

(51) International Patent Classification:
G11B 25/06 (2006.01)(21) International Application Number:
PCT/US2009/042037(22) International Filing Date:
29 April 2009 (29.04.2009)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant (for all designated States except US):
HEWLETT-PACKARD DEVELOPMENT COMPANY, L.P. [US/US]; 11445 Compaq Center Drive W., Houston, TX 77070 (US).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **FASEN, Donald** [US/US]; 11311 Chinden Blvd., Boise, ID 83714-0021 (US).(74) Agents: **CZARNECKI, Michael** et al.; Hewlett-packard Development Company, L.P., Intellectual Property Administration, P.O. Box 272400, Mail Stop 35, Fort Collins, CO 80527-2400 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ,

CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, 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, LY, MA, MD, ME, 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, ST, 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, 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, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- as to the identity of the inventor (Rule 4.17(i))
- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))

Published:

- with international search report (Art. 21(3))

(54) Title: ARRANGEMENT AND PROCESSING OF LONGITUDINAL POSITION INFORMATION ON A DATA STORAGE MEDIUM

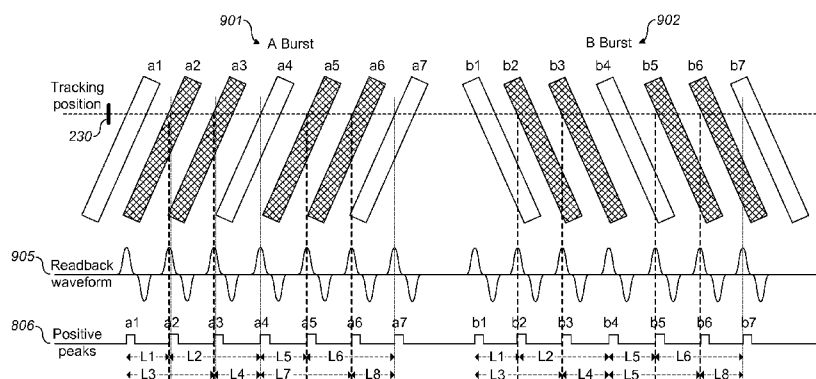


FIG. 9

(57) Abstract: There is described apparatus (800) to decode longitudinal position (LPOS) information from non-shifted servo elements (a1, a4, a7) and an unbroken sequence of plural shifted servo elements (a2-a3, a5-a6), variations in the relative displacement of the non-shifted and shifted elements encoding the LPOS information. The apparatus is operable to receive signals (905) from a transducer head apparatus (131) that detects the servo elements as they move past the transducer head apparatus, and to process the signals to obtain data (L1, L4, L5, L8) related to relative displacement of mutually adjacent shifted and non-shifted elements within respective ones of the servo bursts, and data (L2, L3, L6, L7) related to relative displacement of mutually non-adjacent shifted and non-shifted elements within the respective ones of the servo bursts, and also to process the data to determine LPOS bit values corresponding to the respective ones of the servo bursts.

- 1 -

Arrangement And Processing Of Longitudinal
Position Information On A Data Storage Medium

Technical Field

[0001] The invention relates generally to the field of data storage.

Background

[0002] It is known to use a data storage device to write data to and read data from a data storage medium as the data storage medium is driven relative to a transducer head of the data storage device, the data being arranged in data tracks extending along the data storage medium. It is also known to provide servo information extending in a longitudinal direction of the data tracks, the servo information including longitudinal position information indicative of position along the data storage medium in a direction of the data tracks. In use, with the data storage medium driven relative to a transducer head of the data storage device, the servo information can be detected by one or more transducers of the head, and processed to provide feedback in one or more servo loops to facilitate control, for example, of a lateral position of the transducer head relative to the data tracks, drive speed of the data storage medium, and/or longitudinal positioning of the transducer head along the data storage medium.

[0003] Accurate determination of position and speed of the data storage medium relative to the transducer head, for example in the presence of noise in the detected servo signal, is desirable. As track pitch is increased between generations of storage technology, to provide desired increases in performance including storage density, noise in the servo track signal is likely to increase.

Summary

[0004] According to the invention, there is provided decoder apparatus as claimed in claim 1.

[0005] According to a further aspect of the invention, there is provided a method of decoding longitudinal position information as claimed in claimed 7.

- 2 -

[0006] According to a still further aspect of the invention, there is provided a storage medium having stored thereon longitudinal position information, as claimed in claim 10.

[0007] According to a still further aspect of the invention, there is provided data storage apparatus as claimed in claim 14.

Brief Description Of The Drawings

[0008] In order that the invention may be well understood, by way of example only, various embodiments of the invention will now be described, with reference to the accompanying drawings in which:

[0009] Figure 1 is a perspective view of storage apparatus in the form of portions of a tape drive;

[0010] Figure 2 is a functional diagram of an exemplary control arrangement of the tape drive of figure 1;

[0011] Figure 3 it is a schematic view of a storage medium, including detailed views of an exemplary arrangement of data bands and servo tracks;

[0012] Figure 4 illustrates further details of the data bands, including an exemplary arrangement of data tracks in the data bands;

[0013] Figure 5 is a schematic view of a portion of a servo band and read back signal, illustrating an exemplary arrangement of servo elements in a servo frame;

[0014] Figures 6 and 7 illustrate in exaggerated form respective arrangements of servo elements for encoding an LPOS bit having a value of one and an LPOS bit having a value of zero;

[0015] Figure 8 is a functional diagram of decoder apparatus for processing servo read back signals to decode LPOS information;

[0016] Figure 9 shows a servo element arrangement according to figure 5, together with data values that can be derived from signals generated using the servo elements;

- 3 -

[0017] Figures 10 and 11 illustrate in exaggerated form respective alternative arrangements of servo elements encoding an LPOS bit having a value of one and an LPOS bit having a value of zero;

[0018] Figure 12 shows an alternative servo element arrangement according to figure 10, together with data values that can be derived from signals generated using the servo elements; and

[0019] Figure 13 is a flow diagram illustrating a method of decoding longitudinal position information.

Detailed Description

[0020] Figure 1 shows data storage apparatus in the form of portions of a tape drive 100. A single reel tape cartridge 110 comprising a data storage medium in the form of a magnetic data storage tape 111 is removably receivable in the tape drive 100. In use, a free end of the tape 111 from a cartridge reel 110a is threaded 110 along a path in contact with guides 115, 116 onto a take-up reel 120 of the tape drive 100, enabling the tape 111 to be spooled onto the take-up reel 120. Drive apparatus in the form of respective electric motors 232 (figure 2) is provided to drive the cartridge reel 110a and the take-up reel 120, to move the tape 111 in a longitudinal direction A, B of the tape 111 along the tape path in contact with transducer head elements 220, 230 (figure 2) of a transducer head apparatus 131 having an actuator such as a voice coil motor or other arrangement for moving the transducer head elements 220, 230 laterally of the tape 111. Reel speed sensors 238 (figure 2), for example Hall-effect sensors or any other suitable form of sensor, are provided for sensing the speed of the cartridge reel 110a and the take-up reel 120. The tape drive 100 also comprises data-processing apparatus, described below, for controlling various functions of the tape drive 100.

[0021] Figure 2 is a functional block diagram showing an exemplary tape drive control arrangement 200 including a servo controller 210, a formatter 215, and a tape drive controller 205 for overall control of the tape drive 100. The functions of the tape drive controller 205 are performed by processing apparatus 206 that operates to

- 4 -

execute computer program instructions 207 stored in memory 208 of the tape drive controller 205.

[0022] Under control of the tape drive controller 205, the formatter 215 receives through an interface 217 user data transmitted using any suitable protocol 216 from one or more host computers (not shown). The formatter 215 processes the received user data into suitably formatted code words that are transferred through an internal communications medium 218 to a bank of pre-amplifiers 219 that provide analogue signals to read/write transducer head elements 220 of the transducer head apparatus 131 for writing to the data storage tape 111. Analogue signals read by the read/write transducer head elements 220 from the tape 111 are passed back through the pre-amplifiers 219, converted into digital signals using processing circuitry 221 and timing information received from the servo controller 210, and processed by the formatter 215 for transmission through the interface 217 to a host computer.

[0023] In figure 2, the read/write transducer head elements 220 are shown as 16 horizontally aligned read/write head element pairs, each element of each pair being capable of reading and writing. When the magnetic tape 111 moves past the head elements 220, one element of each head element pair writes data to the magnetic tape and the other elements of each head element pair immediately reads the data for error detection purposes. The roles of the head elements 220 in each pair are reversed when the tape 111 travels in the opposite direction. In alternative embodiments, a greater or lesser number of read/write head elements 220 can be provided, and/or the read/write head elements 220 can be provided in a single array and not in pairs.

[0024] Buffers 222 and 223 are provided to facilitate management of data flows by the host interface 217 and formatter 215 respectively. An automation control interface 224 can be provided to enable operation of the tape drive 100 in a tape library, and/or a user interface 225 can be provided for direct interaction of the tape drive 100 with a user. The functions of the formatter 215 are provided by processing apparatus that operates to execute computer program instructions 226 stored in memory 227.

- 5 -

[0025] Under control of the tape drive controller 205, the servo controller 210 receives, via the pre-amplifiers 219, analogue servo signals produced by servo transducer heads 230 of the transducer head apparatus 131 and processes the received servo signals, as described in further detail below. The servo transducer heads 230 are arranged as horizontally aligned pairs of read elements disposed at opposite ends of the arrays of read/write head elements 220, to respectively read information from two servo bands of a formatted magnetic tape, also described in further detail below.

[0026] The servo controller 210 also receives and processes signals from the reel speed sensors 238. The server controller 210 is operable to deterministically control, communicating through suitable interfaces 231, tape drive functions such as lateral positioning of the data transducer heads 220 by the actuator of the transducer head apparatus 131, operation of the reel motors 232 for controlling tape longitudinal speed and position, and operation of one or more motors 233 for loading and unloading the cartridge 110 and/or actuating a tape lifting device. The functions of the servo controller 210 are provided by processing apparatus 235 that operates to execute computer program instructions 236 stored in memory 237.

[0027] Figure 3 shows the structure and formatting of an exemplary magnetic tape 302, similar to the tape 111. The magnetic tape 302 accords to an LTO (linear tape open) magnetic tape technology standard and extends longitudinally up to 820 m, with a width 304 of 12.65 cm. The magnetic tape has a base substrate such as polyethylene terephthalate, coated with a layer of ferro-magnetic material dispersed in a suitable binder. The tape is divided into seven logical regions bounded by eight logical points LP0 through LP7. The logical regions include a forward servo acquisition region 306, a calibration region 308, a user data region 310, an unspecified data region 312 (which may have zero length depending on tape configuration), and a reverse servo acquisition region 314.

[0028] Figure 3 also shows a detailed view of a portion 322 of the user data region 310 of the tape 302. The user data region 310 has five servo bands 340-344 extending in a longitudinal direction of the tape 302, which can be pre-recorded on the

tape 302 at manufacture. Edge-guard bands 324 and 326 are provided at the top and bottom of the user data region 310, and a respective data band 330-333 is defined between each pair of the servo bands 340-344. Each servo band 340-344 comprises a longitudinally extending sequence of longitudinal position (LPOS) words.

[0029] Figure 3 further shows a detailed view 352 of a portion 350 of one of the servo bands 340. Each LPOS word 354 is encoded over 36 servo frames, such as servo frame 356. Each LPOS word 354 encodes a synchronisation mark, a longitudinal position (LPOS) value, and optional manufacturer's data. Each servo frame encodes one bit of LPOS data. The LPOS words are recorded continuously along the length of the tape, and the LPOS value increments by one every 36 servo frames.

[0030] Figure 4 shows a detailed view of a format structure of one of the data bands 331 of the portion 322 of the user data region 310 of the tape 302. Each of the data bands 330, 332, 333 has a corresponding structure. The data band 331, bounded on each side by servo bands 341 and 342, is divided into 16 data sub-bands 402-417, the number of data sub-bands corresponding to the number of read/write head elements 220. Each sub-band, such as sub-band 403, is in turn divided into 20 parallel data tracks 420-439. The format allows for the servo bands 340-344 to be pre-recorded on the tape 302 at manufacture, the pre-recorded servo bands 340-344 defining the regions of the data bands 330-333, the data tracks 420-439 being written according to the format during use.

[0031] In use, the read/write head elements 220 are positioned within a same one of the data bands 330-333. Each read/write head element 220 pair is aligned with a respective track in a respective sub band 402-417 corresponding to that head element pair. That is, each of the 16 read/write head element pairs reads data from and/or writes data to a data track in a corresponding one of the data sub-bands 402-417. The two servo head 230 element pairs are positioned over respective servo bands 340-344 bounding opposite longitudinal sides of the presently used data band 330-333. The 16 read/write head element 220 pairs, concurrently read from and/or write to the tape 320.

- 7 -

[0032] While the above-described format and structure corresponds to the Ultrium 5 LTO (linear tape open) standard, it will be understood that alternative embodiments can include different, for example significantly increased, numbers of data bands, and/or different, for example significantly increased, numbers of sub-bands within each data band, and/or different, for example significantly increased, numbers of data tracks within each sub-band. Such alternative formats will likely result in an increase in noise in the servo signal, due to the decreased track pitch, that is, the decreased distance between the centre lines of the data tracks.

[0033] In alternative embodiments, at least some of the servo bands could be written during use instead of being pre-recorded, and/or instead of dedicated servo bands, servo information could be written along a longitudinally extending portion of at least some of the data tracks.

[0034] Figures 5-7 and 9 show further details of the servo frames, such as the servo frame 356 of the servo band 340 figure 3. Each servo frame comprises a longitudinally extending sequence of servo elements in the form of pre-recorded magnetic stripes. As shown in figure 5, the exemplary servo frame 356 comprises an A burst 501 having a group of seven azimuthally inclined stripes a1-a7, a B burst 502 having a group of seven oppositely azimuthally inclined stripes b1-b7, a C burst 503 having a group of six stripes c1-c6 azimuthally inclined similarly to the A burst stripes, and a D burst 504 having a group of six stripes oppositely azimuthally inclined to the C burst stripes.

[0035] As the tape 302 moves in a direction to the left as shown in figures 5-7 and 9, respective signals are generated by the servo transducer head elements 230 and transmitted to the servo controller 210 through the preamplifiers 219. An exemplary servo readback signal 505 is shown in figure 5. Broken line 506 shows a typical tracking path of one of the servo head elements 230 along the servo band 340. As the servo head element 230 encounters a positive transition of one of the stripes a1-a7, b1-b7, c1-c6, d1-d6 a corresponding positive peak is produced in the signal 505, for example as shown by broken lines 510-513. Similarly, as the servo head element 230

- 8 -

encounters a negative transition in one of the stripes a1-d6, a corresponding negative peak is produced in the signal 505.

[0036] For a substantially constant tape speed and a substantially constant lateral tracking position, the time between peaks corresponding to stripes of mutually opposite azimuth should progressively change as the servo head 230 traverses the servo band 340, and the time between peaks corresponding to the stripes of the same azimuth should remain substantially constant. The signal 505 can be processed as described in further detail below to detect peaks in the signal to determine a lateral position of the servo head element 230 relative to the tape 302, to control a position of the read/write head elements 220 relative to respective ones of the data tracks 420-439. The difference between the number of stripes in the A and B bursts and the number of stripes in the C and D bursts assists in the identification of the start and end of frames 356 during processing.

[0037] Figure 6 illustrates a servo frame 600 having bursts of servo stripes encoding an LPOS bit having a value of one. The stripes c1-c6 and d1-d6 within each of the C and D bursts 603, 604 have a specified regular relative longitudinal displacement of, for example, 5.00 μm , or any other convenient distance. Stripes a2 and a3 of the A burst 601 have each been shifted from a regular relative displacement, longitudinally away from the non-shifted centre stripe a4 of the A burst 601 (to the left in figure 6) and closer to the non-shifted outer stripe a1 of the A burst by a shift distance of, for example, 0.25 μm , or any other convenient distance. Stripes a5 and a6 of the A burst 601 have each been shifted from a regular relative displacement, longitudinally away from the centre stripe a4 of the A burst 601 (to the right in figure 6) and closer to the non-shifted outer stripe a7 of the A burst by the shift distance of 0.25 μm , or any other convenient distance. It will be apparent that the shift distances as shown in figures 6 and 7 are exaggerated in order to better illustrate the principles described. The pattern of relative displacement between the shifted and non-shifted stripes within the A burst is used to encode the value of the LPOS bit. Stripes b2, b3, b5 and b6 of the B burst 602 are shifted longitudinally away from the centre stripe b4 in a manner analogous to the shifts in the corresponding A burst stripes, to redundantly encode the same LPOS bit value as the A burst 601.

[0038] Figure 7 illustrates a servo frame 700 having bursts of servo stripes encoding an LPOS bit having a value of zero. The stripes c1-c6 and d1-d6 within each of the C and D bursts 703, 704 have a regular relative longitudinal displacement of, for example, 5.00 μm , or any other convenient distance. Stripes a2 and a3 of the A burst 701 have each been shifted from a regular relative displacement, longitudinally towards the non-shifted centre stripe a4 of the A burst 701 (to the right in figure 7) and closer to the non-shifted outer stripe a1 of the A burst 701 by a shift distance of, for example, 0.25 μm , or any other convenient distance. Stripes a5 and a6 of the A burst 701 have each been shifted from a regular relative displacement, longitudinally towards the centre stripe a4 of the A burst 701 (to the left in figure 7) and away from the non-shifted outer stripe a7 of the A burst 701 by the shift distance of 0.25 μm , or any other convenient distance. The pattern of relative displacement between the shifted and non-shifted stripes within the A burst is used to encode the value of the LPOS bit. Stripes b2, b3, b5 and b6 of the B burst 702 are shifted longitudinally towards the centre stripe b4 in a manner analogous to the shifts in the corresponding A burst stripes, to redundantly encode the same LPOS bit value as the A burst 701.

[0039] The A and B bursts of the frames in the servo bands 340-344 similarly redundantly encode a further LPOS bit per frame. Servo signals generated by the A burst 601, 701 and/or B burst 602, 702 can be processed in any convenient manner to decode the LPOS bit value, for example according to a process described below.

[0040] Figure 8 is a functional diagram showing processing apparatus 800 of the servo controller 210, for processing servo readback signals to decode information, including LPOS information, from the servo frames of figures 6 and 7. As shown in figure 8, the servo controller 210 further includes a pulse detector 801 comprising circuitry that receives the pre-amplified and filtered servo readback signal 805 and outputs a series of discrete pulses 806. The leading edges of the pulses 806 correspond to the positive peaks of the readback waveform 805. However, alternatively or additionally, pulses corresponding to other waveform characteristics could be provided, for example corresponding to the negative peaks of the readback waveform 805. The pulses 806 are received by a timestamp pre-processor 807 that creates for each pulse 806 a timestamp consisting of the value of a free running

- 10 -

counter corresponding to the time of receipt of the pulse. The timestamps 809 are stored in registers in a timestamp memory 810, the registers being arranged in banks, each bank corresponding to a servo burst. In the present embodiment, there are four banks storing timestamps from four bursts namely the next burst (not yet completely received), current (most recently completed burst), previous and double previous burst.

[0041] Burst detector and qualifier circuitry 808 is also provided that can include, for example, a burst qualifier and pattern detector. The burst qualifier tests for example whether a detected burst contains a minimum number of pulses and minimum gap between pulses, and is operable to output a qualified end of burst signal QEOB following a successful test. The pattern detector determines whether a detected sequence of bursts is valid, for example whether the last 4 bursts received comprise one of the following sequences: 7766, 7667, 6677 or 6776.

[0042] A timestamp processor 815 is provided for receiving the timestamps 809 of each burst from the timestamp memory 810 and processing the timestamps 809 to determine tape speed, LPOS bit value, and lateral position of the head elements 220, 230 relative to the tape 302.

[0043] Figure 9 shows seven-stripe A and B bursts 901, 902 similar to the A and B bursts 501, 502, 601, 602 of figures 5 and 6. Figure 9 also shows a representation of the pre-amplified and filtered feedback signal 905 generated by the servo transducer head 230, and an exemplary series of pulses 806 generated by passing the readback waveform 905 through the pulse detector 801 and detecting the positive peaks of the waveform 905. Each pulse corresponds to, and has being given a similar reference numeral to, a respective stripe a1-a7, b1-b7 from which it was generated. Narrower vertical broken lines correspond to the theoretical regular (unshifted) positions of positive transitions of all stripes a1-a7, b1-b7 relative to an exemplary tracking position of the servo head element 230, and thicker vertical broken lines correspond to actual positions and signals of the positive transitions of the shifted stripes a2, a3, a5, a6, b2, b3, b5, b6 for the same servo head element tracking position.

- 11 -

[0044] To determine lateral position of the servo head element 230, the timestamp processor is operable to use the timestamps 809 to calculate and accumulate time differences, for example b1-a1, b2-a2, b3-a3, b4-a4, b5-a5, b6-a6, or d1-c1, d2-c2, d3-c3, d4-c4, d5-c5, d6-c6 (figures 5 to 7), between respective corresponding positive signal peaks in consecutive bursts of opposite azimuth, sometimes called the P value. Accumulating the time differences effectively allows for an averaging out of isolated errors in some pulses, for example errors caused by thermal asperities. The timestamp processor is also operable to calculate and accumulate the time differences c1-a1, c2-a2, c3-a3, c4-a4, c5-a5, c6-a6 between respective corresponding positive peaks in selected bursts of the same azimuth, sometimes called the S value, and to calculate the P/S ratio. Alternatively or additionally, another signal characteristic such as negative peaks can be employed, and/or time differences between stripes in other combinations of bursts could be used, including bursts in adjacent frames. The P/S ratio provides an indication of lateral position of the servo head 230 that also accounts for tape speed. The timestamp processor 815 outputs the P, P/S and/or S data to a processor 816 for controlling lateral position of the read/write head elements relative to data tracks 420-439, and/or for controlling speed of the reel motors 232.

[0045] Figure 9 illustrates data values in the form of time difference values L1-L8 that can be obtained by the decoder apparatus from the A and B servo bursts 901, 902, each of which redundantly encodes an LPOS bit value. The four shifted stripes a2, a3, a5, a6 and b2, b3, b5, b6 in each burst 901, 902 are shown with hatching in figure 9. The non-shifted stripes are shown without hatching. The timestamp processor 815 is operable to receive from the timestamp memory an array of timestamps 809 corresponding to the stripes a1-a7 or b1-b7 in an A or B burst, and process the timestamps 809 to generate data in the form of time difference values L1-L8 related to relative displacement of mutually adjacent shifted and non-shifted stripes within the received servo burst.

[0046] In one embodiment, the timestamp processor 815 is operable to generate an LPOS value by accumulating the time difference values L1-L8, with a different sign (positive or negative) being used for the time differences L1, L3, L6, L8 involving the

- 12 -

non-shifted stripes at opposite ends of a burst and the time differences L2, L4, L5, L7 involving the central non-shifted stripe. For example, considering the A burst 901:

$$\text{LPOS value} = (a2-a1)-(a4-a2)+(a3-a1)-(a4-a3)-(a5-a4)+(a7-a5)-(a6-a4)+(a7-a6)$$

The timestamp processor 815 is operable to compare the LPOS value against a zero value to determine if the LPOS bit is a one or zero. In figure 9, the direction of the shift of the shifted stripes a2, a3, a5, a6 and b2, b3, b5, b6 is away from the central non-shifted stripe a4, b4, the LPOS value is negative and the LPOS bit is a one.

Conversely, where the direction of shift is inwardly toward the central non-shifted stripe, the LPOS value is positive and the LPOS bit is a zero.

[0047] The timestamp processor 815 is operable to transmit the resulting LPOS bit data to an LPOS word decoder 817 that is operable to process the LPOS bit values to construct an LPOS word. In some embodiments, the timestamp processor 815 is operable to provide the LPOS word decoder 817 with LPOS bit quality information that can be used by the LPOS word decoder 817 to better determine the correct sense of the LPOS bit where LPOS bit values are redundantly provided from multiple servo bursts.

[0048] In alternative embodiments, the signals in the readback waveform 905 can be processed in other ways. For example, individual time differences could be compared to a nominal reference, the sign of the deviation from the nominal reference (positive or negative) indicating a logical one or a logical zero. Additionally or alternatively, the negative peak signal information can be processed analogously to the processing of the positive peak single information described above.

[0049] Figures 10 to 12 relate to an alternative embodiment, in which the number of stripes in a servo frame 1000, 1100 is further increased. The A and B bursts 1001, 1101, 1002, 1102 respectively contain nine stripes, and the C and D bursts 1003, 1103, 1004, 1104 respectively contain eight stripes. As best shown in exaggerated form in figures 10 and 11, in the A and B bursts the number of shifted stripes in the unbroken sequences, for example a2, a3, a4 and a6, a7, a8 between the non-shifted stripes is increased to three, and the three non-shifted stripes are moved by a shift

- 13 -

distance away from the central non-shifted stripe in each burst 1001, 1002 to encode a one and towards the central non-shifted stripe in each burst 1101, 1102 to encode a zero. In figure 12, narrower vertical broken lines correspond to theoretical regular (unshifted) positions of positive transitions of stripes a1-a9 of the A burst 1001 relative to an exemplary tracking position of the servo head element 230, and thicker vertical broken lines correspond to actual positions and signals of positive transitions of the shifted stripes a2, a3, a4, a6, a7, a8 for the same servo head element tracking position.

[0050] In the embodiment of figures 10 to 12, appropriate processing apparatus can take a similar form to the processing apparatus 800 of figure 8, but is adapted to process the increased number of stripes in the A, B, C and D bursts, including the increased number of shifted stripes in the unbroken sequences. For example, to determine lateral position of the servo head element 230, the timestamp processor is operable to use the timestamps 809 to calculate and accumulate, for example, time differences b1-a1, b2-a2, b3-a3, b4-a4, b5-a5, b6-a6, b7-a7, b8-a8, or d1-c1, d2-c2, d3-c3, d4-c4, d5-c5, d6-c6, d7-c7, d8-c8 between respective corresponding positive signal peaks in consecutive bursts of opposite azimuth, and the time differences c1-a1, c2-a2, c3-a3, c4-a4, c5-a5, c6-a6, c7-a7, c8-a8 between respective corresponding positive peaks in selected bursts of the same azimuth. To generate the LPOS value the time difference values L1-L12, shown in figure 12, are accumulated, with a different sign (positive or negative) being used for the time differences L1, L3, L5, L8, L10, L12 involving the non-shifted stripes at opposite ends of a burst and the time differences L2, L4, L6, L7, L9, L11 involving the central non-shifted stripe. Considering the A burst 1001, the timestamp processor 815 is operable to calculate the LPOS value:

$$\text{LPOS value} = (a2-a1)-(a5-a2)+(a3-a1)-(a5-a3)+(a4-a1)-(a5-a4)-(a6-a5)+ \\ (a9-a6)-(a7-a5)+(a9-a7)-(a8-a5)+(a9-a8)$$

As previously, the timestamp processor 815 is operable to compare the LPOS value against a zero value to determine if the LPOS bit is a one or zero. The resultant LPOS bit, including any redundant LPOS bits, can be transmitted and further processed as described above. In alternative embodiments, there is provided a still further

- 14 -

increased number of shifted stripes in the unbroken sequences, and the processing apparatus 800 of figure 8 is adapted accordingly to process frames having an increased number of stripes in the A, B, C and D bursts.

[0051] Figure 13 illustrates steps in a method of decoding LPOS information from servo elements, such as the servo stripes described with reference to figures 6, 7, 9 and 10 to 12, arranged in a longitudinally extending sequence in servo bursts 901, 902, 1001, 1002, 1101, 1102 on a data storage medium, at least some of the servo bursts including non-shifted elements and an unbroken sequence of plural shifted elements. A signal waveform is generated by a transducer head apparatus detecting the servo elements as they are moved past servo head elements of the transducer head apparatus. The signals are received 1301 and processed 1302, for example using the apparatus described with reference to figure 8, or in any other convenient manner, to obtain data, for example L2, L3, L6, L7 (figure 9), related to relative displacement of respective mutually non-adjacent shifted and non-shifted elements within a servo burst and data, for example L1, L4, L5, L8 (figure 9), related to relative displacement of mutually adjacent shifted and non-shifted elements within the burst. The data is then further processed 1303, for example by accumulation as described above or in any other convenient manner, to determine an LPOS bit value. The LPOS bit value can be output, and a plurality of outputted LPOS bit values used to construct an LPOS word to control a position of the storage medium relative to the transducer head of a storage device such as a tape drive.

[0052] At least some of the embodiments described above are advantageous in that the increased number of servo elements in the bursts of a servo frame, compared to the known five stripe and four stripe LTO Ultrium servo frames, facilitates better recovery of position and/or speed information encoded in the servo frame, mitigating the effects of increased noise particularly in embodiments having a decreased data track pitch. In at least some of the embodiments, better recovery of LPOS information, for example a reduction in the effect of small tape defects or debris causing a shift in peak of one of the readback pulses, is concurrently facilitated by using data related to relative displacement of mutually non-adjacent shifted and non-shifted elements. For example the use of non-adjacent time difference values L2, L3, L6, L7 (figure 9) or L2,

- 15 -

L3, L4, L5, L8, L9, L10, L11 (figure 12), in addition to the adjacent time difference values L1, L4, L5, L8 (figure 9) or L1, L6, L7, L12 (figure 12) increases the number of time difference values used from four in the known five stripe LPOS servo burst method to eight (figure 9) or twelve (figure 12). At least some of the embodiments provide servo bands that are easily readable in both directions of tape movement with relatively little adaptation needed to the decoding process between forward and reverse tape directions. The embodiments are easily applied to future formats requiring still greater numbers of servo elements per servo frame to cope with increasingly narrower data track pitch.

[0053] The terms processing apparatus and processor as used herein can include a computer processor (also called microprocessor), a microcontroller, a processor subsystem including one or more processors or microcontrollers, or any other convenient computing device, and can be implemented, according to cost constraints and the manufacturing flexibility required, by fixed hardware such as one or more integrated circuits, by computer program instructions executing, for example, on an embedded processor such as an ARM processor, by programmable hardware such as a field programmable gate array (FPGA), by any combination of the above, or in any other convenient manner.

[0054] The term memory includes any convenient form of processor-readable medium, for example nonvolatile memory technology including erasable and programmable read-only memories (EPROMs), electrically erasable and programmable read only memories (EEPROMs) and flash memories, and a combination of memories. Alternative possibilities include semiconductor memory devices such as dynamic or static random access memories (DRAM or SRAM), and also magnetic disks and other magnetic and/or optical media.

[0055] It will be appreciated that, while various embodiments are described herein with reference to data storage apparatus in the form of a single reel linear magnetic tape drive, aspects of the invention can also be applied to other forms of data storage apparatus that transfer data to and from a data storage medium comprising servo tracks to facilitate control of speed and position of data tracks on the data storage

- 16 -

medium relative to transducer head apparatus of the data storage apparatus. For example, in alternative embodiments the data storage apparatus can comprise a tape drive for receiving two-reel cartridges, and/or can employ magnetic or optical tape, or can comprise other magnetic or optical storage technology.

Claims

1. Decoder apparatus (800) to decode longitudinal position (LPOS) information from servo elements (a1-a9) arranged in a longitudinally extending sequence in servo bursts on a data storage medium (302), at least some of the servo bursts (901, 902) including non-shifted elements (a1, a4, a7) and an unbroken sequence of plural shifted elements (a2-a3, a5-a6), variations in the relative displacement of the non-shifted and shifted elements within a servo burst encoding the LPOS information, the decoder apparatus being operable to:

receive signals (905) from a transducer head apparatus (131) that detects the servo elements as they move past the transducer head apparatus;

process the signals to obtain data (L1, L4, L5, L8) related to relative displacement of mutually adjacent shifted and non-shifted elements within respective ones of the servo bursts, and data (L2, L3, L6, L7) related to relative displacement of mutually non-adjacent shifted and non-shifted elements within the respective ones of the servo bursts; and

process the data to determine LPOS bit values corresponding to the respective ones of the servo bursts.

2. The decoder apparatus of claim 1, further operable, for an unbroken sequence (a2-a3) of plural shifted elements within a servo burst, to process the signals to obtain data related to the relative displacement of each shifted element in the unbroken sequence and the non-shifted element (a1) immediately preceding said unbroken sequence, and between each shifted element in the unbroken sequence and the non-shifted element (a4) immediately following said unbroken sequence, and process the data to determine LPOS bit values corresponding to the respective ones of the servo bursts.

3. The decoder apparatus of any of the preceding claims, operable to:
process the received signals to generate time values (L1, L4, L5, L8) related to the relative displacement of mutually adjacent shifted and non-shifted elements within the respective ones of the servo bursts, and to generate time values (L2, L3, L6, L7)

- 18 -

related to the relative displacement of mutually non-adjacent shifted and non-shifted elements within the respective ones of the servo bursts; and
process the time values to determine LPOS bit values corresponding to respective ones of the servo bursts.

4. The decoder apparatus of any of the preceding claims, comprising:
a pulse detector (801) to detect pulses in read back waveforms generated from the servo elements;
a timestamp pre-processor (807) to generate respective timestamps (809) corresponding to the pulses and store the timestamps in a register; and
a timestamp processor (815) to process the stored timestamps to generate time difference values (L1-L8) related to the relative displacement of shifted and non-shifted elements, accumulate a plurality of the time difference values for respective ones of the servo bursts, and compare the results of each accumulation with a reference value to determine respective LPOS bit values for the servo bursts.

5. Data storage apparatus (100) comprising transducer head apparatus (131), drive apparatus (232) to cause movement of a data storage medium (111) relative to the transducer head apparatus, and a servo controller (210) comprising the decoder apparatus of any of the preceding claims, wherein the servo elements comprise azimuthally inclined stripes (a1-a7, b1-b7), and the servo controller is operable to process a plurality of the LPOS bit values to construct an LPOS word (354), and to use the LPOS word and lateral position information determined from the servo elements to control longitudinal movement of the storage medium (111, 302) and lateral movement of the transducer head apparatus (131).

6. A linear tape drive comprising an apparatus as claimed in any of the preceding claims.

7. A method of decoding longitudinal position (LPOS) information from servo elements (a1-a9) arranged in a longitudinally extending sequence in servo bursts on a data storage medium (302), at least some of the servo bursts (901, 902) including non-shifted elements (a1, a4, a7) and an unbroken sequence of plural shifted elements (a2-a3, a5-a6), variations in the relative displacement of the non-shifted and

- 19 -

6 shifted elements within a servo burst encoding the LPOS information, the method
7 comprising:
8 receiving signals (905) from a transducer head apparatus (131) that detects the
9 servo elements as they move past the transducer head apparatus;
10 processing the signals to obtain data (L1, L4, L5, L8) related to relative
11 displacement of mutually adjacent shifted and non-shifted elements within respective
12 ones of the servo bursts, and data (L2, L3, L6, L7) related to relative displacement of
13 mutually non-adjacent shifted and non-shifted elements within the respective ones of
14 the servo bursts; and
15 processing the data to determine an LPOS bit value.

1 8. The method of claim 7, further comprising outputting the LPOS bit value, using
2 a plurality of outputted LPOS bit values to construct an LPOS word (354), and using
3 the LPOS word to control a position of the storage medium (111, 302) relative to a
4 transducer head (131) of a storage device (100).

1 9. The method of claim 7 or 8, comprising, for an unbroken sequence of plural
2 shifted elements (a2-a3) within a burst, processing the signals to obtain data related to
3 the relative displacement of each shifted element in the unbroken sequence and the
4 non-shifted element (a1) immediately preceding said unbroken sequence, and
5 between each shifted element in the unbroken sequence and the non-shifted element
6 (a4) immediately following said unbroken sequence, and processing the data to
7 determine LPOS bit values corresponding to the respective ones of the servo bursts.

1 10. A storage medium (111, 302) having stored thereon longitudinal position
2 (LPOS) information encoded in servo elements (a1-a7, b1-b7, c1-c6, d1-d6) arranged
3 in a longitudinally extending sequence in servo bursts (501, 502, 503, 504), at least
4 some of the servo bursts comprising non-shifted elements (a1, a4, a7, b1, b4, b7) and
5 an unbroken sequence of plural shifted elements (a2-a3, a5-a6, b2-b3, b5-b6),
6 variations in the relative displacement of non-shifted and shifted elements within a
7 servo burst encoding the LPOS information.

1 11. The storage medium of claim 10, at least some of the servo bursts comprising
2 at least three non-shifted elements (a1, a4, a7), and an unbroken sequence of plural

- 20 -

shifted elements (a2-a3, a5-a6) between each non-shifted element and a next sequential non-shifted element.

12. The storage medium of claim 10 or 11, wherein each unbroken sequence of plural shifted elements in the same burst contains the same number of shifted elements, the burst sequence information being the same when read in either longitudinal direction.

13. The storage medium of claim 11 or 12, comprising a magnetic tape medium, the elements comprising respective magnetized stripes, at least some of the stripes being mutually oppositely azimuthally inclined relative to a transverse direction of the tape to enable determination of lateral alignment of the storage medium relative to read/write head elements (220) of a transducer head apparatus (131).

14. Data storage apparatus having:

a servo controller (210) comprising decoder apparatus (800) to decode longitudinal position (LPOS) information from servo elements (a1-a9) arranged in a longitudinally extending sequence in servo bursts on a data storage medium (302), at least some of the servo bursts (901, 902) including non-shifted elements (a1, a4, a7) and an unbroken sequence of plural shifted elements (a2-a3, a5-a6), variations in the relative displacement of the non-shifted and shifted elements within a servo burst encoding the LPOS information;

drive apparatus (232) to cause longitudinal movement of the data storage medium; and

transducer head apparatus (131) to generate signals from the servo elements as the data storage medium moves past the transducer head apparatus;

the servo controller (210) being operable to:

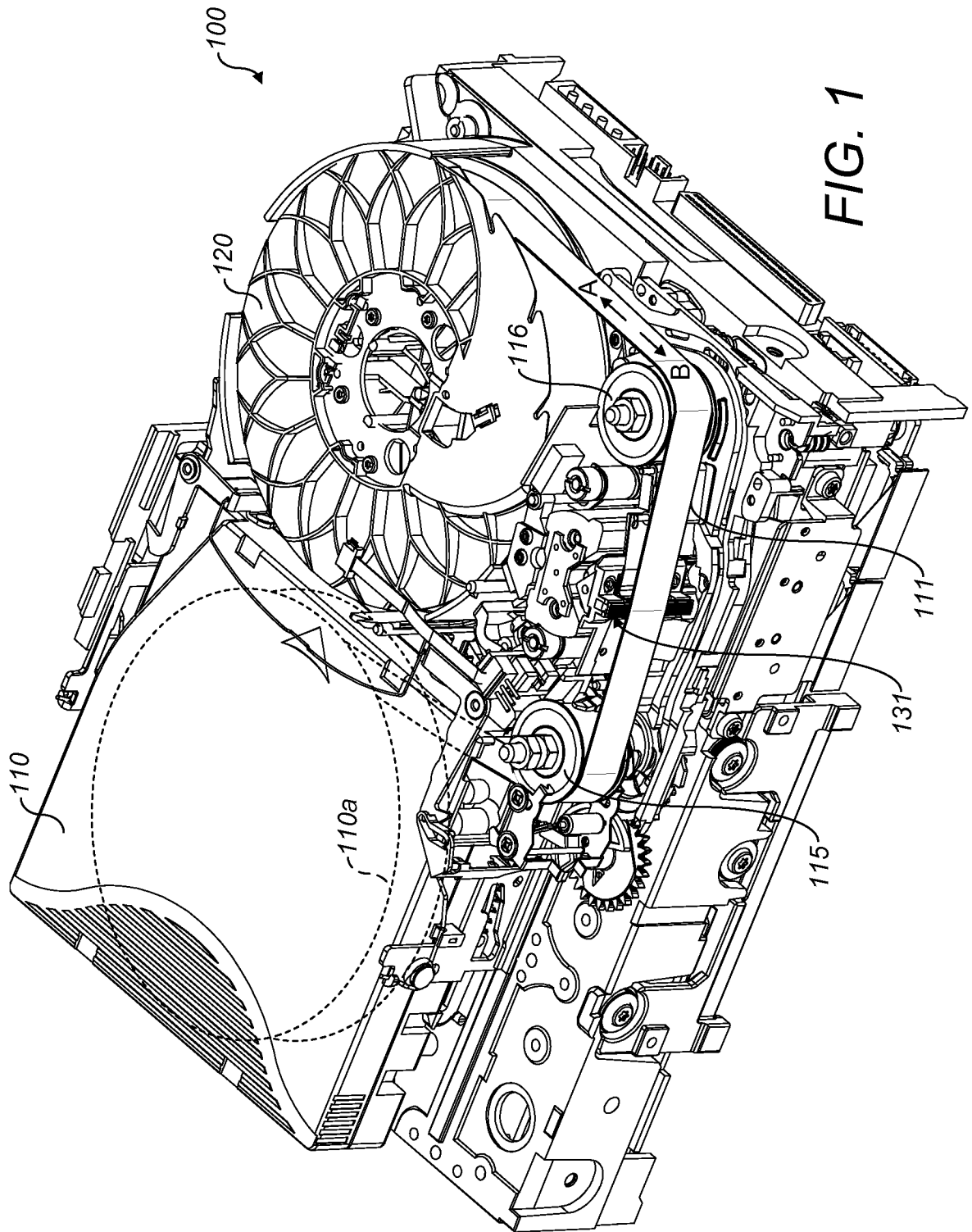
receive signals (905) generated by the transducer head apparatus;

process the signals to obtain data (L1, L4, L5, L8) related to relative displacement of mutually adjacent shifted and non-shifted elements within respective ones of the servo bursts, and data (L2, L3, L6, L7) related to relative displacement of mutually non-adjacent shifted and non-shifted elements within the respective ones of the servo bursts;

- 21 -

20 process the data to determine LPOS bit values corresponding to the respective
21 ones of the servo bursts;
22 use a plurality of the determined LPOS bit values to construct an LPOS
23 word (354); and
24 output the LPOS word for controlling the drive apparatus.

1 15. The data storage apparatus of claim 14, wherein:
2 the decoder apparatus (800) is to decode LPOS information in which the at
3 least some servo bursts comprise at least three non-shifted elements (a1, a4, a7), and
4 unbroken sequences of plural shifted elements (a2-a3, a5-a6) between each non-
5 shifted element and a next sequential non-shifted element, the unbroken sequences
6 containing the shifted elements in equal numbers; and
7 the servo controller (210) is further operable, for an unbroken sequence of
8 plural shifted elements (a2-a3) within a servo burst (901), to process the signals to
9 obtain data related to the relative displacement of each shifted element in the
10 unbroken sequence and the non-shifted element (a1) immediately preceding said
11 unbroken sequence, and between each shifted element in the unbroken sequence
12 and the non-shifted element (a4) immediately following said unbroken sequence, and
13 process the data to determine LPOS bit values corresponding to the respective ones
14 of the servo bursts (901).



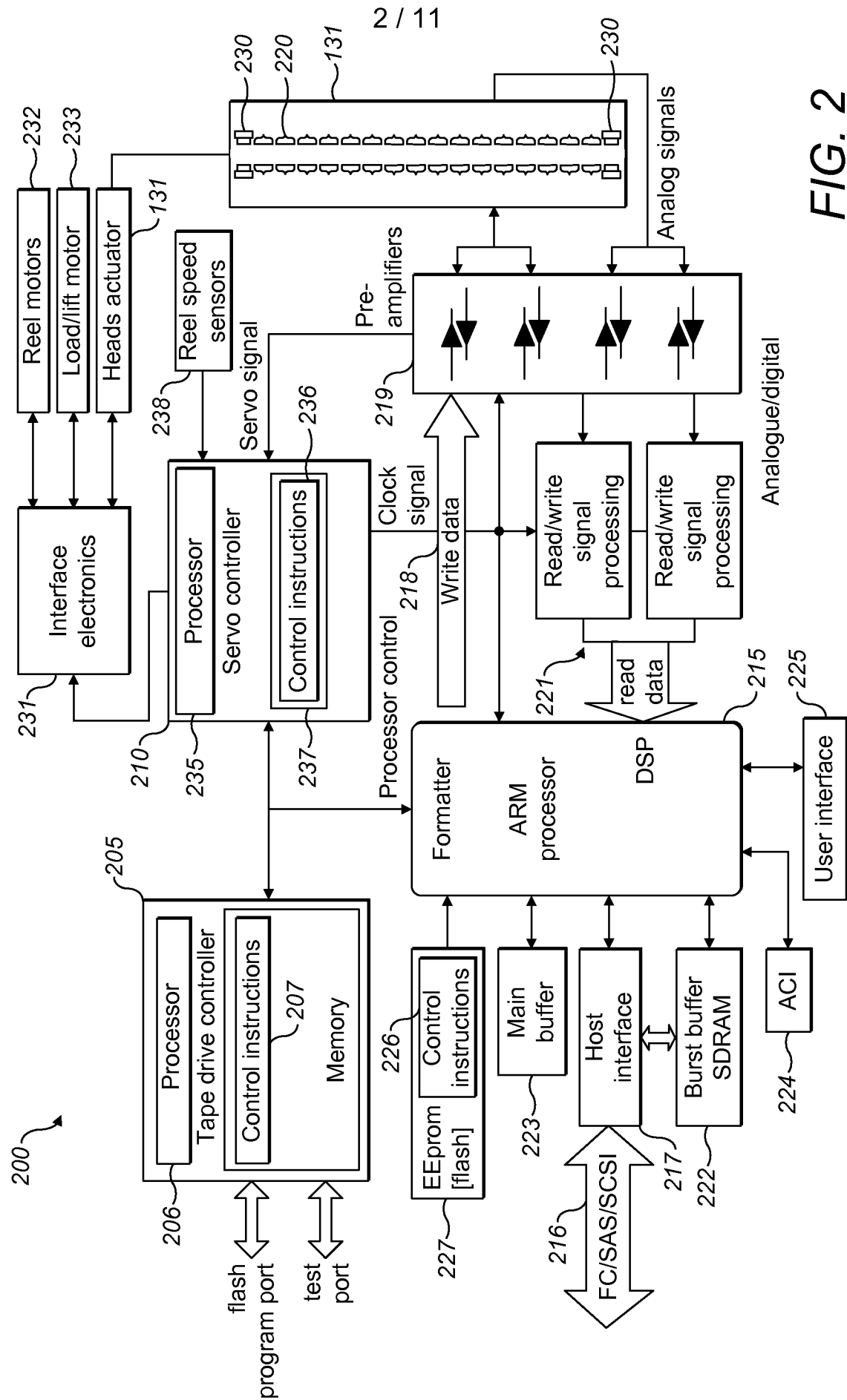


FIG. 2

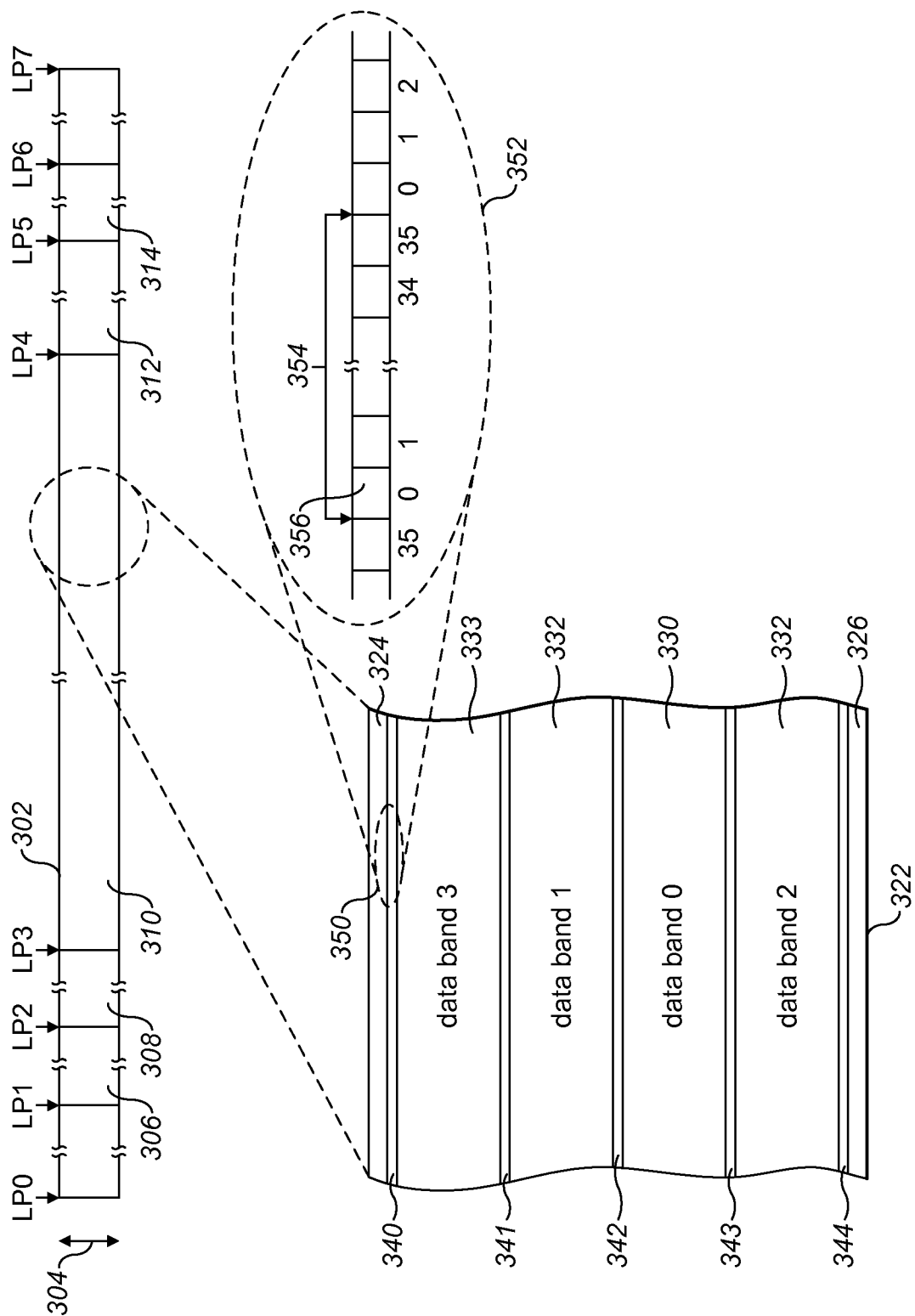


FIG. 3

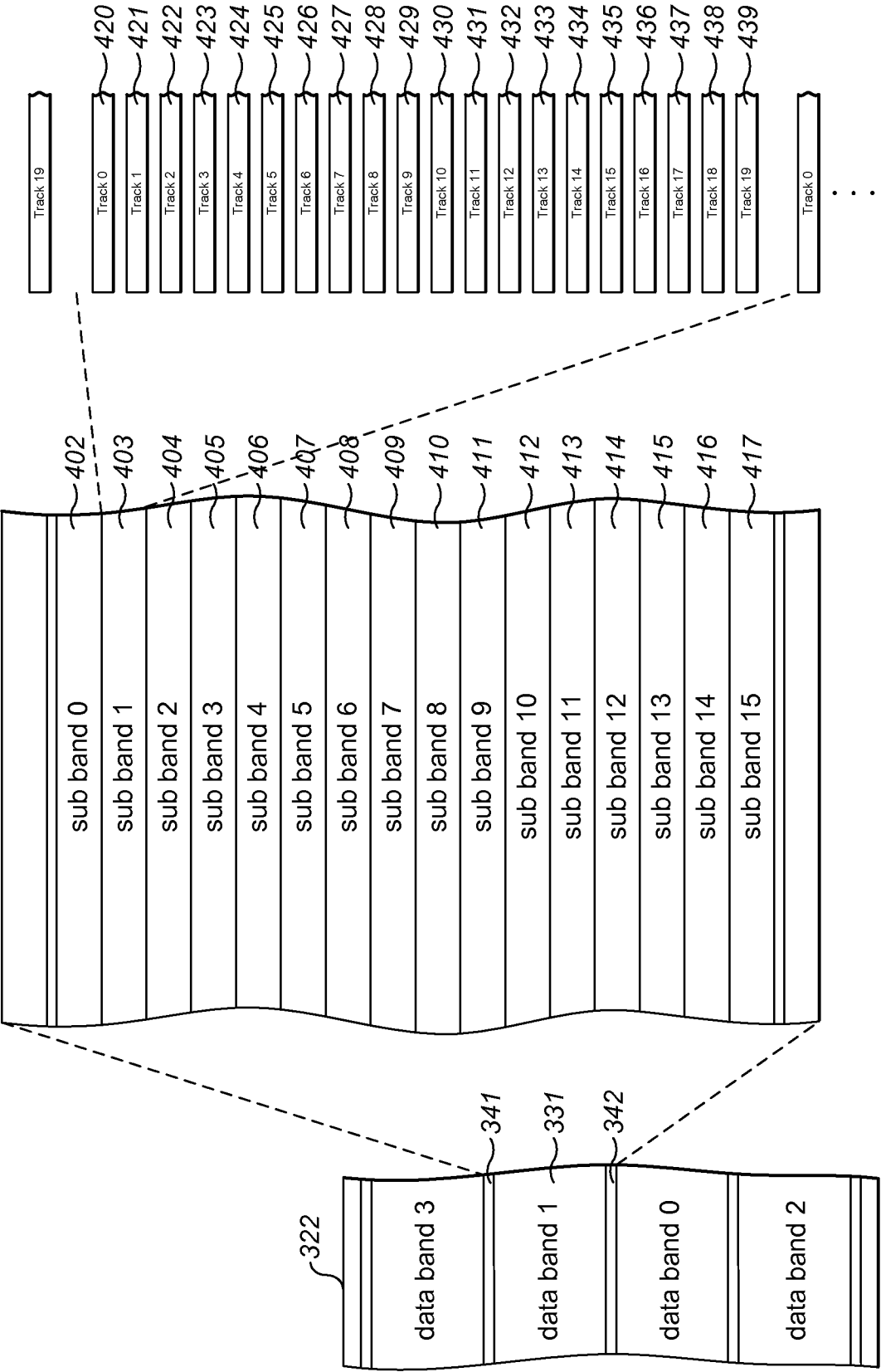


FIG. 4

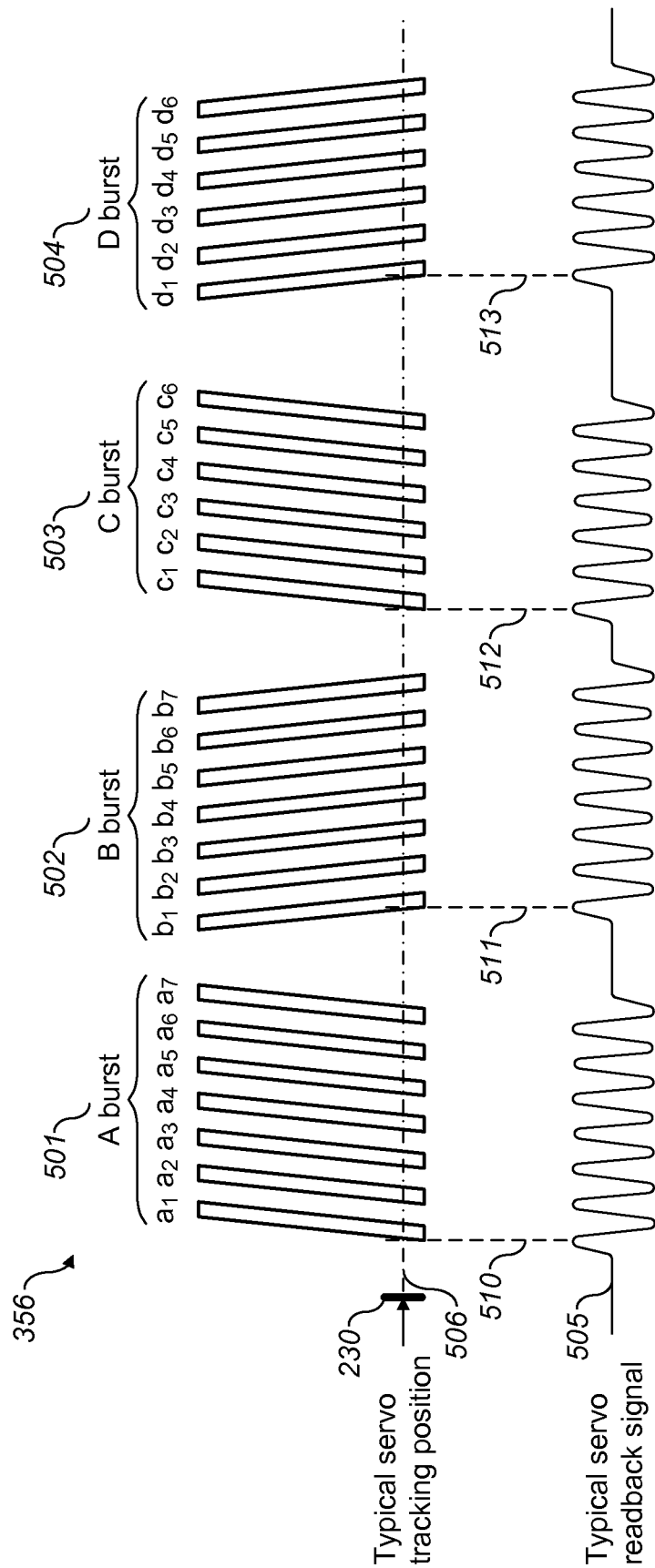


FIG. 5

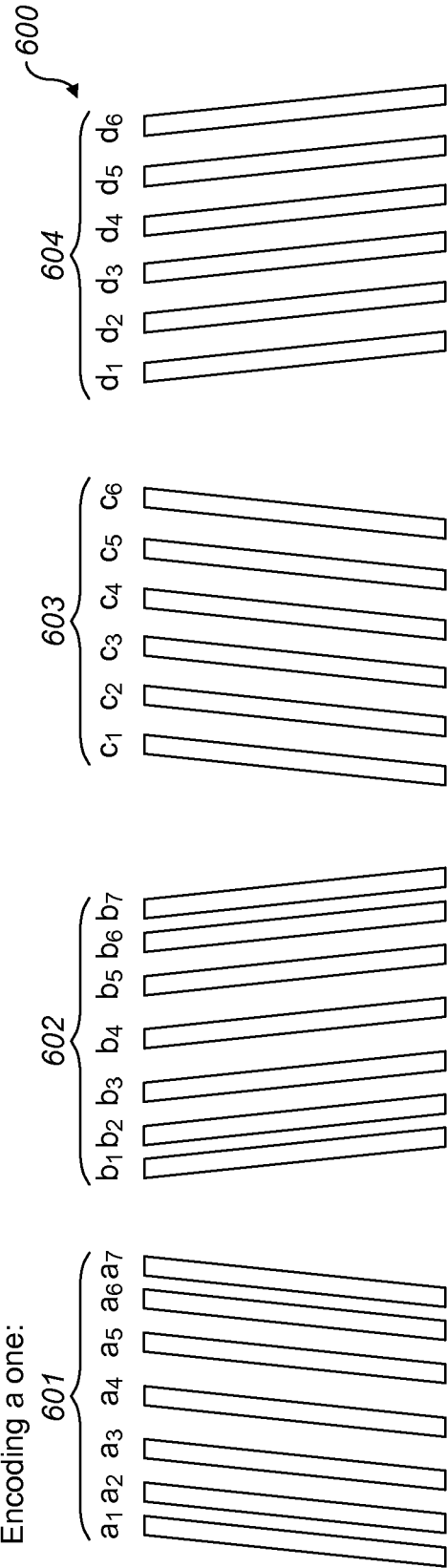


FIG. 6

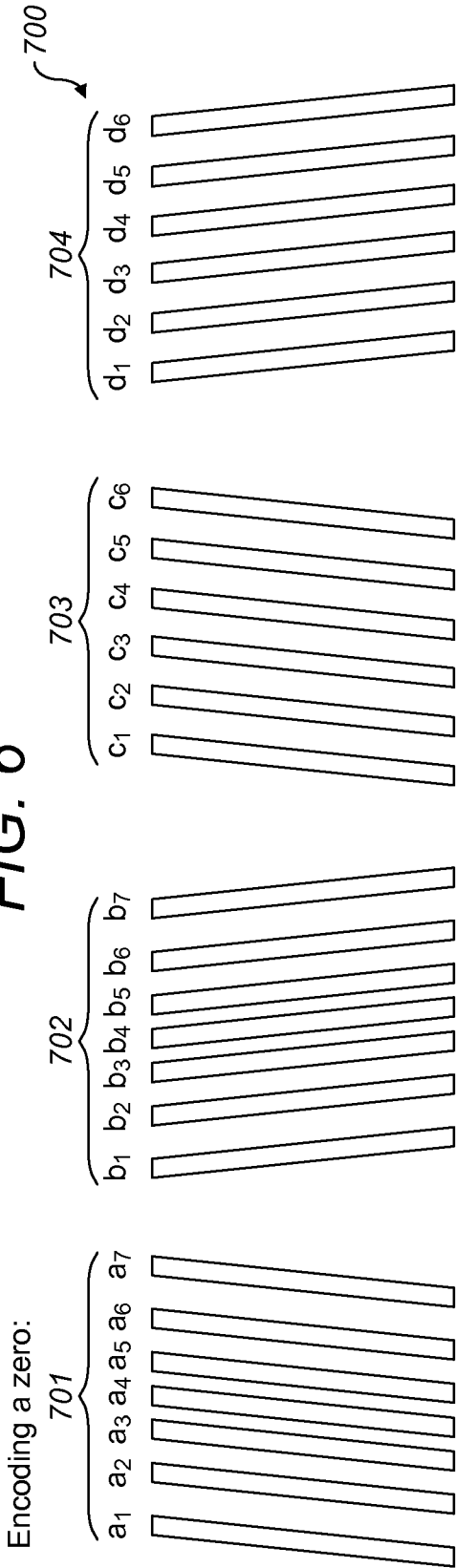


FIG. 7

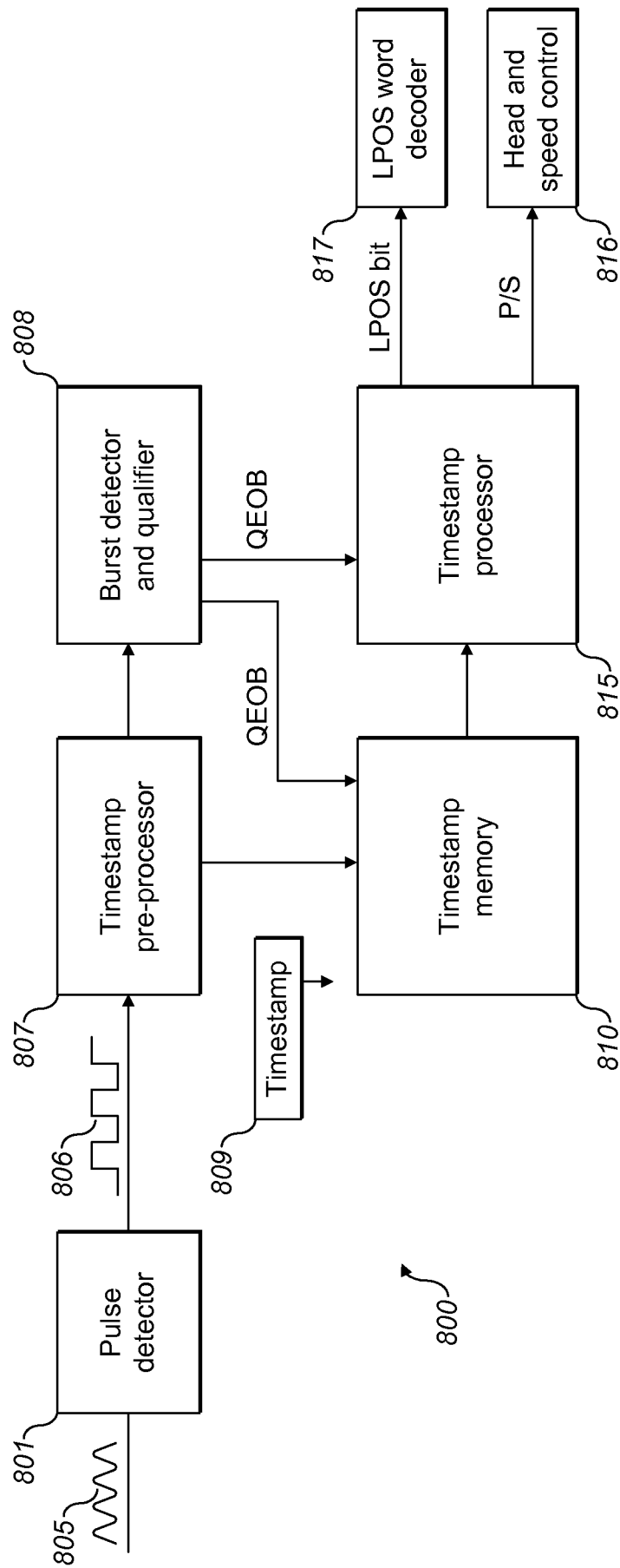


FIG. 8

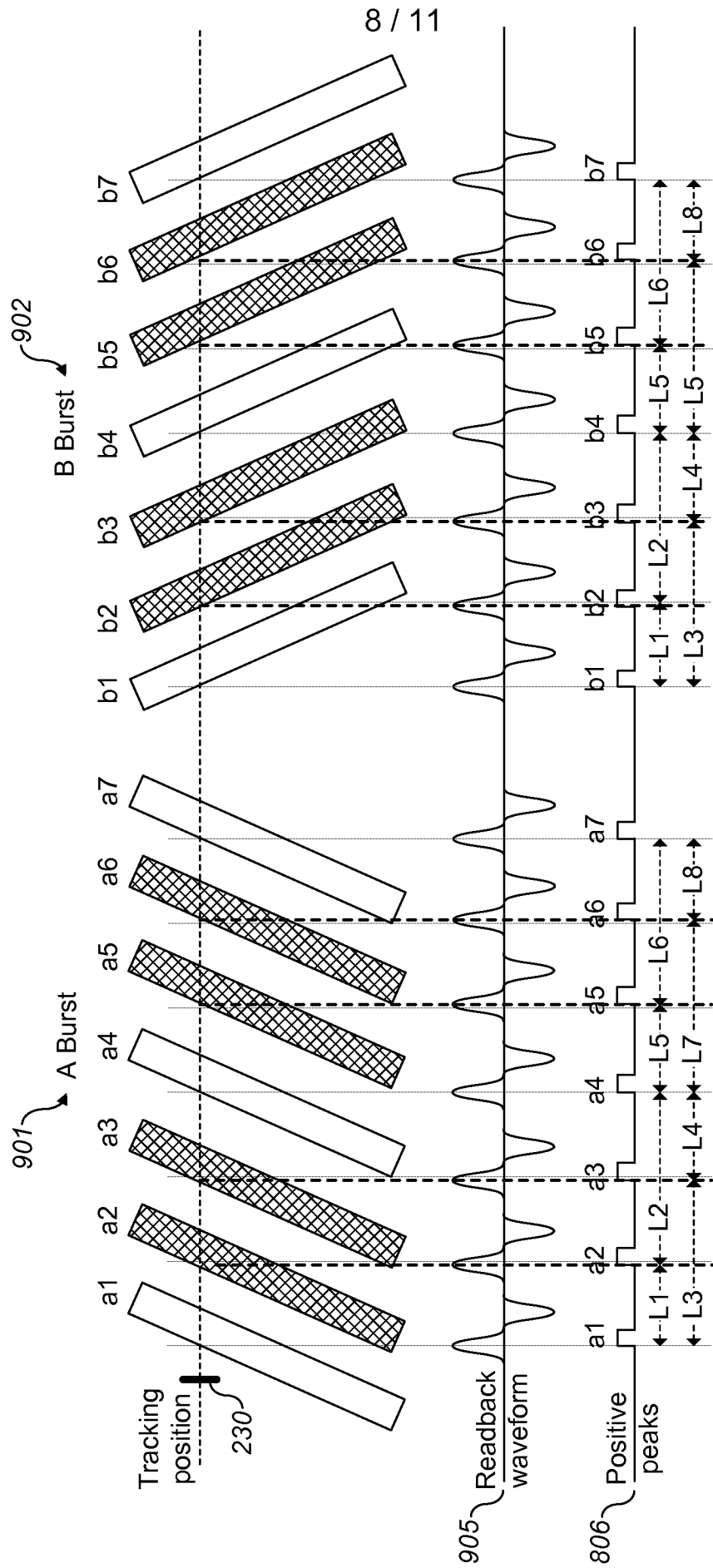


FIG. 9

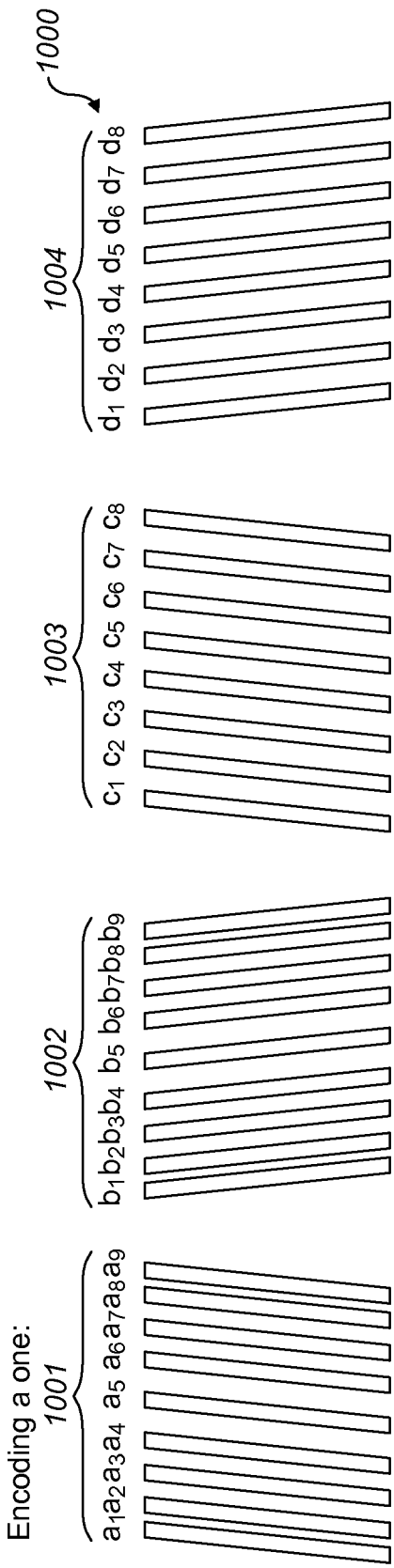


FIG. 10

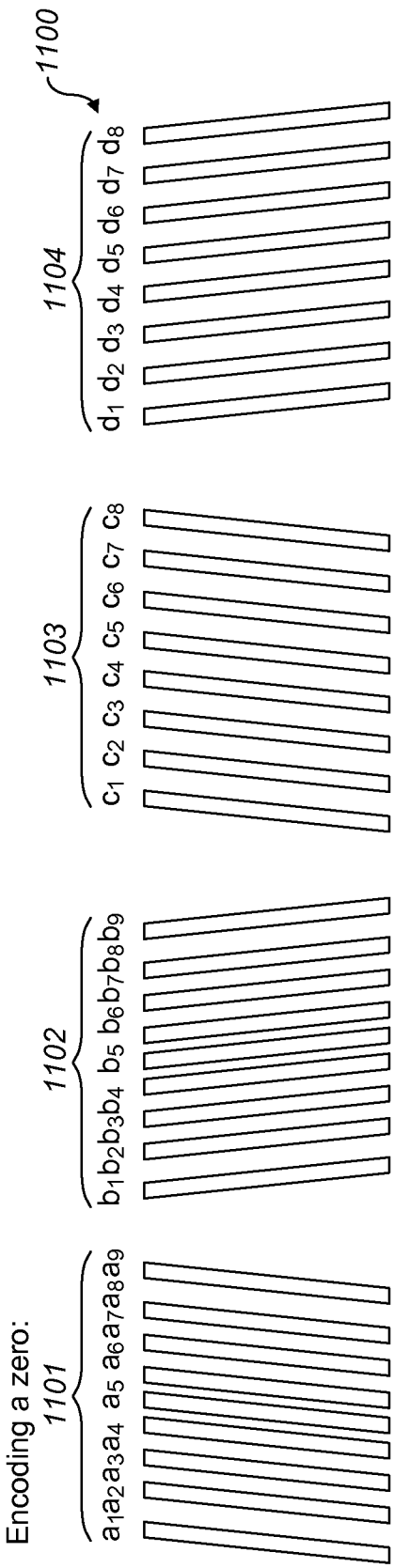


FIG. 11

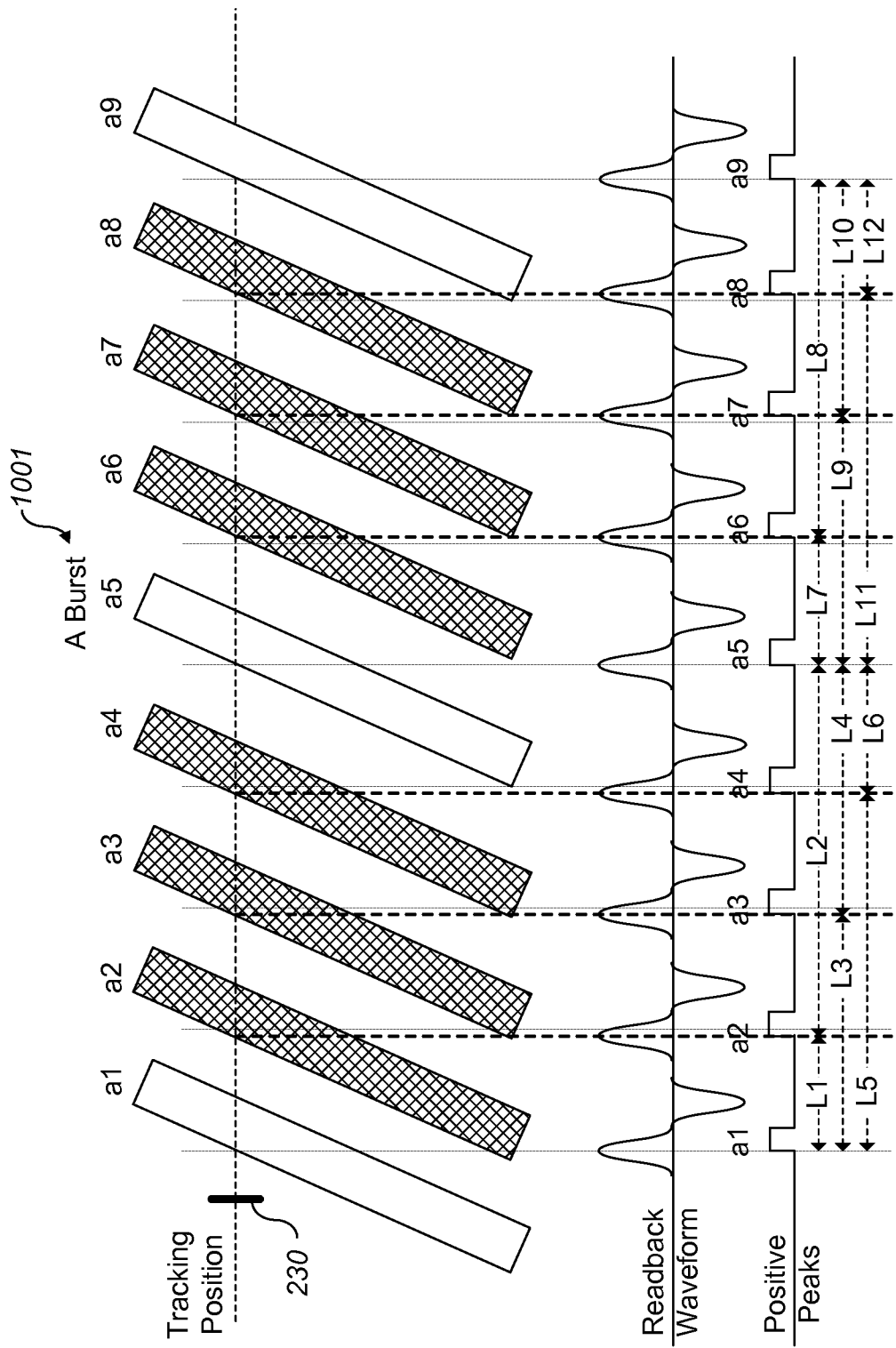
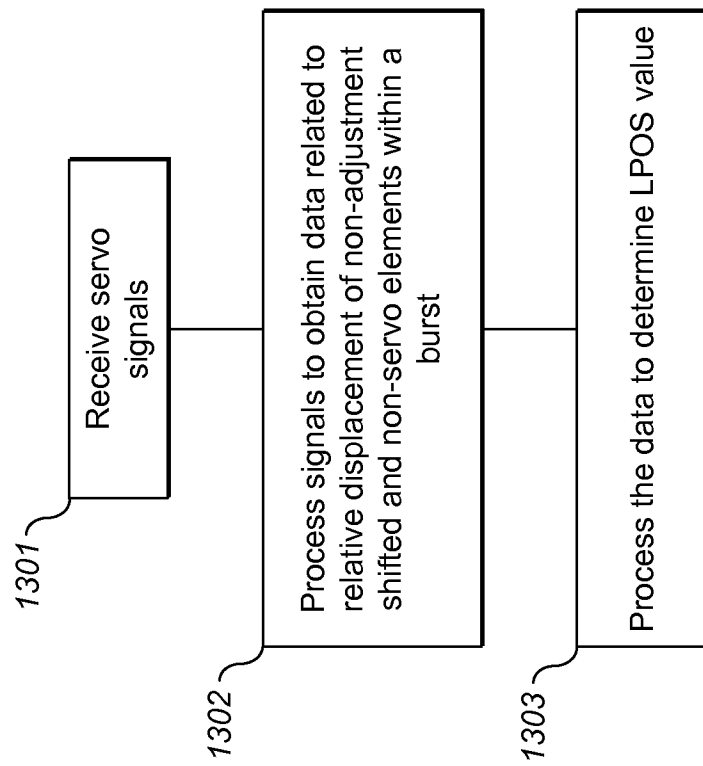


FIG. 12

*FIG. 13*

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2009/042037**A. CLASSIFICATION OF SUBJECT MATTER***G11B 25/06(2006.01)i*

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)

IPC8 : G11B

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

Korean Utility models and applications for Utility models since 1975

Japanese Utility models and applications for Utility models since 1975

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

eKOMPASS(KIPO internal) "Servo, burst, shift, storage, information, data"

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 7355805 B2 (TORU NAKAO et al.) 08 April 2008 See abstract; column 4, line 37 - column 9, line 25; figures 1,2,6-8.	1-3, 7-12, 14, 15
A	US 7440224 B2 (RICHARD M. EHRLICH et al.) 21 October 2008 See abstract; column 2, line 41 - column 11, line 9; figures 3-10.	1-3, 7-12, 14, 15
A	JP 2006-221729 A (SONY CORPORATION) 24 August 2006 See abstract; paragraphs [0015]-[0067]; claims 1-4; figures 1-6.	1-3, 7-12, 14, 15
A	US 2005-0254160 A1 (ZVONIMIR Z. BANDIC et al.) 17 November 2005 See abstract; paragraphs [0025]-[0062]; claims 1-12; figures 1-12.	1-3, 7-12, 14, 15



Further documents are listed in the continuation of Box C.



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 application or patent 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 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

30 DECEMBER 2009 (30.12.2009)

Date of mailing of the international search report

31 DECEMBER 2009 (31.12.2009)

Name and mailing address of the ISA/KR

Korean Intellectual Property Office
Government Complex-Daejeon, 139 Seonsa-ro, Seo-
gu, Daejeon 302-701, Republic of Korea

Facsimile No. 82-42-472-7140

Authorized officer

Lee Byoung Soo

Telephone No. 82-42-481-5697



INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2009/042037**Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☒ Claims Nos.: 4-6,13
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2009/042037

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 7355805 B2	08.04.2008	JP 4157412 B2 JP 2004-318983 A US 2004-0207943 A1	01.10.2008 11.11.2004 21.10.2004
US 7440224 B2	21.10.2008	US 2007-171564 A1	26.07.2007
JP 2006-221729 A	24.08.2006	None	
US 2005-0254160 A1	17.11.2005	EP 1596390 A2 EP 1596390 A3 EP 1596390 B1 JP 2005-327448 A US 06967808 B1	16.11.2005 28.12.2005 13.06.2007 24.11.2005 22.11.2005