and a second timing recovery function for processing a timing error from the second interpolator to calculate interpolation timing information used by the interpolator to interpolate a servo channel signal input to the second servo channel; and a second path coupled to the second timing recovery function and the interpolator in the at least one data channel to communicate the interpolation timing information to the interpolator in the at least one data channel, wherein the interpolator in the at least one data channel is configured to use the interpolation timing information to interpolate an asynchronous data channel signal; and a monitoring function to select one of the first or second servo channel to supply interpolation time instants to the at least one data channel.

Preferably, the servo channel comprises a first servo channel, wherein the interpolator in the servo channel comprises a first interpolator, and wherein the path comprises a first path, further comprising: a second servo channel including a second interpolator, wherein the timing recovery function is configured to process the timing error from the first and second interpolators in the first and second servo channels to calculate the interpolation timing information.

Preferably, the timing recovery function is configured to combine the timing error from the first and second interpolators and use the combined timing error to calculate a timing correction to adjust an interpolation interval between two samples generated by the interpolators in the servo channels, wherein a new interpolation instant is used to determine coefficients used by the interpolator in the at least one data channel.

Preferably, the timing errors are combined by assigning a greater weighting to the timing error from the first or second interpolator providing an interpolated signal having a better signal-to-noise ratio than the timing error from the other interpolator.

Preferably, the at least one data channel comprises a first and second data channels, wherein the first data channel includes a first interpolator and first adaptive equalizer that equalizes the signal from the first interpolator, wherein the second data channel includes a second interpolator and second adaptive equalizer that equalizes the signal from the second interpolator, further comprising: a signal processing component for processing equalized output signals from the first and second adaptive equalizers to provide feedback to the first and second interpolators to improve quality of interpolation.

Preferably, the signal processing component is configured to provide feedback to the first and second adaptive equalizers to improve quality of equalization and cancel cross-track interference.

Preferably, the signal processing component comprises a multiple-input and multiple output (MIMO) system.

Preferably, there are a plurality of data channels each including one equalizer and interpolator, and wherein the timing recovery function provides the interpolation timing information to the interpolators in the data channels.

In a second aspect, there is provided a storage drive for performing Input/Output (I/O) operations with respect to a storage medium coupled to the storage drive, comprising: a head to read data from the storage medium; and a read channel in data communication with the head to process signals the head reads from the storage medium, comprising: at least one data channel including an interpolator and equalizer; a servo channel including an interpolator; a timing recovery function for processing a timing error from the interpolator in the servo channel to calculate interpolation timing information used by the interpolator to interpolate a servo channel signal; and a path coupled to the timing recovery function and the interpolator in the at least one data channel to communicate the interpolation timing information to the interpolator in the at least one data channel, wherein the interpolator in the at least one data channel is configured to use the interpolation timing information to interpolate an asynchronous data channel signal.

Preferably, each data channel and the servo channel includes an analog-to-digital converter (ADC), further comprising: an oscillator for providing a clock signal to each ADC in each data channel and the servo channel.

Preferably, the timing recovery function is implemented in the servo channel, and wherein the asynchronous data channel signal is interpolated to a synchronous signal.

Preferably, the timing recovery function is further configured to calculate interpolation timing information by: using a timing error to calculate a timing correction to adjust an interpolation interval between two samples generated by the interpolator, wherein a new interpolation instant is used to determine coefficients used by the interpolator to interpolate the servo channel signal.

Preferably, the interpolation timing information communicated on the path to each data channel comprises the timing corrections, and wherein each data channel is configured to calculate the coefficients used by the interpolator from the timing corrections.

Preferably, the servo channel comprises a first servo channel, wherein the interpolator in the servo channel comprises a first interpolator, and wherein the timing recovery function comprises a first timing recovery function included in the first servo channel, and wherein the path comprises a first path, wherein the read channel further comprises: a second servo channel including: a second interpolator; and a second timing recovery function for processing a timing error from the second interpolator to calculate interpolation timing information used by the interpolator to interpolate a servo channel signal input to the second servo channel; and a second path coupled to the second timing recovery function and the interpolator in the at least one data channel to communicate the interpolation timing information to the interpolator in the at least one data channel, wherein the interpolator in the at least one data channel is configured to use the interpolation timing information to interpolate an asynchronous data channel signal; and a monitoring function to select one of the first or second servo channel to supply interpolation time instants to the at least one data channel.

Preferably, the servo channel comprises a first servo channel, wherein the interpolator in the servo channel comprises a first interpolator, and wherein the path comprises a first path, wherein the read channel further comprises: a second servo channel including a second interpolator, wherein the timing recovery function is configured to process the timing error from the first and second interpolators in the first and second servo channels to calculate the interpolation timing information.

Preferably, the timing recovery function is configured to combine the timing error from the first and second interpolators and use the combined timing error to calculate a timing correction to adjust an interpolation interval between two samples generated by the interpolators in the servo channels, wherein a new interpolation instant is used to determine coefficients used by the interpolator in the at least one data channel.

Preferably, the at least one data channel comprises a first and second data channels, wherein the first data channel includes a first interpolator and first adaptive equalizer that equalizes the signal from the first interpolator, wherein the second data channel includes a second interpolator and second adaptive equalizer that equalizes the signal from the second interpolator, wherein the read channel comprises: a signal processing component for processing equalized output signals from the first and second adaptive equalizers to provide feedback to the first and second interpolators to improve quality of interpolation.

Preferably, the signal processing component comprises a multiple-input and multiple output (MIMO) system.

Preferably, the read channel includes a plurality of data channels each including one equalizer and interpolator, and wherein the timing recovery function provides the interpolation timing information to the interpolators in the data channels.

In a third aspect, there is provided a method to process signals read from a storage medium, comprising: processing a timing error from an interpolator in a servo channel to calculate interpolation timing information used by the interpolator to interpolate a servo channel signal; and communicating the interpolation timing information to an interpolator in at least one data channel; and using the interpolation timing information to interpolate an asynchronous data channel signal.

The method may further comprises providing a clock signal to each data channel and the servo channel.

Preferably, the asynchronous data channel signal is interpolated to a synchronous signal.

Preferably, calculating the interpolation timing information further comprises: using a timing error to calculate a timing correction to adjust an interpolation interval between two samples generated by the interpolator, wherein a new interpolation instant is used to determine coefficients used by the interpolator to interpolate the servo channel signal.

Preferably, the interpolation timing information communicated to each data channel comprises the timing corrections, and wherein each data channel is configured to calculate the coefficients used by the interpolator from the timing corrections.

Preferably, the timing error comprises a first timing error, wherein the calculated interpolation timing information comprises first interpolation timing information, wherein the interpolator using the first interpolation timing information comprises a first interpolator, and wherein the servo channel comprises a first servo channel, wherein the first servo channel comprises a first servo channel signal interpolated by the first interpolator, further comprising, further comprising: processing, at a second servo channel, a second timing error from a second interpolator to calculate second interpolation timing information used by the second interpolator to interpolate a second servo channel signal; selecting one of the first or second servo channel to supply interpolation time instants to the at least one data channel.

The method of claim 26, wherein the servo channel comprises a first servo channel, wherein the interpolator in the servo channel comprises a first interpolator, further comprising:

processing the timing error from the first interpolator in the first servo channel and a second interpolator in a second servo channel to calculate the interpolation timing information.

The method may further comprise: combining the timing error from the first and second interpolators; and using the combined timing error to calculate a timing correction to adjust an interpolation interval between two samples generated by the interpolators in the servo channels, wherein a new interpolation instant is used to determine coefficients used by the interpolator in the at least one data channel.

The method may further comprise: processing equalized output signals from first and second adaptive equalizers to provide feedback to first and second interpolators to improve quality of interpolation.

Preferably, there are a plurality of data channels each including one equalizer and interpolator, further comprising: providing the interpolation timing information to the interpolators in the data channels.

Provided is thus a read channel, storage drive, and method to process signals read from a storage medium. At least one data channel including an interpolator and equalizer and a servo channel includes an interpolator. A timing recovery function processes a timing error from the interpolator in the servo channel to calculate interpolation timing information used by the interpolator to interpolate a servo channel signal. A path is coupled to the timing recovery function and the interpolator in the at least one data channel to communicate the interpolation timing information to the interpolator in the at least one data channel. The interpolator in the at least one data channel is configured to use the interpolation timing information to interpolate an asynchronous data channel signal.

In a further embodiment, each data channel and the servo channel includes an analog-to-digital converter (ADC), further comprising:

In a further embodiment, an oscillator provides a clock signal to each ADC in each data channel and the servo channel.

In a further embodiment, the timing recovery function is implemented in the servo channel and the asynchronous data channel signal is interpolated to a synchronous signal.

In a further embodiment, the timing recovery function is further configured to calculate interpolation timing information by using a timing error to calculate a timing correction to adjust an interpolation interval between two samples generated by the interpolator. A new interpolation instant is used to determine coefficients used by the interpolator to interpolate the servo channel signal.

In a further embodiment, the timing recovery function implements a loop filter of a second order loop to generate the timing correction from the timing error.

In a further embodiment, the interpolation timing information communicated on the path to each data channel comprises the timing corrections. Each data channel is configured to calculate the coefficients used by the interpolator from the timing corrections.

In a further embodiment, the servo channel comprises a first servo channel, the interpolator in the servo channel comprises a first interpolator, and the timing recovery function comprises a first timing recovery function included in the first servo channel, and the path comprises a first path. A second servo channel includes: a second interpolator; a second timing recovery function for processing a timing error from the second interpolator to calculate interpolation timing information used by the interpolator to interpolate a servo channel signal input to the second servo channel; and a second path coupled to the second timing recovery function and the interpolator in the at least one data channel to communicate the interpolation timing information to the interpolator in the at least one data channel. The interpolator in the at least one data channel is configured to use the interpolation timing information to interpolate an asynchronous data channel signal. A monitoring function selects one of the first or second servo channel to supply interpolation time instants to the at least one data channel.

In a further embodiment, the servo channel comprises a first servo channel, the interpolator in the servo channel comprises a first interpolator, and the path comprises a first path. A second servo channel includes a second interpolator. The timing recovery function is configured to process the timing error from the first and second interpolators in the first and second servo channels to calculate the interpolation timing information.

In a further embodiment, the timing recovery function is configured to combine the timing error from the first and second interpolators and use the combined timing error to calculate a timing correction to adjust an interpolation interval between two samples generated by the interpolators in the servo channels. A new interpolation instant is used to determine coefficients used by the interpolator in the at least one data channel.

In a further embodiment, the timing errors are combined by assigning a greater weighting to the timing error from the first or second interpolator providing an interpolated signal having a better signal-to-noise ratio than the timing error from the other interpolator.

In a further embodiment, the at least one data channel comprises a first and second data channels. The first data channel includes a first interpolator and first adaptive equalizer that equalizes the signal from the first interpolator. The second data channel includes a second interpolator and second adaptive equalizer that equalizes the signal from the second interpolator. A signal processing component processes equalized output signals from the first and second adaptive equalizers to provide feedback to the first and second interpolators to improve quality of interpolation.

In a further embodiment, wherein the signal processing component is configured to provide feedback to the first and second adaptive equalizers to improve quality of equalization and cancel cross-track interference.

In a further embodiment, the signal processing component comprises a multiple-input and multiple output (MIMO) system.

In a further embodiment, there are a plurality of data channels each including one equalizer and interpolator. The timing recovery function provides the interpolation timing information to the interpolators in the data channels.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates an embodiment of a tape drive.

FIGs. 2-7 illustrate embodiments of a read channel including timing recovery components.

FIG. 8 illustrates an embodiment of operations to process signals and calculate interpolation timing information.

DETAILED DESCRIPTION

FIG. 1 illustrates an embodiment of a magnetic tape drive 10. The magnetic tape drive provides a means for reading and writing information with respect to a magnetic tape 14 of a magnetic tape cartridge 12. Magnetic tape cartridges include a magnetic tape storage medium to record data to be retrieved at a subsequent time. Further, the magnetic tape cartridges may be interchanged between tape drives, such that a magnetic tape written on one tape drive will be read by another tape drive. The magnetic tape cartridge 12 comprises a length of magnetic tape 14 wound on one or two reels 15, 16.

A single reel magnetic tape cartridge 12 is illustrated, examples of which are those adhering to the Linear Tape Open (LTO) format. An example of a magnetic tape drive 10 is the IBM 3580 Ultrium magnetic tape drive based on LTO technology. A further example of a single reel magnetic tape drive and associated cartridge is the IBM 3592 TotalStorage Enterprise magnetic tape drive and associated magnetic tape cartridge. An example of a dual reel cartridge is the IBM 3570 magnetic tape cartridge and associated drive. In alternative embodiments, additional tape formats that may be used include Digital Linear Tape (DLT), Digital Audio Tape (DAT), etc.

The magnetic tape drive 10 comprises one or more controllers 18 of a recording system for operating the magnetic tape drive in accordance with commands received from a host system 20 received at an interface 21. A controller typically comprises logic and/or one or more microprocessors with a memory 19 for storing information and program information for operating the microprocessor(s). The program information may be supplied to the memory via the interface 21, by an input to the controller 18 such as a floppy or optical disk, or by read from a magnetic tape cartridge, or by any other suitable means. The magnetic tape drive 10 may comprise a standalone unit or comprise a part of a tape library or other subsystem. The magnetic tape drive 10 may be coupled to the host system 20 directly, through a library, or over a network, and employ at interface 21 a Small Computer Systems Interface (SCSI), an optical fiber channel interface, etc. The magnetic tape cartridge 12 may be inserted in the magnetic tape drive 10, and loaded by the magnetic tape drive so that one or more read and/or write heads 23 of the recording system read and/or write information in the form of signals with respect to the magnetic tape 14 as the tape is moved longitudinally by motors 25 which rotate the reels 15, 16. The magnetic tape typically comprises a plurality of parallel tracks, or groups of tracks. In certain tape formats, such as the LTO format, the tracks are arranged in a serpentine back and forth pattern of separate wraps, as is known to those of skill in the art. Also as known to those of skill in the art, the recording system may comprise a wrap control system 27 to electronically switch to another set of read and/or write heads, and/or to seek and move the read and/or write heads 23 laterally of the magnetic tape, to position the heads at a desired wrap or wraps, and, in some embodiments, to track follow the desired wrap or wraps. The wrap control system may also control the operation of the motors 25 through motor drivers 28, both in response to instructions by the controller 18.

Controller 18 also provides the data flow and formatter for data to be read from and written to the magnetic tape, employing a buffer 30 and a read/write channel 32, as is known to those of skill in the art.

The tape drive 10 system further includes motors 25 and reels 15, 16 to move the magnetic tape 14 with respect to the read head(s) 23 such that the read head(s) may detect magnetic signals on the magnetic tape. A read channel of the read/write channel 32 digitally samples the magnetic signals detected by the read head(s) to provide digital samples of the magnetic signals for further processing.

FIG. 2 illustrates an embodiment of a read channel 50 for a multi-track storage system, such as a tape drive. The read channel 50 may comprise a portion of a read channel of the read/write channel 32 of FIG. 1. The read channel 50 includes a plurality of data channels 52a….52n and one servo channel 54. The data channels 52a…52n and the servo channel 54 respectively include analog-to-digital converters (ADCs) 56a…56n and 58 that process readback data and servo signals read from the storage medium, e.g., tape, and convert the signals to digital signals that are provided to interpolators 60a…60n and 62. The output signals of the ADCs 56a…56n in the data channels 52a…52n may be processed by digital front-end functions before being provided to the interpolators 60a…60n to transform the signals from the asynchronous time domain to the synchronous domain. The data channels 52a…52n further include adaptive equalizers 64a…64n to equalize the signals in the synchronous domain. In one embodiment, a single oscillator (OSC) 66 provides clock signals to drive the ADCs 56a…56n and 58

The servo channel 54 further includes a detector 69 that receives the adjusted synchronous signal from the interpolator 62 to determine the servo information represented by the digital samples. The output from the detector 69 may further include longitudinal position (LPOS) information, which comprises longitudinal position information in the tape. The servo channel 54 further includes a timing recovery function 68 comprising circuitry that processes interpolated signal samples, which may be regarded as timing errors, from the interpolator 62 to generate interpolation timing information that is supplied to the interpolators 60a…60n in the data channels to use to generate synchronous sample sequences.

FIG. 3 provides further detail of the servo channel 54 shown in FIG. 2. A timing error 70 from the interpolator 62 is supplied to two multipliers 72 and 74 that multiply the timing error 70 by the loop parameters æ and ã. The result of the multiplication at the multiplier 72 is supplied to the integrator 76, and the output of the integrator 76 is added by adder 78 to the result of the multiplication at multiplier 74 to produce the timing correction instants $-_{n}$ 80. The multipliers 72, 74, integrator 76, and adder 78 comprise a loop filter of the second order. The computed timing correction instants $-_{n}$ 80 are supplied to the interpolation interval computation circuit 82. Timing intervals T are calculated at circuit 82 such that $T_{i,n} = T_{i,0} + -_{n}$, where $T_{i,0}$ denotes the nominal interpolation interval, and $T_{i,n}$ is the actual interval between consecutive sampling instances n and n+1, at which interpolated signal samples are generated by the interpolator 62. The interpolation time computation 84 circuit indicates an integer number of ADC sampling intervals $(k_{n+1} - k_{n})$ 86 and a fractional interval $(0 = ì_{n+1} < 1)$ 88 that are provided to the interpolator 62 to use to transform the sequence of input signal samples from the asynchronous to the synchronous domain.

The timing recovery function 68 may provide the timing correction instants $-_n$ 80 to the data channel interpolators 60a…60n to use to compute the integer and fractional intervals used for interpolation or, alternatively, the timing recovery function 68 may provide the calculated integer 86 and fractional 88 intervals to the data channel interpolators 60a…60n.

FIG. 4 illustrates a further embodiment of a read channel 100 including two servo channels 102a and 102b that each includes an ADC 104a, 104b, interpolator 106a, 106b, timing recovery function 108a, 108b, and detector 110a, 110b. The servo channels 102a and 102b may implement the timing recovery function 68 described with respect to FIGs. 2 and 3. The read channel 100 further includes multiple data channels 112a…112n, wherein each data channel respectively includes an ADC 114a…114n, interpolator 116a…116n, and adaptive equalizer 118a…118n. The data channel interpolators 116a…116n receive timing information, such as the timing correction instants $-_n$, from the timing recovery function 108a, 108b from one of the servo channels 102a, 102b to use for interpolation. A single oscillator (OSC) 120 supplies clock signals to the ADCs 104a, 104b, 114a…114n.

In the embodiment of FIG. 4, each servo channel includes a monitoring function 122a, 122b that determines the reliability of the servo channels 102a and 102b. The monitoring functions 122a, 122b may communicate to determine which servo channel 102a, 102b produces timing information having a higher reliability, such as timing information that is obtained by a servo signal having a higher signal-to-distortion ratio and/or lower disturbances. The servo channel 102a or 102b providing more reliable timing information may then be used to supply the timing information to the data channel interpolators 116a…116n. The monitoring functions 122a, 122b may periodically check the reliability to determine if the system needs to switch to using the other timing recovery function 108a, 108b to supply the timing information. In an alternative embodiment, the monitoring functions 122a, 122b may estimate LPOS error rates for the servo channels 102a, 102b. In the case the servo channel 102a or 102b, which is being used to supply the timing information to the data channel interpolators 116a…116n, exhibits higher LPOS error rate than the other servo channel, the servo channel 102a or 102b not currently supplying timing information is then selected to provide the timing information to the data channel interpolators 116a…116n. In this way, the monitoring functions 122a, 122b are together used to select one of the servo channels 102a and 102b to supply the timing information to the data channel interpolators 116a…116n, such that the servo channel 102a or 102b producing better quality timing information is selected to provide the timing information.

FIG. 5 illustrates an additional embodiment of the read channel 150 including two servo channels 152a and 152b, wherein each servo channel respectively includes an ADC 154a, 154b, an interpolator 156a, 156b, and detector 158a, 158b. The read channel 150 further includes multiple data channels 160a…160n, wherein each read channel respectively includes an ADC 162a…162n, interpolator 164a…164n, and adaptive equalizer 166a…166n. A single oscillator (OSC) 168 supplies clock signals to the ADCs 154a, 154b, 162a…162n. In the embodiment of FIG. 5, the timing recovery function 170 is located external to the servo channels 152a, 152b. The timing recovery function 170 combines the timing errors from both servo channels 152a, 152b and then calculates the timing correction instants $-_{n}$ in the manner described above. The timing recovery function 170 supplies timing corrections to the data channel interpolators 164a…164n and the servo channel interpolators 156a, 156b.

FIG. 6 provides further detail of the data/servo read channel 150 shown in FIG. 5. Timing errors 170a, 170b from the servo channel interpolators 156a, 156b are supplied to a combining unit 172 that weights the timing errors 170a, 170b from the different servo channels to produce a combined timing error 174. The combining unit 172 may assign a greater weighting to the timing error from the one of the two interpolators 156a, 156b providing an interpolated signal with the better signal-to-noise ratio or least amount of error or degradation. The combined timing error 174 is then provided to multipliers 176 and 178 that multiply the timing error 174 by æ and ã, respectively. The result of the multiplication at the multiplier 176 is supplied to an integrator 180, and the output of the integrator 180 is added by adder 182 to the result of the multiplication at multiplier 178 to produce the timing correction instants $-_{n}$ 184. The multipliers 176, 178, integrator 180, and adder 182 comprise a loop filter of the second order. The computed timing correction instants $-_{n}$ 184 are supplied to the interpolation interval computation circuit 186. Timing intervals T are calculated at circuit 186 such that $T_{i,n} = T_{i,0} + -_{n}$, where $T_{i,0}$ denotes the nominal interpolation interval, and $T_{i,n}$ is the actual interval between consecutive sampling instances n and n+1, at which interpolated signal samples are generated by the interpolators 156a, 156b. The interpolation time computation 188 circuit indicates an integer number of ADC sampling intervals $(k_{n+1} - k_{n})$ 190 and a fractional interval (0 = ì$_{n+1}$

< 1) 192 that are provided to the interpolators 156a, 156b to use to transform the sequences of input signal samples from the asynchronous to the synchronous domain.

The timing recovery function 170 which may implement the combining unit 172, the loop filter of the second order (i.e., components 176, 178, 180, and 182), the circuit 186, and the interpolator time computation unit 188 may provide the timing correction instants $-_n$ 184 to the data channel interpolators 164a…164n to use to compute the integer and fractional intervals used for interpolation or, alternatively, the timing recovery function 170 may provide the calculated integer 190 and fractional 192 intervals to the data channel interpolators 164a…164n.

FIG. 7 illustrates an additional embodiment of a read channel 200, where the read channel of FIG. 6 is modified to include a multiple input, multiple output (MIMO) digital signal processor and detector. The read channel 200 components 202a, 202b, 204a, 204b, 206a, 206b, 208a, 208b, 210a…210n, 212a…212n, 214a…214n, 216a…216n, 218, and 220 are the same as the read channel 150 components 152a, 152b, 154a, 154b, 156a, 156b, 158a, 158b, 160a…160n, 162a…162n, 164a…164n, 166a…166n, 168, and 170, respectively, described with respect to FIG. 5. Further, the timing recovery function 220 may implement the timing recovery components described with respect to FIG. 6. The read channel 200 additionally includes a MIMO system 222 that receives the output from the adaptive equalizers 216a…216n to process all the equalizer output signals together to generate feedback which the MIMO system 222 provides to the interpolators 214a…214n and adaptive equalizers 216a..216n to improve system performance especially in the presence of inter-track interference. The MIMO feedback is provided for cross-equalization and cancellation of interference signals, to improve adaptivity across channels, and to improve the quality of interpolation. The MIMO feedback to the data channel interpolators 214a…214n improves the quality of the generation of the signals using the timing correction instants $-_n$.

FIG. 8 illustrates operations performed by the components in the read channels described above to obtain and use timing information. Upon initiating (at block 300) operations to process signals read from a storage medium, a clock signal is provided (at block 302) to each data channel and a servo channel. A timing error is processed (at block 304) from an interpolator in a servo channel to calculate interpolation timing information used by the interpolator to interpolate a servo channel signal. The timing error may be used (at block 306) to calculate a timing correction to adjust an interpolation interval between two samples generated by the interpolator. A new interpolation instant is used to determine coefficients used by the interpolator to interpolate the servo channel signal. The interpolation timing information is communicated (at block 308) to an interpolator in at least one data channel. The interpolation timing information is used (at block 310) to interpolate an asynchronous data channel signal, wherein the asynchronous data channel signal is interpolated to a synchronous signal.

Described embodiments provide techniques to obtain timing information from one or more servo channel signals that is supplied to multiple data channels. The data channel signals are digitally interpolated to generate synchronous sample sequences using the timing information from one or more of the servo channels. Described embodiments may further provide decoupling of the adaptive equalization and timing recovery.

The described components of the read channels 32, 50, 100, 150, and 200 described in FIGs. 1-7 may comprise discrete logic, ASIC (application specific integrated circuit), FPGA (field programmable gate array), custom processors, etc.

The described components of the read channel embodiments and the operations of the read channel components described with respect to FIGs. 2-7 may alternatively be implemented in subroutines in programs or other software implementations executed by a processor. Such programs implementing the operations of the read channel components described with respect to FIGs. 2-7 may be implemented in a computer readable medium, such as magnetic storage medium (e.g., hard disk drives, floppy disks, tape, etc.), optical storage (CD-ROMs, DVDs, optical disks, etc.), volatile and non-volatile memory devices (e.g., EEPROMs, ROMs, PROMs, RAMs, DRAMs, SRAMs, Flash Memory, firmware, programmable logic, etc.), etc. The code implementing the described operations may further be implemented in hardware logic (e.g., an integrated circuit chip, Programmable Gate Array (PGA), Application Specific Integrated Circuit (ASIC), etc.).

Components in FIGs. 1-7 shown as separate components may be implemented in a single circuit device or functions of one illustrated component may be implemented in separate circuit devices. Moreover, operations described with respect to certain components, such as the timing recovery, may be performed by other components in the read channel external to the specific timing recovery circuit.

Those of skill in the art will understand that changes may be made with respect to the components illustrated herein. Further, those of skill in the art will understand that differing specific component arrangements may be employed than those illustrated herein.

The foregoing description of various embodiments of the invention has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of the above teaching.

CLAIMS

1. A read channel incorporated in a storage device to process signals read from a storage medium, comprising:

at least one data channel including an interpolator and equalizer; and a servo channel including an interpolator;

a timing recovery function for processing a timing error from the interpolator in the servo channel to calculate interpolation timing information used by the interpolator to interpolate a servo channel signal; and

a path coupled to the timing recovery function and the interpolator in the at least one data channel to communicate the interpolation timing information to the interpolator in the at least one data channel, wherein the interpolator in the at least one data channel is configured to use the interpolation timing information to interpolate an asynchronous data channel signal.

2. The read channel of claim 1, wherein the timing recovery function is further configured to calculate interpolation timing information by:

using a timing error to calculate a timing correction to adjust an interpolation interval between two samples generated by the interpolator, wherein a new interpolation instant is used to determine coefficients used by the interpolator to interpolate the servo channel signal.

3. The read channel of claim 1 or claim 2, wherein the servo channel comprises a first servo channel, wherein the interpolator in the servo channel comprises a first interpolator, and wherein the timing recovery function comprises a first timing recovery function included in the first servo channel, and wherein the path comprises a first path, further comprising:

a second servo channel including:
a second interpolator;

and a second timing recovery function for processing a timing error from the second interpolator to calculate interpolation timing information used by the interpolator to interpolate a servo channel signal input to the second servo channel; and a second path coupled to the second timing recovery function and the interpolator in the at least one data channel to communicate the interpolation timing information to the interpolator in the at least one data channel, wherein the interpolator in the at least one data channel is configured to use the interpolation timing information to interpolate an asynchronous data channel signal; and

a monitoring function to select one of the first or second servo channel to supply interpolation time instants to the at least one data channel.

4. The read channel of any preceding claim, wherein the servo channel comprises a first servo channel, wherein the interpolator in the servo channel comprises a first interpolator, and wherein the path comprises a first path, further comprising:

a second servo channel including a second interpolator, wherein the timing recovery function is configured to process the timing error from the first and second interpolators in the first and second servo channels to calculate the interpolation timing information.

5. The read channel of claim 4, wherein the timing recovery function is configured to combine the timing error from the first and second interpolators and use the combined timing error to calculate a timing correction to adjust an interpolation interval between two samples generated by the interpolators in the servo channels:

wherein a new interpolation instant is used to determine coefficients used by the interpolator in the at least one data channel;

wherein the timing errors are combined by assigning a greater weighting to the timing error from the first or second interpolator providing an interpolated signal having a better signal-to-noise ratio than the timing error from the other interpolator; and

wherein the at least one data channel comprises a first and second data channels, wherein the first data channel includes a first interpolator and first adaptive equalizer that equalizes the signal from the first interpolator, wherein the second data channel includes a second interpolator and second adaptive equalizer that equalizes the signal from the second interpolator, further comprising:

a signal processing component for processing equalized output signals from the first and second adaptive equalizers to provide feedback to the first and second interpolators to improve quality of interpolation.

6. A method to process signals read from a storage medium, comprising:

processing a timing error from an interpolator in a servo channel to calculate interpolation timing information used by the interpolator to interpolate a servo channel signal; and

communicating the interpolation timing information to an interpolator in at least one data channel; and

using the interpolation timing information to interpolate an asynchronous data channel signal.

7. The method of claim 6, wherein calculating the interpolation timing information further comprises:

using a timing error to calculate a timing correction to adjust an interpolation interval between two samples generated by the interpolator, wherein a new interpolation instant is used to determine coefficients used by the interpolator to interpolate the servo channel signal.

8. The method of claim 6 or claim 7, wherein the interpolation timing information communicated to each data channel comprises the timing corrections, and wherein each data channel is configured to calculate the coefficients used by the interpolator from the timing corrections.

9. The method of any of claims 6 to 8, wherein the timing error comprises a first timing error, wherein the calculated interpolation timing information comprises first interpolation timing information, wherein the interpolator using the first interpolation timing information comprises a first interpolator, and wherein the servo channel comprises a first servo channel, wherein the first servo channel comprises a first servo channel signal interpolated by the first interpolator, further comprising, further comprising:

processing, at a second servo channel, a second timing error from a second interpolator to calculate second interpolation timing information used by the second interpolator to interpolate a second servo channel signal;

selecting one of the first or second servo channel to supply interpolation time instants to the at least one data channel.

10. The method of claim 26, wherein the servo channel comprises a first servo channel, wherein the interpolator in the servo channel comprises a first interpolator, further comprising:

processing the timing error from the first interpolator in the first servo channel and a second interpolator in a second servo channel to calculate the interpolation timing information;

combining the timing error from the first and second interpolators and using the combined timing error to calculate a timing correction to adjust an interpolation interval between two samples generated by the interpolators in the servo channels, wherein a new interpolation instant is used to determine coefficients used by the interpolator in the at least one data channel; and

processing equalized output signals from first and second adaptive equalizers to provide feedback to first and second interpolators to improve quality of interpolation.

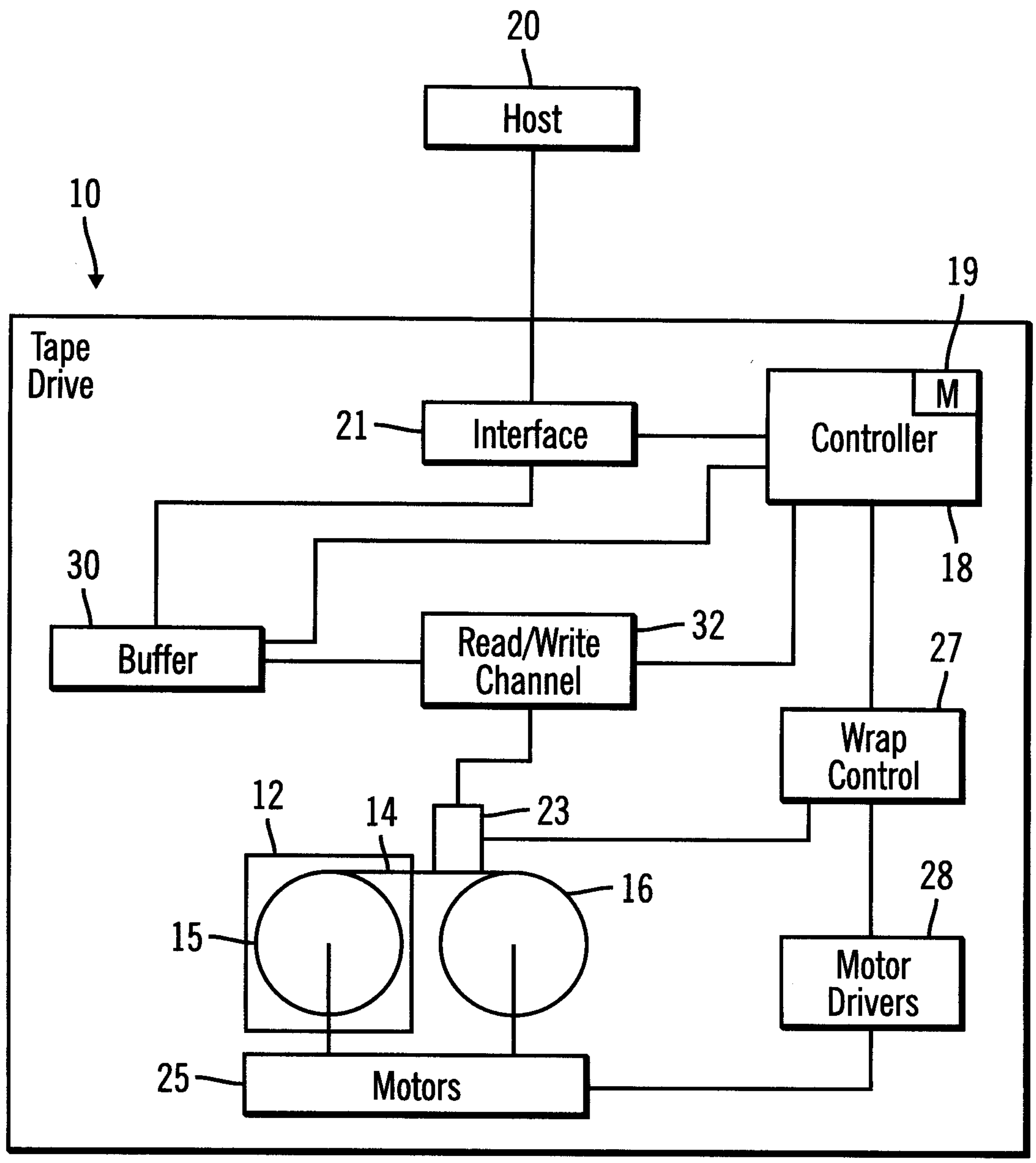
20
Host
10
Tape Drive
19
M
Controller
21
Interface
18
30
Buffer
Read/Write Channel
32
27
Wrap Control
12
14
23
16
15
28
Motor Drivers
25
Motors

FIG. 1

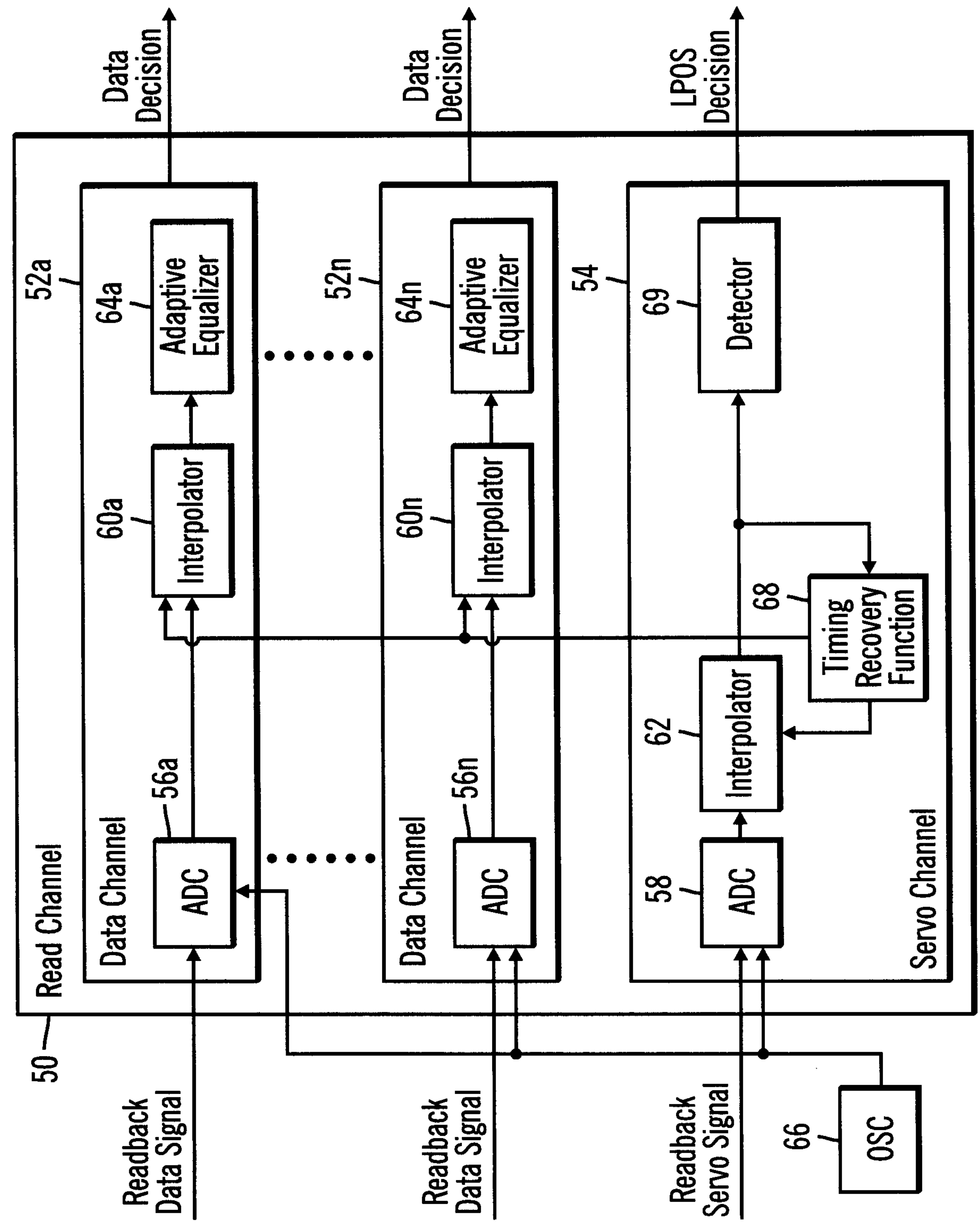
Data Decision
Data Decision
LPOS Decision
Read Channel
50
52a
52n
54
Data Channel
Data Channel
Servo Channel
64a
Adaptive Equalizer
64n
Adaptive Equalizer
69
Detector
60a
Interpolator
60n
Interpolator
68
Timing Recovery Function
62
Interpolator
56a
ADC
56n
ADC
58
ADC
Readback Data Signal
Readback Data Signal
Readback Servo Signal
66
OSC

FIG. 2

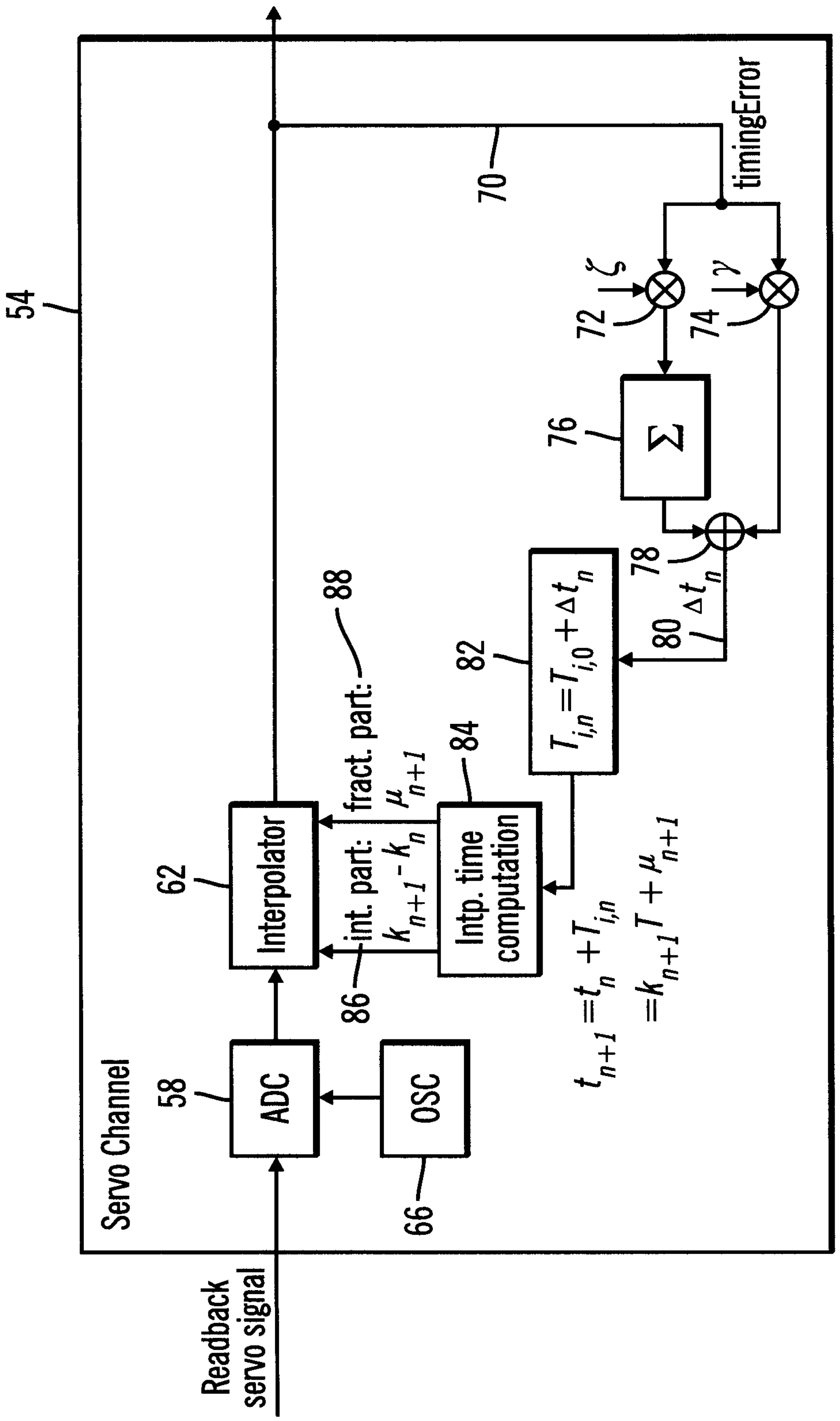
54
Servo Channel
Readback servo signal
ADC
58
OSC
66
Interpolator
62
int. part: $k_{n+1}-k_n$
86
fract. part: μ_{n+1}
88
Intp. time computation
84
$t_{n+1}=t_n+T_{i,n}$
$=k_{n+1}T+\mu_{n+1}$
$T_{i,n}=T_{i,0}+\Delta t_n$
82
Δt_n
80
78
Σ
76
72
ζ
74
γ
70
timingError

FIG. 3

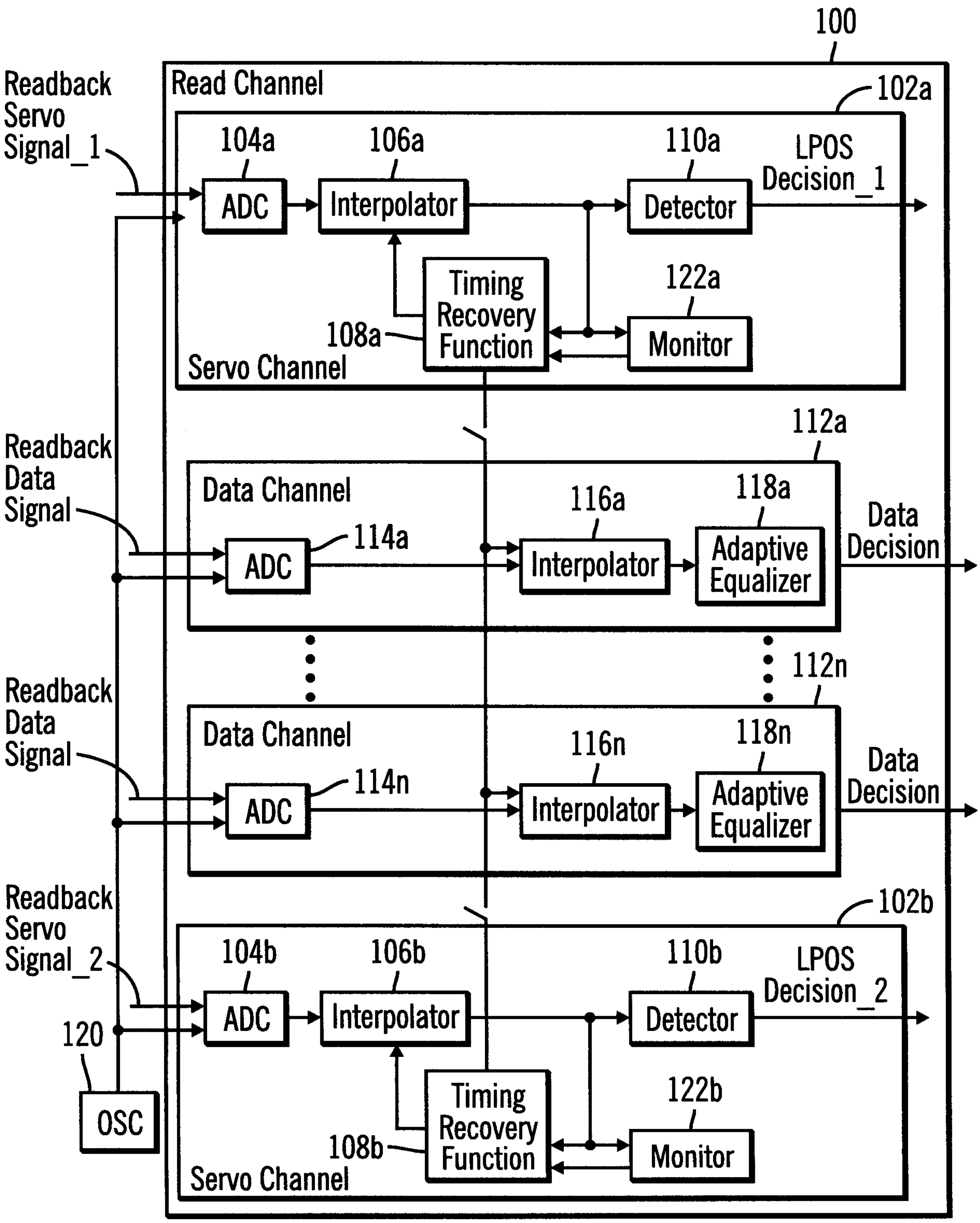
100
Read Channel
102a
Readback Servo Signal_1
104a
ADC
106a
Interpolator
110a
Detector
LPOS Decision_1
Timing Recovery Function
108a
122a
Monitor
Servo Channel
112a
Readback Data Signal
Data Channel
ADC
114a
116a
Interpolator
118a
Adaptive Equalizer
Data Decision
112n
Readback Data Signal
Data Channel
ADC
114n
116n
Interpolator
118n
Adaptive Equalizer
Data Decision
102b
Readback Servo Signal_2
104b
ADC
106b
Interpolator
110b
Detector
LPOS Decision_2
120
OSC
Timing Recovery Function
108b
122b
Monitor
Servo Channel

FIG. 4

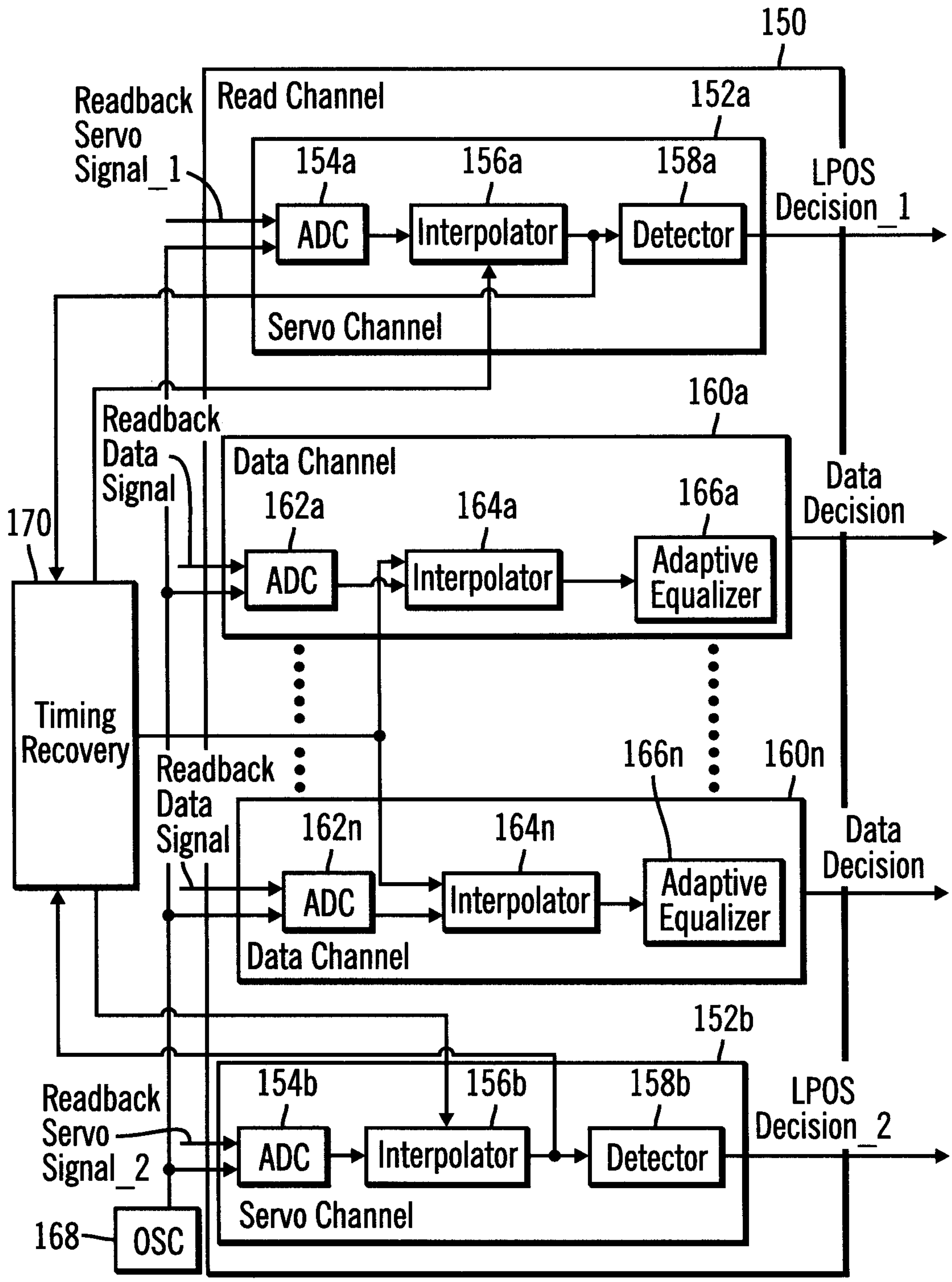
150
Read Channel
152a
Readback Servo Signal_1
154a
156a
158a
ADC
Interpolator
Detector
LPOS Decision_1
Servo Channel
160a
Readback Data Signal
Data Channel
162a
164a
166a
ADC
Interpolator
Adaptive Equalizer
Data Decision
170
Timing Recovery
Readback Data Signal
166n
160n
162n
164n
ADC
Interpolator
Adaptive Equalizer
Data Decision
Data Channel
152b
Readback Servo Signal_2
154b
156b
158b
ADC
Interpolator
Detector
LPOS Decision_2
Servo Channel
168
OSC

FIG. 5

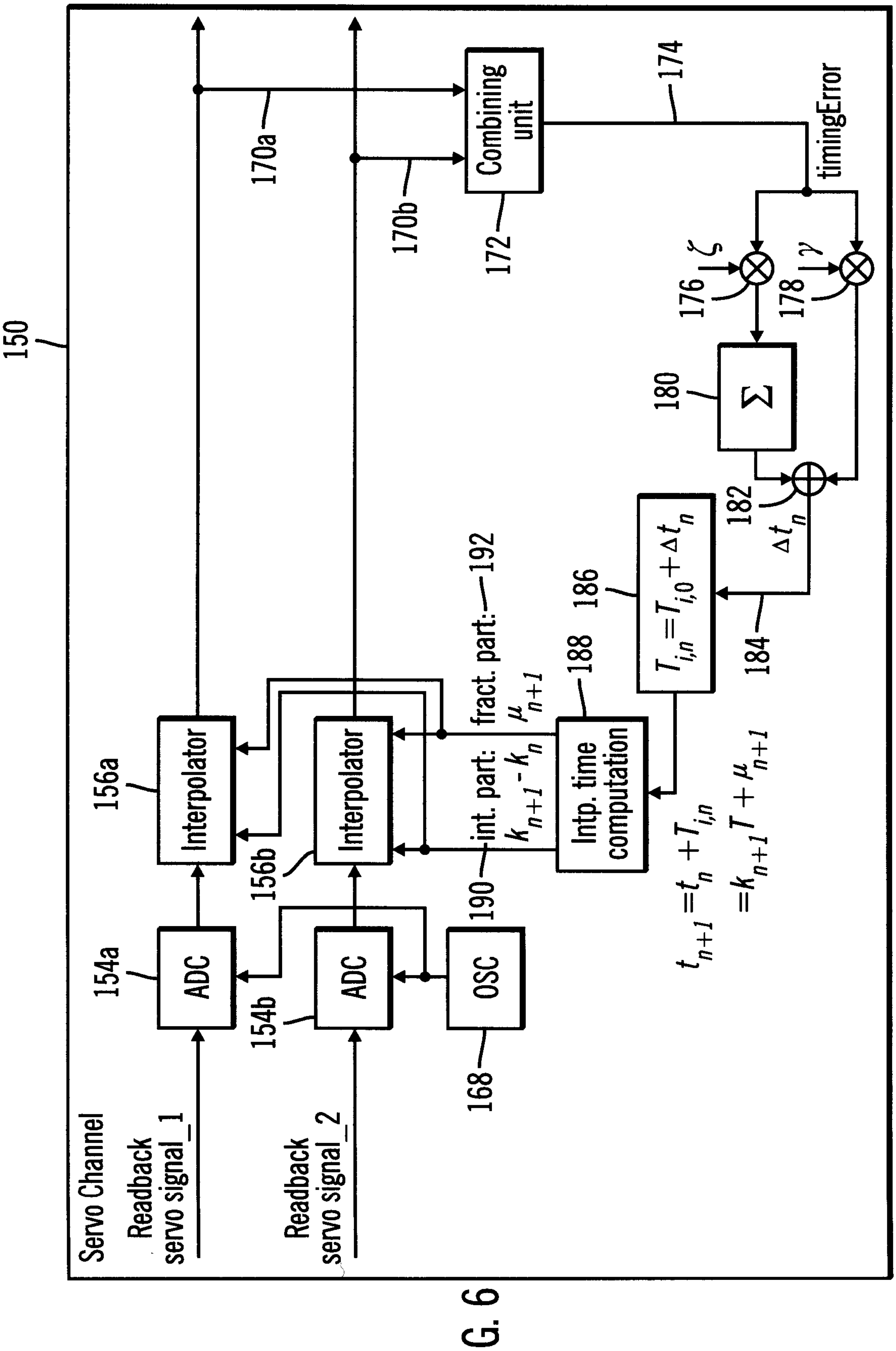
150
Servo Channel
Readback servo signal_1
Readback servo signal_2
ADC
ADC
OSC
154a
154b
168
Interpolator
Interpolator
156a
156b
190
int. part:
$k_{n+1}-k_n$
fract. part:
μ_{n+1}
192
Intp. time computation
188
$T_{i,n}=T_{i,0}+\Delta t_n$
186
184
Δt_n
182
Σ
180
176
ζ
178
γ
timingError
174
Combining unit
172
170a
170b
$t_{n+1}=t_n+T_{i,n}$
$=k_{n+1}T+\mu_{n+1}$

FIG. 6

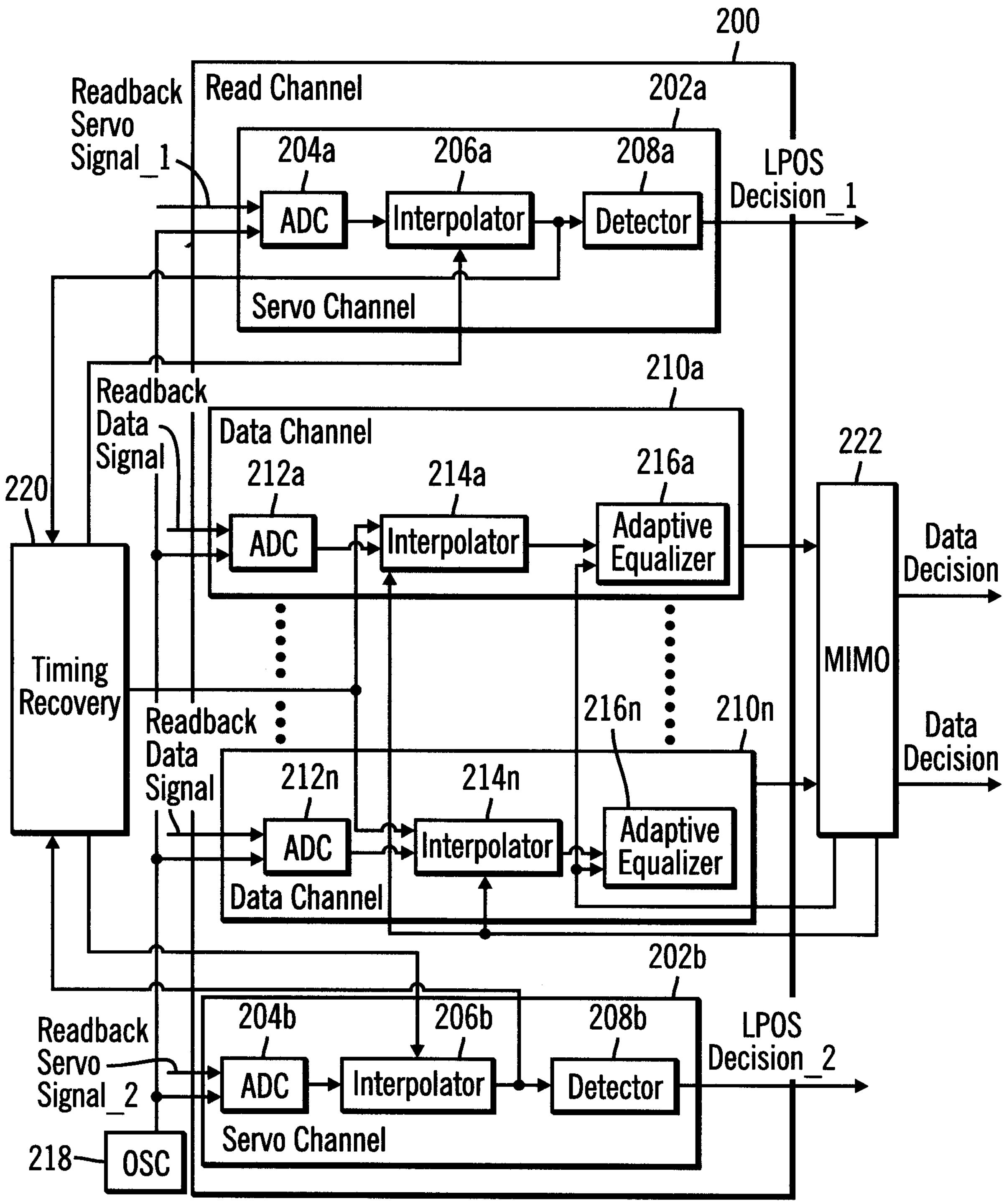
200
Read Channel
202a
Readback Servo Signal_1
204a
206a
208a
ADC
Interpolator
Detector
LPOS Decision_1
Servo Channel
210a
Readback Data Signal
Data Channel
212a
214a
216a
ADC
Interpolator
Adaptive Equalizer
222
220
Timing Recovery
MIMO
Data Decision
Data Decision
Readback Data Signal
216n
210n
212n
214n
ADC
Interpolator
Adaptive Equalizer
Data Channel
202b
Readback Servo Signal_2
204b
206b
208b
ADC
Interpolator
Detector
LPOS Decision_2
Servo Channel
218
OSC

FIG. 7

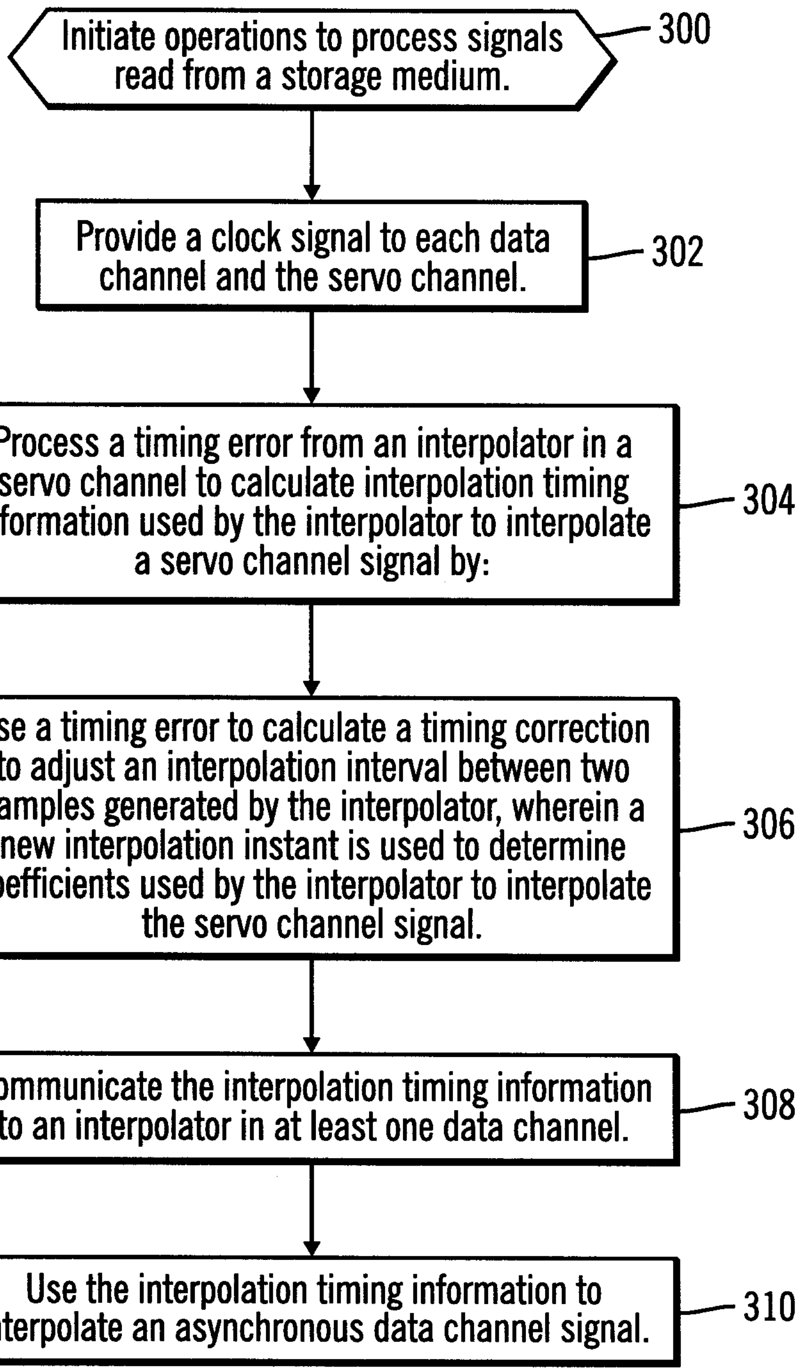
Initiate operations to process signals read from a storage medium.
300
Provide a clock signal to each data channel and the servo channel.
302
Process a timing error from an interpolator in a servo channel to calculate interpolation timing information used by the interpolator to interpolate a servo channel signal by:
304
Use a timing error to calculate a timing correction to adjust an interpolation interval between two samples generated by the interpolator, wherein a new interpolation instant is used to determine coefficients used by the interpolator to interpolate the servo channel signal.
306
Communicate the interpolation timing information to an interpolator in at least one data channel.
308
Use the interpolation timing information to interpolate an asynchronous data channel signal.
310

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2007/050772

A. CLASSIFICATION OF SUBJECT MATTER
INV. G11B27/10 G11B20/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G11B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 01/18808 A (ZEN RES N V [NL]) 15 March 2001 (2001-03-15) figures 1-5,8 page 1 - page 6 page 7, line 16 - page 13, line 11 page 14, line 1 - page 18, line 2	1-10
Y	WO 2005/031738 A1 (SONY CORP [JP]; HIGASHINO SATORU [JP]) 7 April 2005 (2005-04-07) figures 1,13	1,2,6-8
P,Y	& EP 1 669 994 A1 (SONY CORP [JP]) 14 June 2006 (2006-06-14) abstract paragraphs [0036] - [0049] paragraphs [0085] - [0087] figures 1,13	1,2,6-8

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 June 2007	19/06/2007

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	BAREL-FAUCHEUX, C

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2007/050772

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6 724 561 B1 (WYMAN ROBERT O [US]) 20 April 2004 (2004-04-20) column 6, line 23 - column 8, line 14 figures 5-7	3-5,9,10
A	EP 0 901 125 A (HEWLETT PACKARD CO [US]) 10 March 1999 (1999-03-10) paragraphs [0029] - [0032] figures 2,3	1-10
A	US 2002/154430 A1 (RAE JAMES W [US] ET AL) 24 October 2002 (2002-10-24) paragraphs [0111] - [0117] pages 41-43 figures 6-8	1-10
A	WO 01/80238 A1 (INFINEON TECHNOLOGIES CORP [US]) 25 October 2001 (2001-10-25) page 16, line 7 - page 17, line 17 page 73 - page 75 figures 6-8	1-10
A	US 2003/043898 A1 (HUANG KE-CHIANG [TW] ET AL) 6 March 2003 (2003-03-06) figure 1 paragraphs [0017] - [0034]	1-10

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2007/050772

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			CA	2382538	A1	15-03-2001
			EP	1218885	A1	03-07-2002
			JP	2003509795	T	11-03-2003
			TW	494390	B	11-07-2002
			US	6418101	B1	09-07-2002
WO 2005031738	A1	07-04-2005	CN	1860546	A	08-11-2006
			EP	1669994	A1	14-06-2006
			JP	2005108295	A	21-04-2005
			US	2007035867	A1	15-02-2007
EP 1669994	A1	14-06-2006	CN	1860546	A	08-11-2006
			JP	2005108295	A	21-04-2005
			WO	2005031738	A1	07-04-2005
			US	2007035867	A1	15-02-2007
US 6724561	B1	20-04-2004	NONE			
EP 0901125	A	10-03-1999	NONE			
US 2002154430	A1	24-10-2002	NONE			
WO 0180238	A1	25-10-2001	NONE			
US 2003043898	A1	06-03-2003	TW	236229	B	11-07-2005
			US	2005220184	A1	06-10-2005