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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
07 April 2022 (07.04.2022)

WIPO | PCT

(10) International Publication Number
WO 2022/072015 A1

(51) International Patent Classification:
G11B 5/55 (2006.01) *G11B 5/008* (2006.01)

(21) International Application Number:
PCT/US2021/038154

(22) International Filing Date:
19 June 2021 (19.06.2021)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
63/086,153 01 October 2020 (01.10.2020) US
17/176,024 15 February 2021 (15.02.2021) US

(71) Applicant: **WESTERN DIGITAL TECHNOLOGIES, INC.** [US/US]; 5601 Great Oaks Parkway, San Jose, CA 95119 (US).

(72) Inventors: **YAMAMOTO, Satoshi**; c/o Western Digital Technologies, Inc., 5601 Great Oaks Parkway, San Jose, CA 95119 (US). **BURTON, Derrick, E.**; c/o Western Digital Technologies, Inc., 5601 Great Oaks Parkway, San Jose, CA 95119 (US). **KOBAYASHI, Masahito**; c/o Western Digital Technologies, Inc., 5601 Great Oaks Parkway, San Jose, CA 95119 (US).

(74) Agent: **VERSTEEG, Steven, H.**; Patterson & Sheridan, LLP, 24 Greenway Plaza, Suite 1600, Houston, TX 77046 (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, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, IT, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(54) Title: DATA STORAGE DEVICE DEMODULATING SERVO STRIPES USING MATCHED FILTER

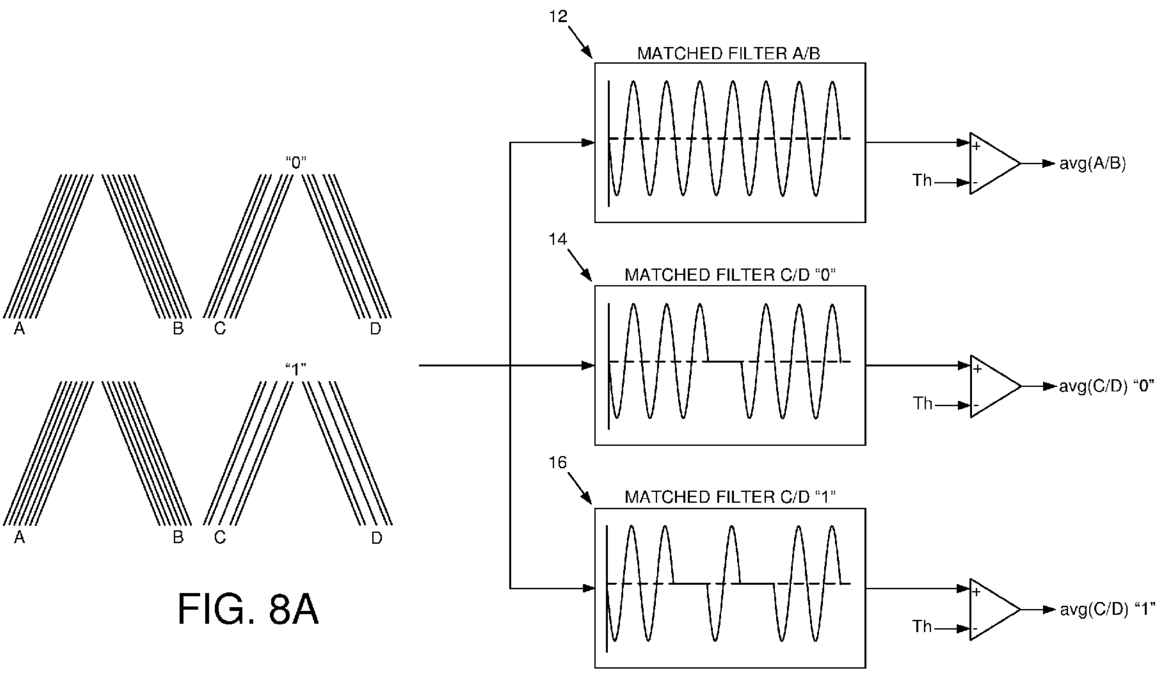


FIG. 8A

(57) Abstract: A data storage device is disclosed comprising at least one head configured to access a magnetic tape comprising a plurality of servo frames each comprising a plurality of servo bursts, wherein each servo burst comprises a plurality of servo stripes. The servo stripes in a first servo burst are read using the head to generate a first read signal that is processed using a first matched filter matched to the first servo burst in order to generate an average time stamp for the servo stripes in the first servo burst. A position error signal (RES) is generated based on the average time stamp of the first servo burst, and the head is positioned relative to the magnetic tape based on the PES.

WO 2022/072015 A1

[Continued on next page]

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, 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, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:
— *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))*

DATA STORAGE DEVICE DEMODULATING SERVO STRIPES USING MATCHED FILTER

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Patent Application Serial No. 17/176,024, filed on February 15, 2021 which claims priority to U.S. Provisional Patent Application Serial No. 63/086,153, filed on October 01, 2020, which are hereby incorporated by reference in their entirety.

BACKGROUND

Conventional tape drive storage systems comprise a magnetic tape wound around a dual reel (reel-to-reel cartridge) or a single reel (endless tape cartridge), wherein the reel(s) are rotated in order to move the magnetic tape over one or more transducer heads during write/read operations. The format of the magnetic tape may be single track or multiple tracks that are defined linearly, diagonally, or arcuate with respect to the longitudinal dimension along the length of the tape. With a linear track format, the heads may remain stationary relative to the longitudinal dimension of the tape, but may be actuated in a lateral dimension across the width of the tape as the tape moves past the heads. With a diagonal or arcuate track format, the heads may be mounted on a rotating drum such that during access operations both the heads and tape are moved relative to one another (typically in opposite directions along the longitudinal dimension of the tape).

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A shows a data storage device according to an embodiment comprising at least one head configured to access a magnetic tape.

FIG. 1B is a flow diagram according to an embodiment wherein digital data is demodulated based on a number of servo stripes in a servo frame.

FIG. 1C and 1D show a servo frame wherein an A and B servo burst consists of five servo stripes, and a C and D servo burst consists of four servo stripes when representing a digital “0” or three servo stripes when representing a digital “1”.

FIG. 1E shows a data storage device comprising a cartridge assembly comprising a magnetic tape, and a tape drive assembly configured to access the magnetic tape.

FIGs. 2A and 2B show a prior art servo frame wherein digital data is demodulated from the C and D bursts based on a time shift of the servo stripes.

FIGs. 3A and 3B show an embodiment wherein a format of the servo stripes in the A and B servo bursts matches a format of the servo stripes in the C and D servo bursts except for one or two missing servo stripes depending on whether the servo stripes represent a digital “0” or “1”.

FIGs. 4A-4D show an embodiment wherein the missing servo stripes in the C and D servo bursts represent one of four digital values.

FIGs. 5A-5H show an embodiment wherein the missing servo stripes in the C and D servo bursts represent one of eight digital values.

FIGs. 6A and 6B show an embodiment wherein a position error signal (PES) is generated at a rate of two measurements per servo frame.

FIGs. 7A and 7B show an embodiment wherein a position error signal (PES) is generated at a rate of four measurements per servo frame.

FIGs. 8A and 8B show embodiments wherein a plurality of matched filters measure an average timestamp for each servo burst.

DETAILED DESCRIPTION

FIGs. 1A and 1B show a data storage device according to an embodiment comprising at least one head 2 configured to access a magnetic tape 4 comprising a plurality of servo frames each comprising a plurality of servo stripes (e.g., FIGs. 1C or 1D). The data storage device further comprises control circuitry 6 configured to execute the flow diagram of FIG. 1B, wherein the servo stripes are read using the head to generate a read signal which is processed to detect a position error signal (PES) used to control a position of the head relative to the magnetic tape (block 8). The read signal is also demodulated into digital data based on a number of servo stripes detected in each servo frame (block 10).

In the embodiment of FIG. 1A, the data storage device comprises an embedded magnetic tape 4 installed into a tape drive assembly which, in one embodiment, may be the same form factor as a conventional disk drive. In another embodiment shown in FIG. 1E, the magnetic tape 4 may be housed in a cartridge assembly 3 that is inserted into (and ejected from) a tape drive assembly 5 similar to a conventional tape drive manufactured under the Linear Tape-Open (LTO) standard. In one embodiment, the tape drive assembly 5 comprises the head 2 configured to access the magnetic tape 4, and the control circuitry 6 configured to execute the flow diagram of FIG. 1B.

FIGs. 1C and 1D show an example servo frame according to an embodiment wherein a first subframe comprises A and B servo bursts each consisting of five servo stripes, and a second subframe comprises C and D servo bursts each consisting of four servo stripes when representing a digital “0” or three servo stripes when representing a digital “1”. Any suitable digital data may be encoded into the servo frames, such as a longitudinal position of the head along the length of the magnetic tape. In the example embodiment of FIGs. 1C and 1D, a single bit of the digital data is encoded into each servo frame, whereas in other embodiments described in greater detail below, multiple bits may be encoded into each servo frame. In one embodiment, the differing number of servo stripes between the sub-frames may also be used to distinguish between the subframes. That is, in one embodiment the A and B servo bursts of the first subframe may be considered a “sync” subframe which is distinguished from the second subframe due to having five servo stripes per servo burst as compared to four or three servo stripes per servo burst. Each servo stripe may be written to the magnetic tape in any suitable manner, wherein in one embodiment each servo stripe may be written as an isolated dibit using a suitable write head.

In one embodiment, the PES for controlling the lateral position of the head relative to the width of the magnetic tape is generated based on a ratio of time intervals detected between the servo stripes. For example, a first time interval may be measured between a servo stripe in the A servo burst and a corresponding servo stripe in the B servo burst, and a second time interval may be measured between the servo stripe in the A servo burst and a corresponding servo stripe in the C servo burst. The PES may then be generated as the ratio of the first and second time intervals, wherein the ratio is independent of the speed of the magnetic tape. In one embodiment, multiple time intervals may be measured for multiple of the servo stripes, wherein the resulting ratios may be averaged in order to generate the PES in a manner that attenuates noise that may otherwise obfuscate a single ratio measurement. In another embodiment described below, an average timestamp may be generated for each servo burst and the time intervals measured based on the average timestamps in order to attenuate noise in the PES measurement.

FIGs. 2A and 2B shows a prior art format of a {5,4} servo frame meaning the first subframe of A and B servo bursts consist of five servo stripes, and the second subframe of C and D servo bursts consist of four servo stripes. A digital "0" or "1" is encoded into the second subframe based on time shifting the servo stripes. That is, in FIG. 2A a "0" is encoded into the second subframe by recording the servo stripes without a time shift, and in FIG. 2B a "1" is encoded into the second subframe by recording the second and fourth servo stripes with a time shift relative to the first and second servo stripes.

FIGs. 3A and 3B show an embodiment wherein a digital value is encoded by varying the number of servo stripes written to the C and D servo bursts. In FIG. 3A a "0" is encoded by writing a {5,4} servo frame, and in FIG. 3B a "1" is encoded by writing a {5,3} servo frame. In this embodiment, a format of the servo stripes in the first subframe of A and B servo bursts matches a format of the servo stripes in the second subframe of C and D servo bursts except for a single missing servo stripe (the middle servo stripe) when encoding a "0" as shown in FIG. 3A. A format of the servo stripes in the first subframe of A and B servo bursts matches a format of the servo stripes in the second subframe of C and D servo bursts except for two missing servo stripes (the second and third servo stripes) when encoding a "1" as shown in FIG. 3B. Accordingly in this embodiment, when measuring the PES time intervals between the servo stripes within a subframe as well as between the subframes the pairing of the servo stripes remains constant. Alternatively when measuring an average timestamp for each servo burst, one or more missing servo strips within a servo burst does not change the average timestamp measurement. Also in this embodiment, the spacing of the servo stripes (including the missing servo stripes) in the first and second subframes remains constant such that the width of the first and second subframes are substantially equal, thereby simplifying the demodulation of the servo frames regardless as to the direction of tape movement (forward or backward).

FIGs. 4A-4D show an embodiment wherein the second subframe encodes one of four digital values (i.e., the second subframe encodes two bits of data). In FIG. 4A a “0” is encoded by writing a {7,6} servo frame with the fourth servo stripe missing in the second subframe. In FIG. 4B a “1” is encoded by writing a {7,5} servo frame with the third and fifth servo stripe missing in the second subframe. In FIG. 4C a “2” is encoded by writing a {7,4} servo frame with the second, fourth, and sixth servo stripes missing in the second subframe. In FIG. 4D a “3” is encoded by writing a {7,5} servo frame with the second and sixth servo stripes missing from the second subframe.

FIGs. 5A-5H show an embodiment wherein the second subframe encodes one of eight digital values (i.e., the second subframe encodes three bits of data) by writing various permutations of a {9,N} servo frame. That is, nine servo stripes are written in the first subframe, and N = 8, 7, 6 or 5 servo stripes are written in the second subframe depending on the digital value encoded into the second subframe as shown in FIGs. 5A-5H.

FIGs. 6A and 6B show an embodiment wherein a PES for controlling the lateral position of the head is generated at a rate of two measurements per servo frame. In this embodiment, an average timestamp generated for each servo burst is used to measure an average time interval between the servo bursts. The PES is then generated based on the ratio of selected intervals as shown in FIGs. 6A and 6B in a manner that is independent of tape speed. FIGs. 7A and 7B show a similar embodiment wherein a PES for controlling the lateral position of the head is generated at a rate of four measurements per servo frame.

FIG. 8A shows an embodiment wherein a plurality of matched filters each matched to the servo stripes of a servo burst generates the average timestamp in order to generate the PES in the embodiments described above. In addition, the output of the matched filters matched to the C/D servo bursts are also used to demodulate the digital value(s) encoded into the C/D servo bursts. In the example of FIG. 8A, the servo frame format is {7,6} when encoding a digital “0” value or {7,5} when encoding a digital “1” value. A first matched filter 12 correlates the read signal with an expected series of pulses matching the servo stripes of the A/B bursts, a second matched filter 14 correlates the read signal with an expected series of pulses matching the servo stripes of the C/D bursts encoding a “0” digital value, and a third matched filter 16 correlates the read signal with an expected series of pulses matching the servo stripes of the C/D bursts encoding a “1” digital value. In the embodiment of FIG. 8A, the output of each matched filter is compared to a threshold, and the time at which the output exceeds the threshold becomes the average timestamp for the corresponding servo burst. That is, the output of the matched filter that matches the servo burst being read will exceed the threshold due to the correlation exceeding the threshold. In addition, when the output of the matched filter matched to the C/D servo burst exceeds the threshold, the corresponding digital value is also demodulated as shown in FIG. 8A.

FIG. 8B shows an embodiment wherein the outputs of the matched filters are compared to one another to facilitate generating the timestamps and demodulating the digital values. For example, in one embodiment a timestamp is generated (and a digital value demodulated) when the outputs of each matched filter exceeds a gating threshold indicating the pulses in the read signal align with each of the matched filters (i.e., the correlations reach a maximum). At this point, the matched filter having the highest output (highest correlation) corresponds to the servo burst being read and is therefore used to generate the timestamp as well as demodulate the digital value.

In the embodiment of FIGs. 8A and 8B, the matched filters are shown as operating in continuous time meaning the analog read signal is correlated with an analog filter having a continuous time impulse response substantially matched to the pulses generated by reading the servo stripes in each servo burst. In another embodiment, the matched filters may operate in discrete time meaning the analog signal is sampled, and the signal samples filtered with a digital filter having a discrete time impulse response substantially matched to the signal samples of the pulses generated by reading the servo stripes in each servo burst.

Any suitable control circuitry may be employed to implement the flow diagrams in the above embodiments, such as any suitable integrated circuit or circuits. For example, the control circuitry may be implemented within a read channel integrated circuit, or in a component separate from the read channel, such as a data storage controller, or certain operations described above may be performed by a read channel and others by a data storage controller. In one embodiment, the read channel and data storage controller are implemented as separate integrated circuits, and in an alternative embodiment they are fabricated into a single integrated circuit or system on a chip (SOC). In addition, the control circuitry may include a suitable preamp circuit implemented as a separate integrated circuit, integrated into the read channel or data storage controller circuit, or integrated into a SOC.

In one embodiment, the control circuitry comprises a microprocessor executing instructions, the instructions being operable to cause the microprocessor to perform the flow diagrams described herein. The instructions may be stored in any computer-readable medium. In one embodiment, they may be stored on a non-volatile semiconductor memory external to the microprocessor, or integrated with the microprocessor in a SOC. In yet another embodiment, the control circuitry comprises suitable logic circuitry, such as state machine circuitry. In some embodiments, at least some of the flow diagram blocks may be implemented using analog circuitry (e.g., analog comparators, timers, etc.), and in other embodiments at least some of the blocks may be implemented using digital circuitry or a combination of analog/digital circuitry.

In addition, any suitable electronic device, such as computing devices, data server devices, media content storage devices, etc. may comprise the storage media and/or control circuitry as described above.

The various features and processes described above may be used independently of one another, or may be combined in various ways. All possible combinations and subcombinations are intended to fall within the scope of this disclosure. In addition, certain method, event or process blocks may be omitted in some implementations. The methods and processes described herein are also not limited to any particular sequence, and the blocks or states relating thereto can be performed in other sequences that are appropriate. For example, described tasks or events may be performed in an order other than that specifically disclosed, or multiple may be combined in a single block or state. The example tasks or events may be performed in serial, in parallel, or in some other manner. Tasks or events may be added to or removed from the disclosed example embodiments. The example systems and components described herein may be configured differently than described. For example, elements may be added to, removed from, or rearranged compared to the disclosed example embodiments.

While certain example embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions disclosed herein. Thus, nothing in the foregoing description is intended to imply that any particular feature, characteristic, step, module, or block is necessary or indispensable. Indeed, the novel methods and systems described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the methods and systems described herein may be made without departing from the spirit of the embodiments disclosed herein.

WHAT IS CLAIMED IS:

1. A data storage device configured to access a magnetic tape comprising a plurality of servo frames each comprising a plurality of servo bursts, wherein each servo burst comprises a plurality of servo stripes, the data storage device comprising:

at least one head configured to access the magnetic tape; and

control circuitry configured to:

read the servo stripes in a first servo burst using the head to generate a first read signal;

process the first read signal using a first matched filter matched to the first servo burst in order to generate an average time stamp for the servo stripes in the first servo burst;

generate a position error signal (PES) based on the average time stamp of the first servo burst; and

control a position of the head relative to the magnetic tape based on the PES.

2. The data storage device as recited in claim 1, wherein the data storage device comprises the magnetic tape.

3. The data storage device as recited in claim 1, wherein:

the magnetic tape is housed in a cartridge assembly; and

the data storage device comprises a tape drive assembly configured to receive the cartridge assembly.

4. The data storage device as recited in claim 1, wherein a first servo frame comprises a first subframe comprising the first servo burst and a second servo burst, and a second subframe comprising a third servo burst and a fourth servo burst, wherein the control circuitry is further configured to:

read the servo stripes in the third servo burst using the head to generate a second read signal;

process the second read signal using a second matched filter matched to the third servo burst in order to generate an average time stamp for the servo stripes in the third servo burst; and

generate the position error signal (PES) based on the average time stamp of the first servo burst and the average time stamp of the third servo burst.

5. The data storage device as recited in claim 4, wherein the control circuitry is further configured to process an output of the first matched filter and an output of the second matched filter in order to distinguish between the first servo burst and the third servo burst.

6. The data storage device as recited in claim 4, wherein the control circuitry is further configured to generate a first digital value based on an output of the second matched filter.

7. The data storage device as recited in claim 6, wherein a second servo frame comprises a first subframe comprising the first servo burst and the second servo burst, and a second subframe comprising a fifth servo burst and a sixth servo burst, wherein the control circuitry is further configured to:

read the servo stripes in the fifth servo burst using the head to generate a third read signal;

process the third read signal using a third matched filter matched to the fifth servo burst; and

generate a second digital value based on an output of the third matched filter.

8. The data storage device as recited in claim 7, wherein the control circuitry is further configured to:

detect the first digital value when the output of the second matched filer exceeds a threshold; and

detect the second digital value when the output of the third matched filter exceeds a threshold.

9. The data storage device as recited in claim 7, wherein the control circuitry is further configured to:

detect the first digital value when the output of the second matched filer exceeds the output of the third matched filter; and

detect the second digital value when the output of the third matched filter exceeds the output of the second matched filter.

10. A data storage device configured to access a magnetic tape, the data storage device comprising:

at least one head configured to access the magnetic tape; and

control circuitry configured to:

read servo stripes in a first servo burst on the magnetic tape using the head to generate a first read signal;

process the first read signal using a first matched filter matched to the first servo burst in order to generate an average time stamp for the servo stripes in the first servo burst;

generate a position error signal (PES) based on the average time stamp of the first servo burst; and

control a position of the head relative to the magnetic tape based on the PES.

11. The data storage device as recited in claim 10, wherein the data storage device comprises the magnetic tape.

12. The data storage device as recited in claim 10, wherein:
the magnetic tape is housed in a cartridge assembly; and
the data storage device comprises a tape drive assembly configured to receive the cartridge assembly.

13. The data storage device as recited in claim 10, wherein the control circuitry is further configured to:
read servo stripes in a second servo burst using the head to generate a second read signal;
process the second read signal using a second matched filter matched to the second servo burst in order to generate an average time stamp for the servo stripes in the second servo burst; and
generate the position error signal (PES) based on the average time stamp of the first servo burst and the average time stamp of the second servo burst.

14. The data storage device as recited in claim 13, wherein the control circuitry is further configured to process an output of the first matched filter and an output of the second matched filter in order to distinguish between the first servo burst and the second servo burst.

15. The data storage device as recited in claim 13, wherein the control circuitry is further configured to generate a first digital value based on an output of the second matched filter.

16. The data storage device as recited in claim 15, wherein the control circuitry is further configured to:
read servo stripes of a third servo burst using the head to generate a third read signal;

process the third read signal using a third matched filter matched to the third servo burst; and

generate a second digital value based on an output of the third matched filter.

17. The data storage device as recited in claim 16, wherein the control circuitry is further configured to:

detect the first digital value when the output of the second matched filer exceeds a threshold; and

detect the second digital value when the output of the third matched filter exceeds a threshold.

18. The data storage device as recited in claim 16, wherein the control circuitry is further configured to:

detect the first digital value when the output of the second matched filer exceeds the output of the third matched filter; and

detect the second digital value when the output of the third matched filter exceeds the output of the second matched filter.

19. A data storage device configured to access a magnetic tape, the data storage device comprising:

at least one head configured to access the magnetic tape;

a means for reading servo stripes in a first servo burst on the magnetic tape using the head to generate a first read signal;

a means for generating an average time stamp for the servo stripes in the first servo burst;

a means for generating a position error signal (PES) based on the average time stamp of the first servo burst; and

a means for controlling a position of the head relative to the magnetic tape based on the PES.

20. The data storage device as recited in claim 19, further comprising:

a means for reading servo stripes in a second servo burst using the head to generate a second read signal; and

a means for processing the second read signal to generate an average time stamp for the servo stripes in the second servo burst;,

wherein the PES is generated based on the average time stamp of the first servo burst and the average time stamp of the second servo burst.

21. The data storage device as recited in claim 20, further comprising a means for demodulating a first digital value based from the second read signal.

22. The data storage device as recited in claim 20, further comprising:

a means for reading servo stripes of a third servo burst using the head to generate a third read signal; and

a means for demodulating a second digital value from the third read signal.

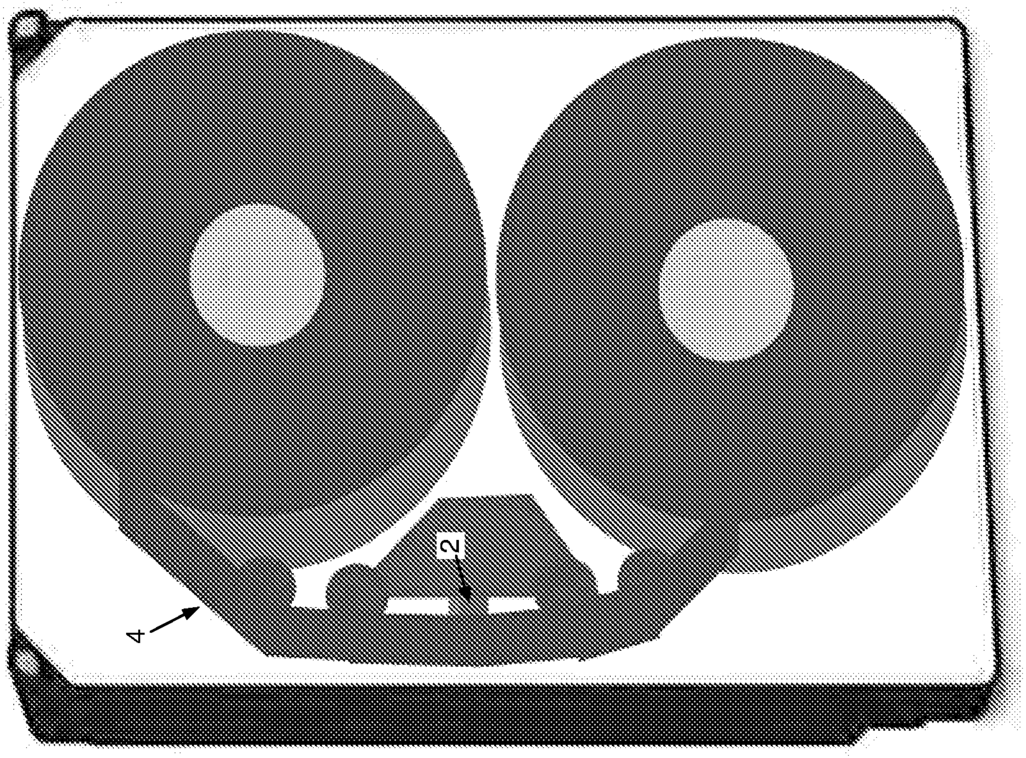


FIG. 1A

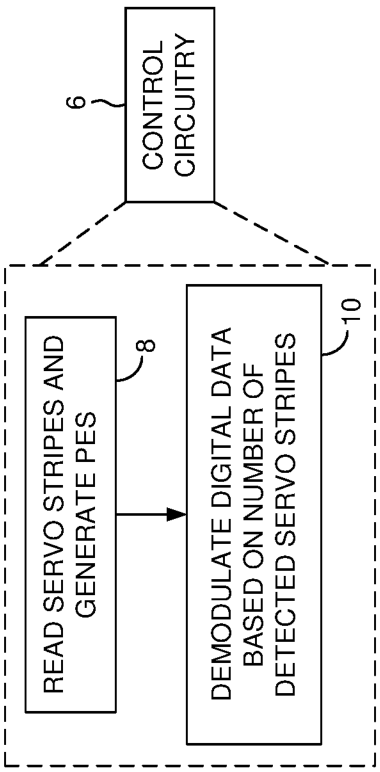


FIG. 1B

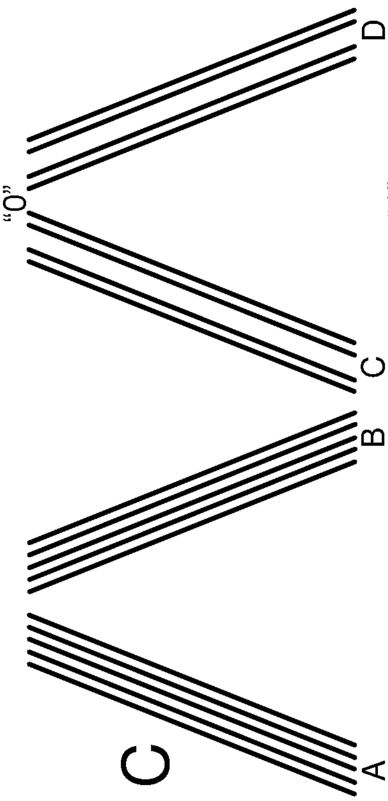


FIG. 1C

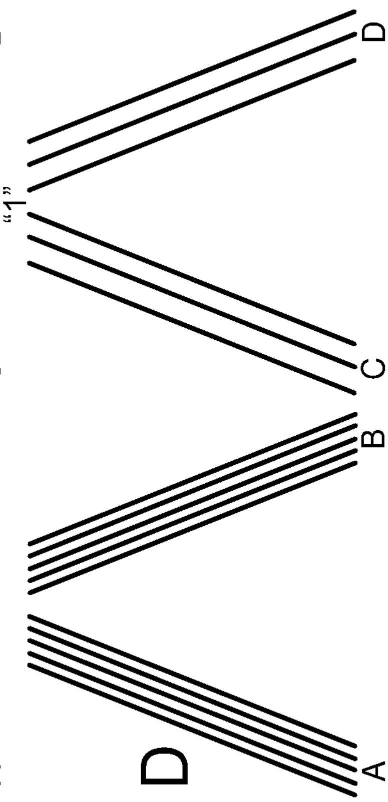


FIG. 1D

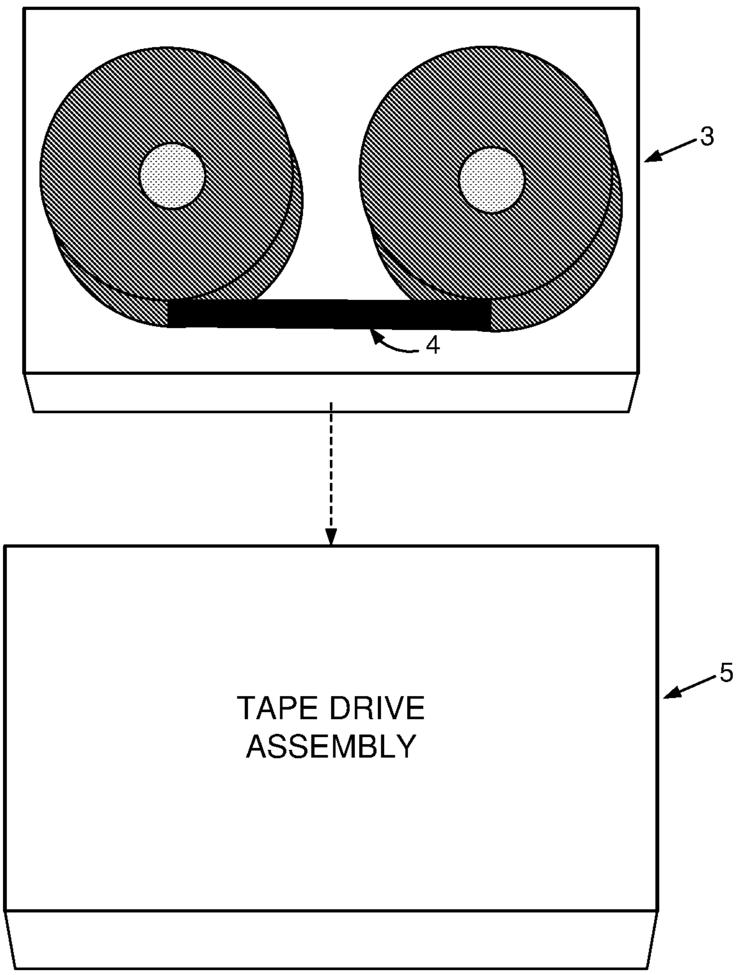


FIG. 1E

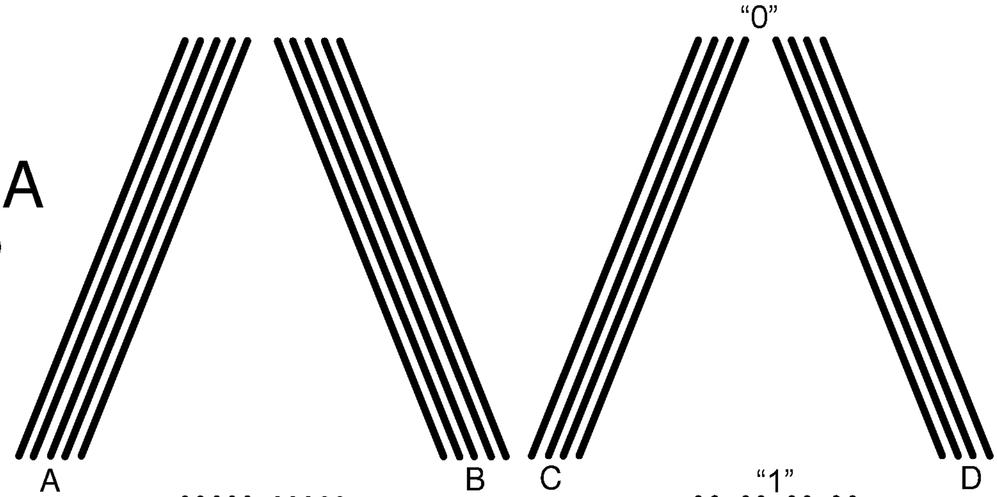


FIG. 2A
(Prior Art)

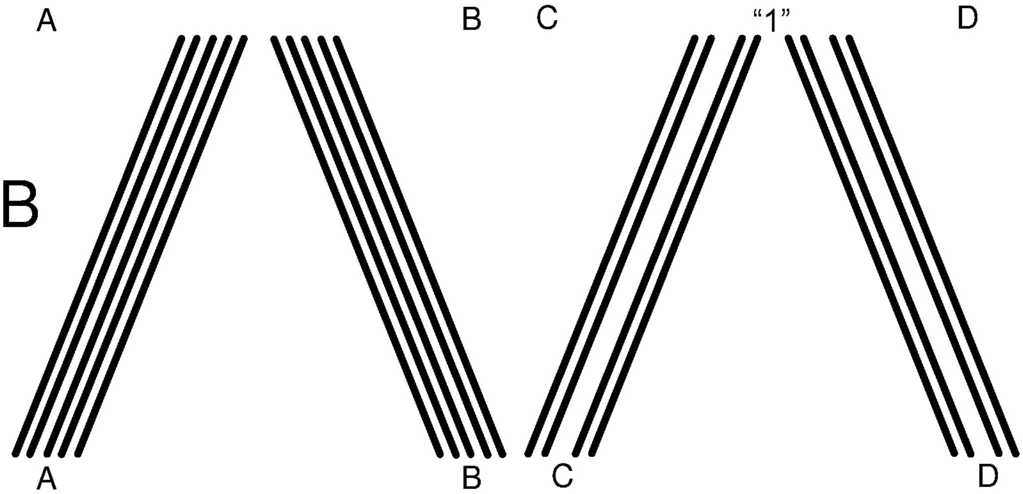


FIG. 2B
(Prior Art)

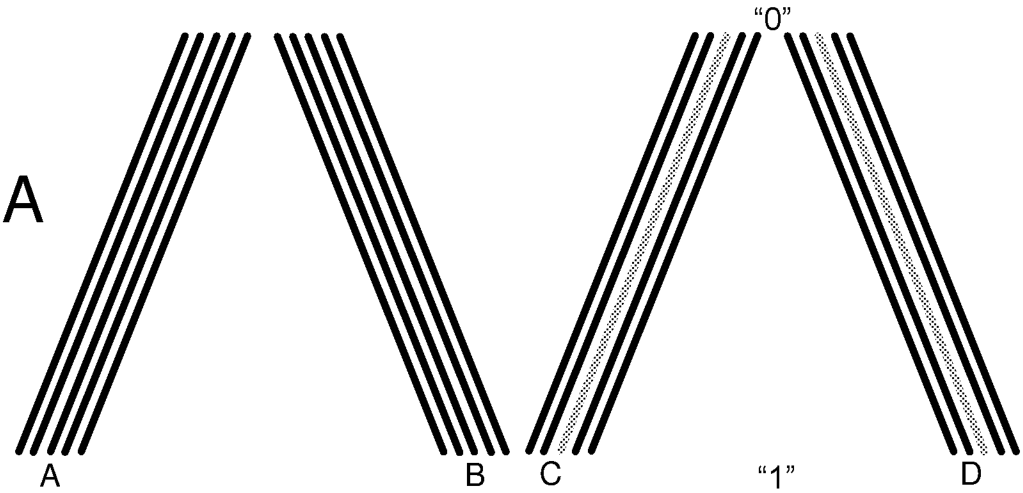


FIG. 3A

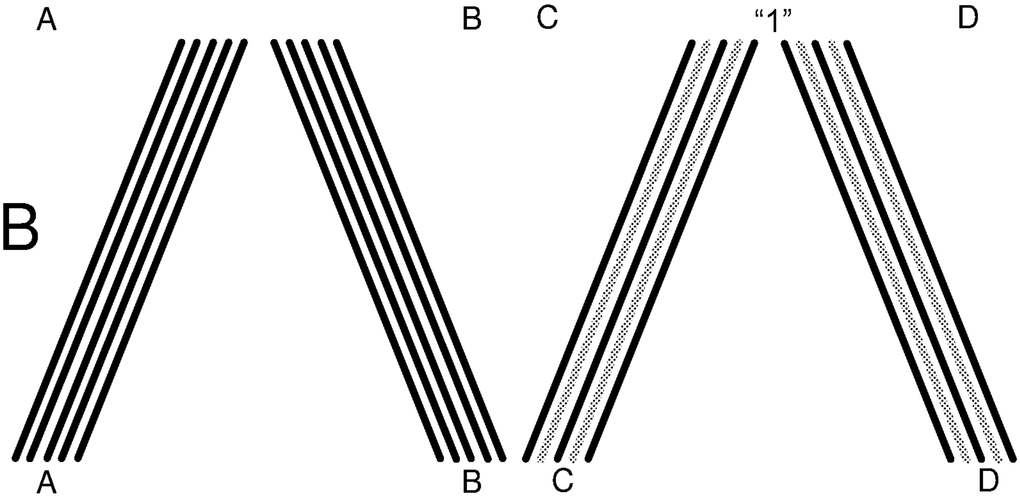


FIG. 3B

FIG. 4A

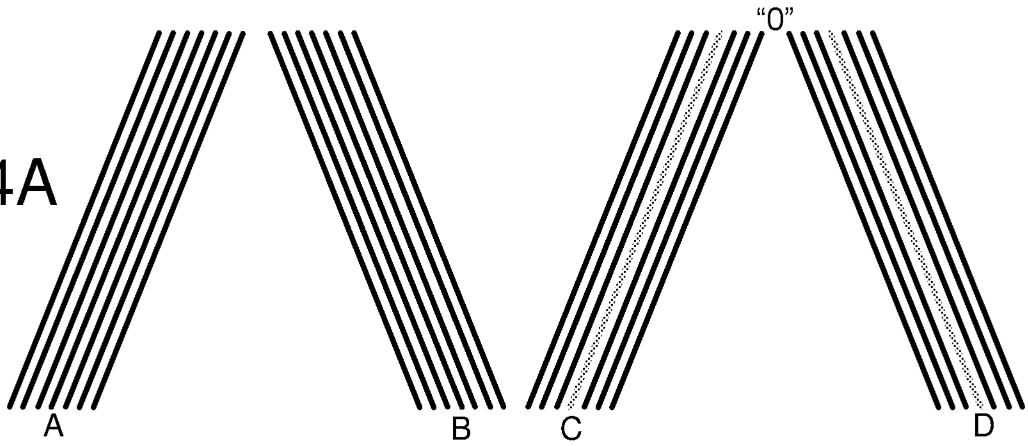


FIG. 4B

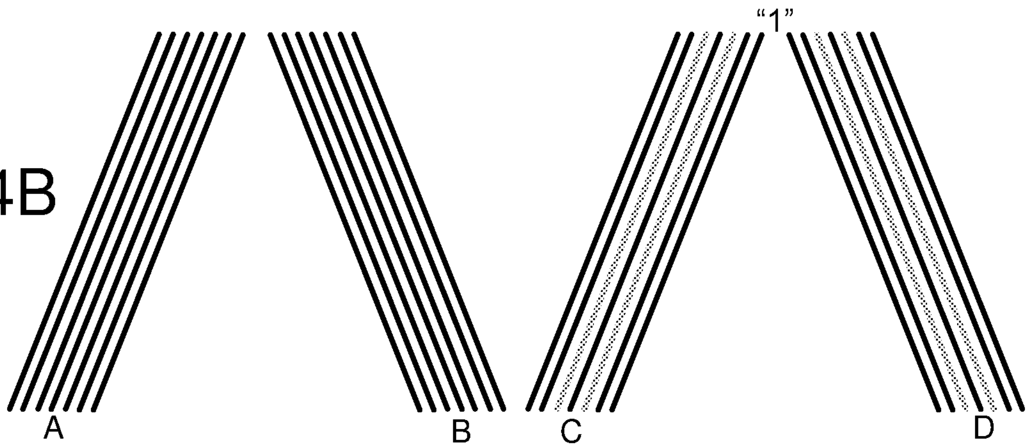


FIG. 4C

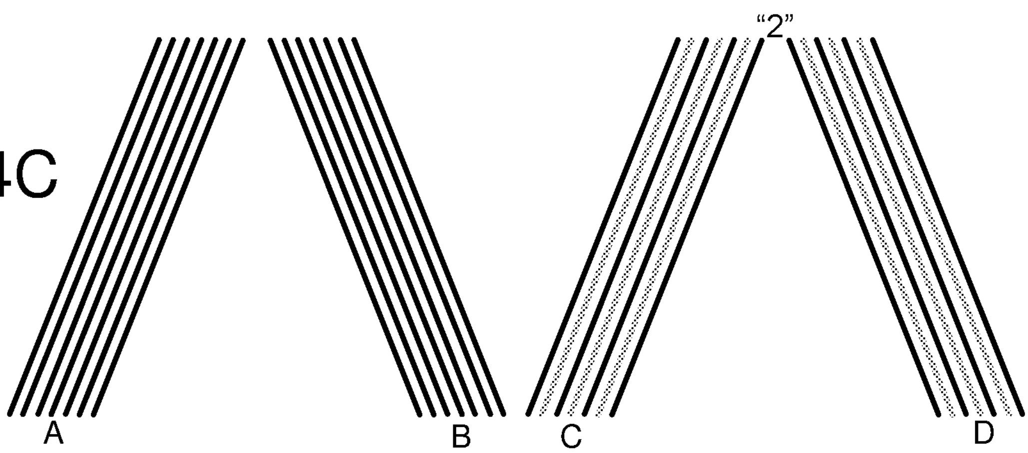


FIG. 4D

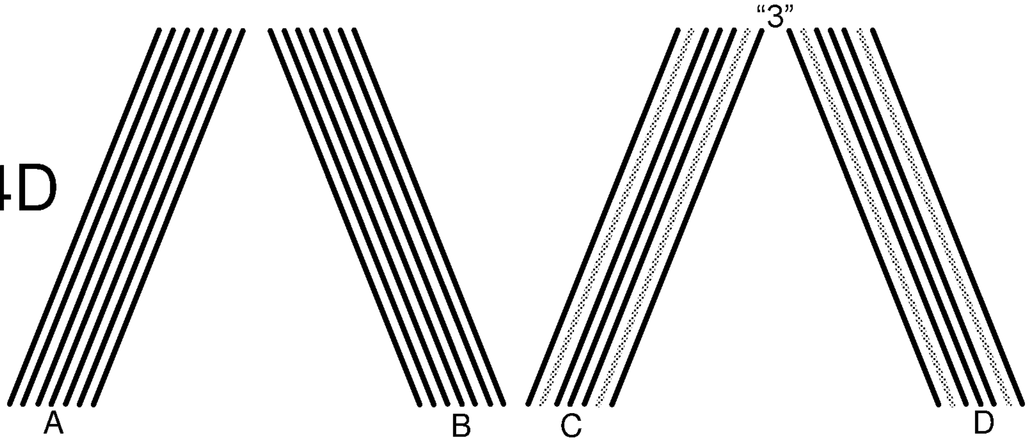


FIG. 5A

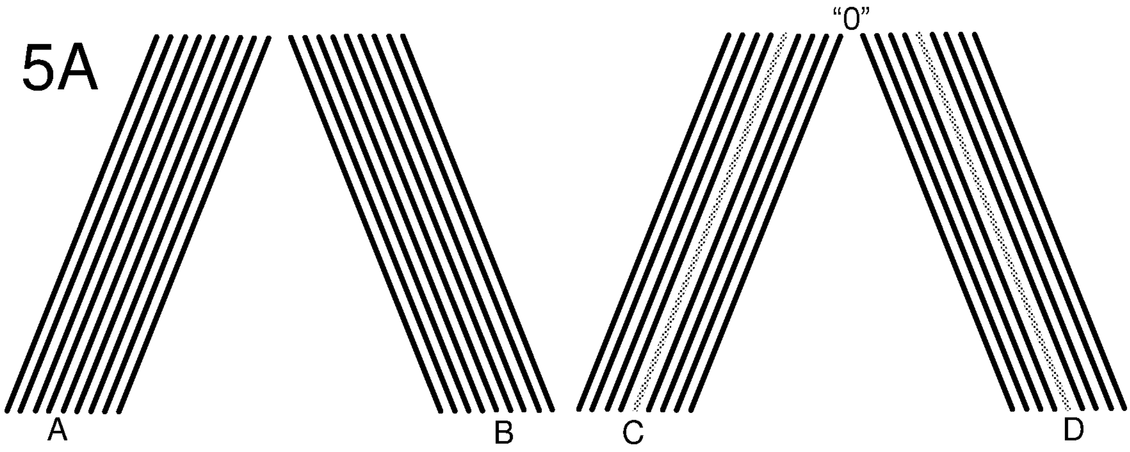


FIG. 5B

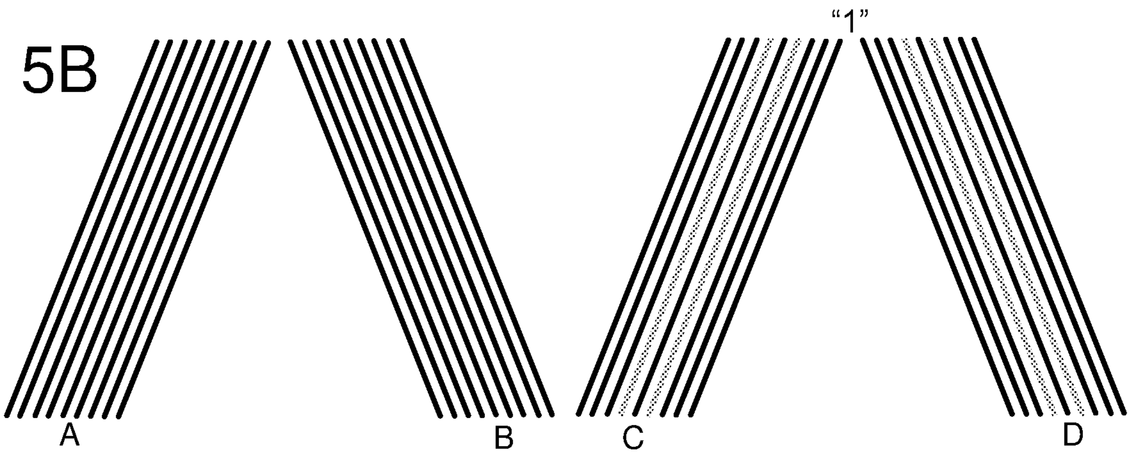


FIG. 5C

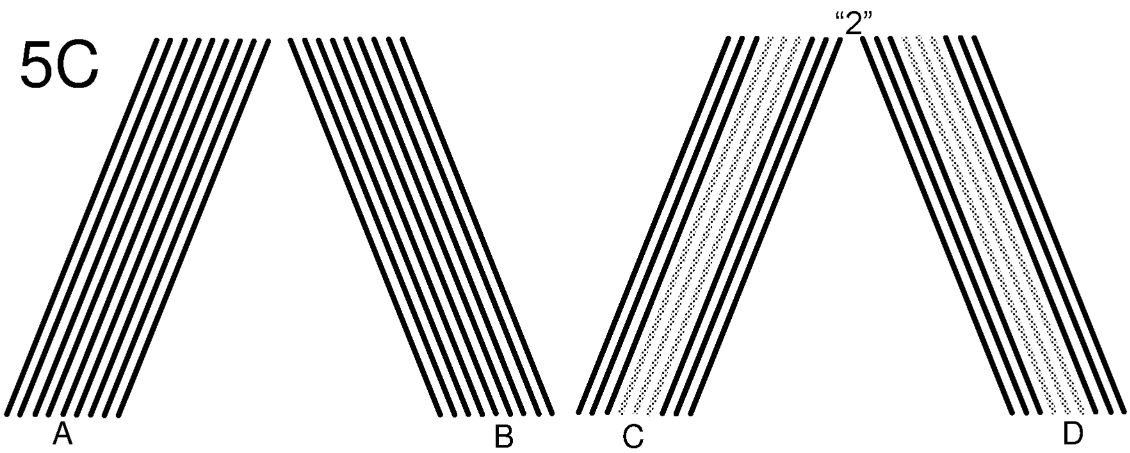


FIG. 5D

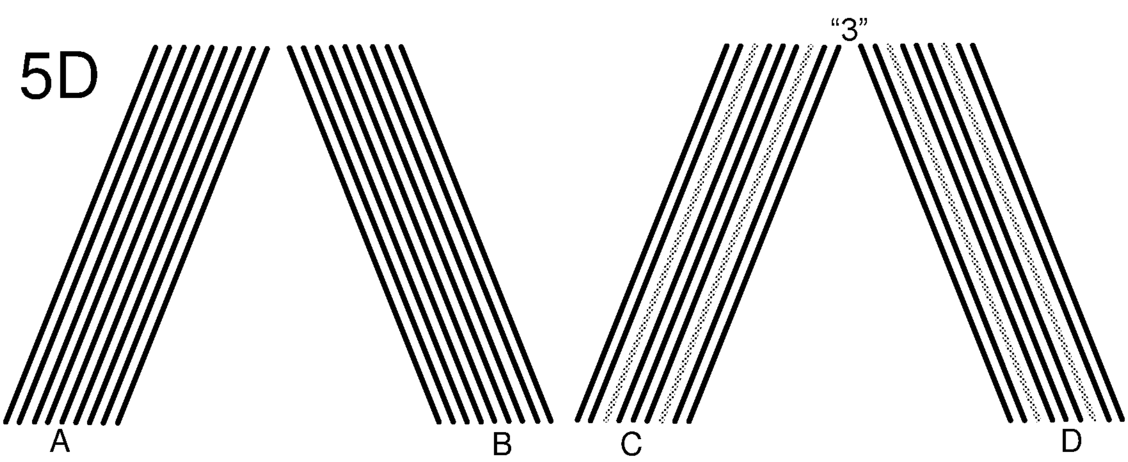


FIG. 5E

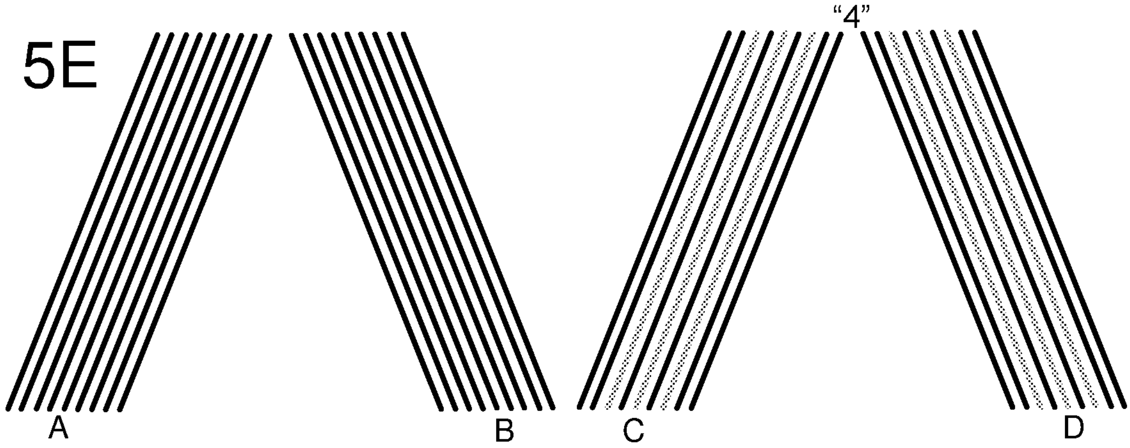


FIG. 5F

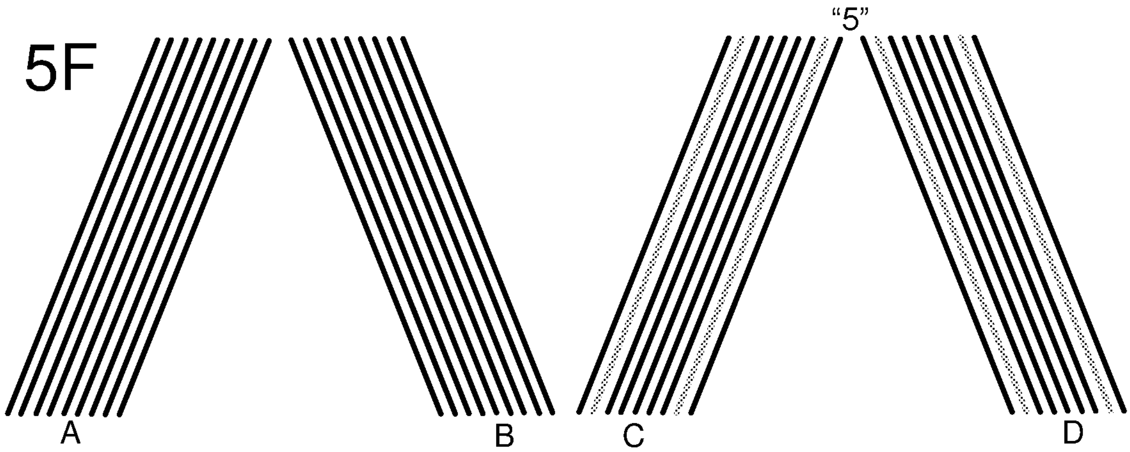


FIG. 5G

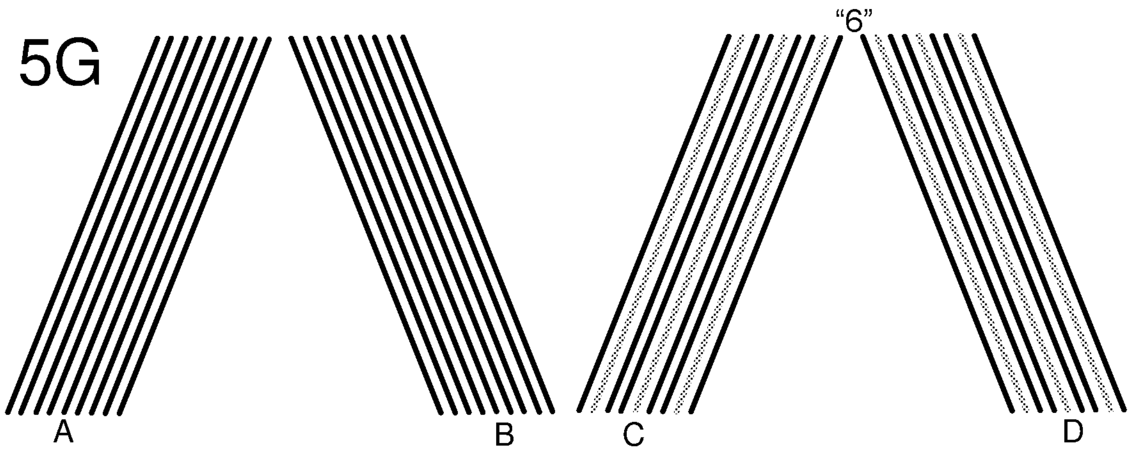
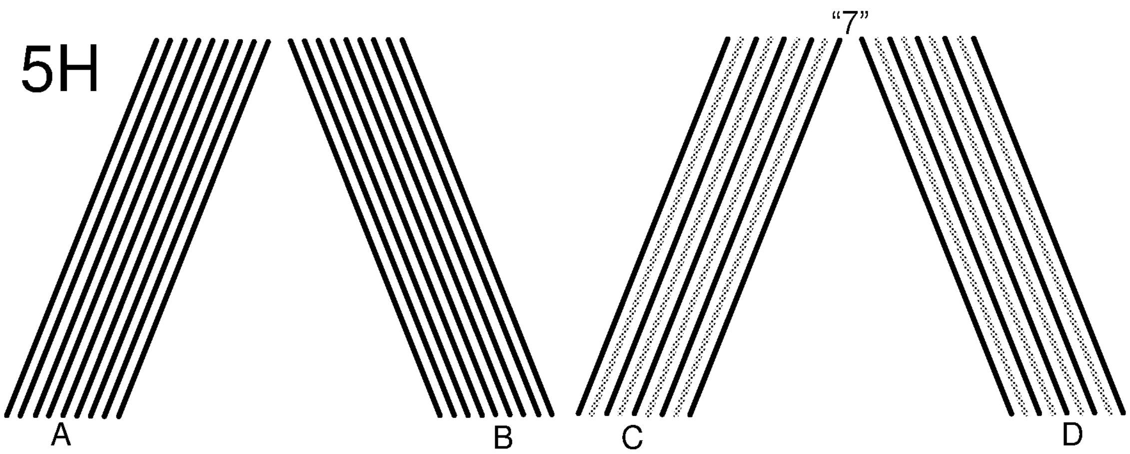


FIG. 5H



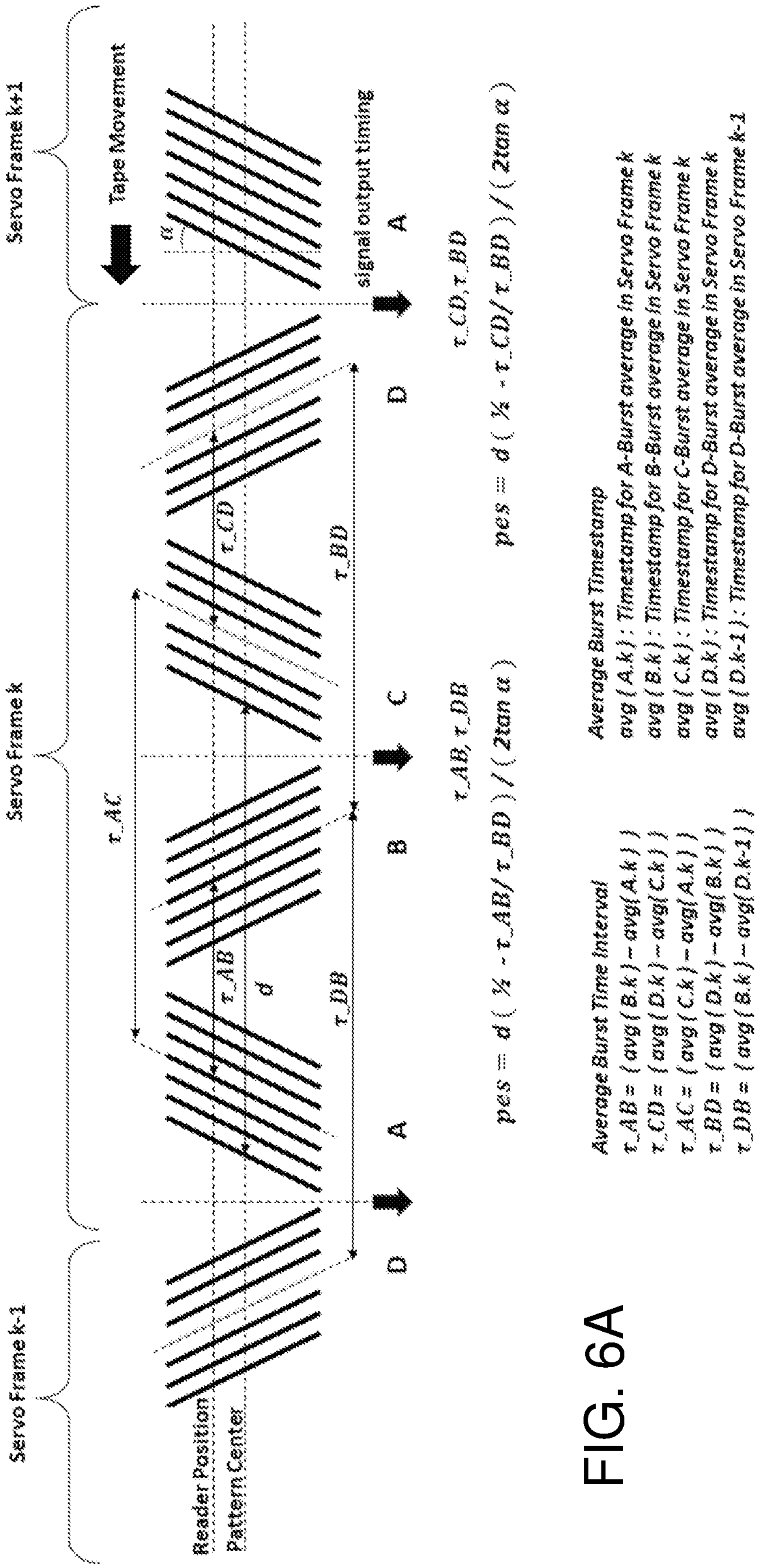

Servo Frame k-1
Servo Frame k
Servo Frame k+1
Tape Movement
Reader Position
Pattern Center
signal output timing
α
D
A
B
C
D
A
τ_AB
d
τ_AC
τ_CD
τ_BD
τ_DB
τ_AB, τ_DB
τ_CD, τ_BD
$pes = d\ (\ \frac{1}{2}\ -\ \tau\_AB/\ \tau\_BD\ )\ /\ (\ 2\tan\alpha\ )$
$pes = d\ (\ \frac{1}{2}\ -\ \tau\_CD/\ \tau\_BD\ )\ /\ (\ 2\tan\alpha\ )$
Average Burst Time Interval
$\tau\_AB = (\ avg(\ B.k\ ) - avg(\ A.k\ )\ )$
$\tau\_CD = (\ avg(\ D.k\ ) - avg(\ C.k\ )\ )$
$\tau\_AC = (\ avg(\ C.k\ ) - avg(\ A.k\ )\ )$
$\tau\_BD = (\ avg(\ D.k\ ) - avg(\ B.k\ )\ )$
$\tau\_DB = (\ avg(\ B.k\ ) - avg(\ D.k\text{-}1\ )\ )$
Average Burst Timestamp
avg (A.k) : Timestamp for A-Burst average in Servo Frame k
avg (B.k) : Timestamp for B-Burst average in Servo Frame k
avg (C.k) : Timestamp for C-Burst average in Servo Frame k
avg (D.k) : Timestamp for D-Burst average in Servo Frame k
avg (D.k-1) : Timestamp for D-Burst average in Servo Frame k-1

FIG. 6A

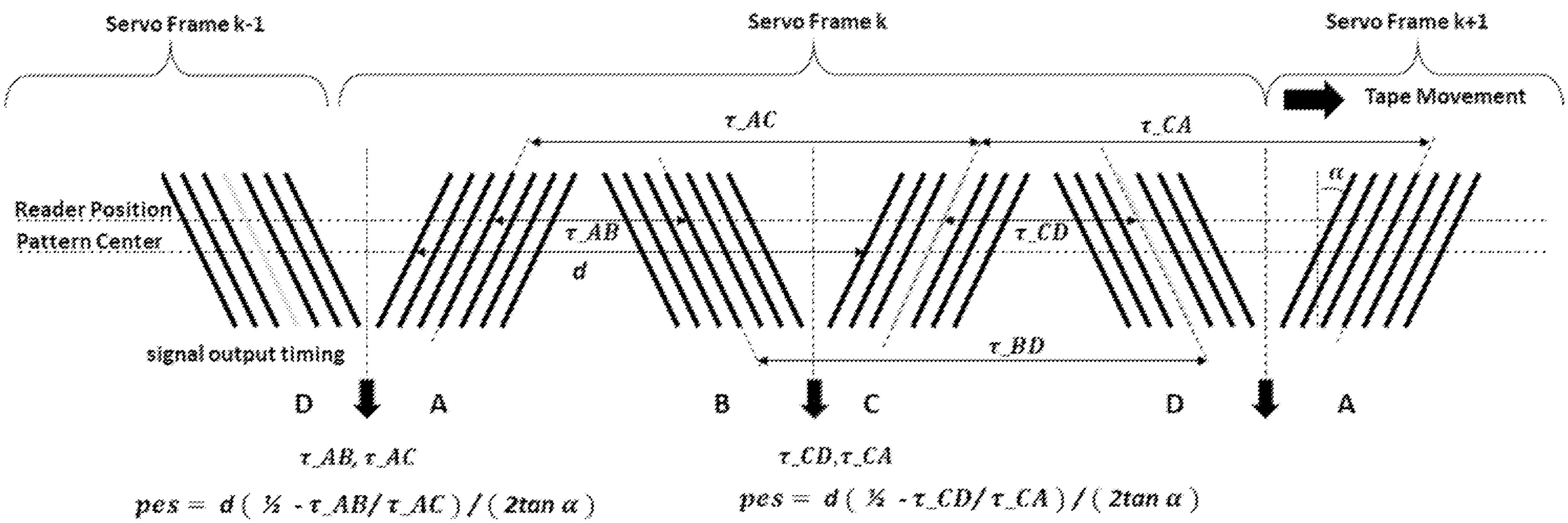


FIG. 6B

Average Burst Time Interval

τ_AB = { avg (A.k) – avg(B.k) }

τ_CD = { avg (C.k) – avg(D.k) }

τ_AC = { avg (A.k) – avg(C.k) }

τ_BD = { avg (B.k) – avg(D.k) }

τ_CA = { avg (C.k) – avg(A.k+1) }

Average Burst Timestamp

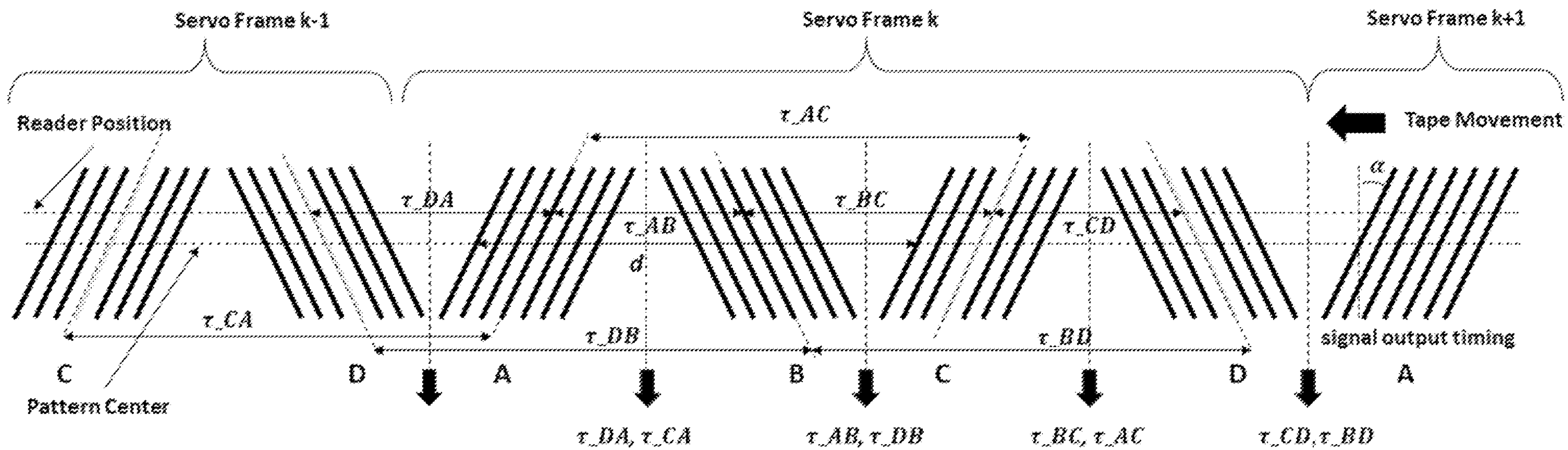
avg (A.k) : Timestamp for A-Burst average in Servo Frame k

avg (B.k) : Timestamp for B-Burst average in Servo Frame k

avg (C.k) : Timestamp for C-Burst average in Servo Frame k

avg (D.k) : Timestamp for D-Burst average in Servo Frame k

avg (A.k+1) : Timestamp for A-Burst average in Servo Frame k+1



$$pes = d\,(\tau\_DA/\tau\_CA - ½)\,/\,(2\tan\alpha)$$

$$pes = d\,(½ - \tau\_AB/\tau\_DB)\,/\,(2\tan\alpha)$$

$$pes = d\,(\tau\_BC/\tau\_AC - ½)\,/\,(2\tan\alpha)$$

$$pes = d\,(½ - \tau\_CD/\tau\_BD)\,/\,(2\tan\alpha)$$

Average Burst Time Interval

τ_AB = { avg { B.k } – avg{ A.k } }
τ_CD = { avg { D.k } – avg{ C.k } }
τ_AC = { avg { C.k } – avg{ A.k } }
τ_BD = { avg { D.k } – avg{ B.k } }
τ_CA = { avg { A.k } – avg{ C.k-1 } }
τ_DB = { avg { B.k } – avg{ D.k-1 } }

Average Burst Timestamp

avg { A.k } : Timestamp for A-Burst average in Servo Frame k
avg { B.k } : Timestamp for B-Burst average in Servo Frame k
avg { C.k } : Timestamp for C-Burst average in Servo Frame k
avg { D.k } : Timestamp for D-Burst average in Servo Frame k
avg { C.k-1 } : Timestamp for C-Burst average in Servo Frame k-1
avg { D.k-1 } : Timestamp for D-Burst average in Servo Frame k-1

FIG. 7A

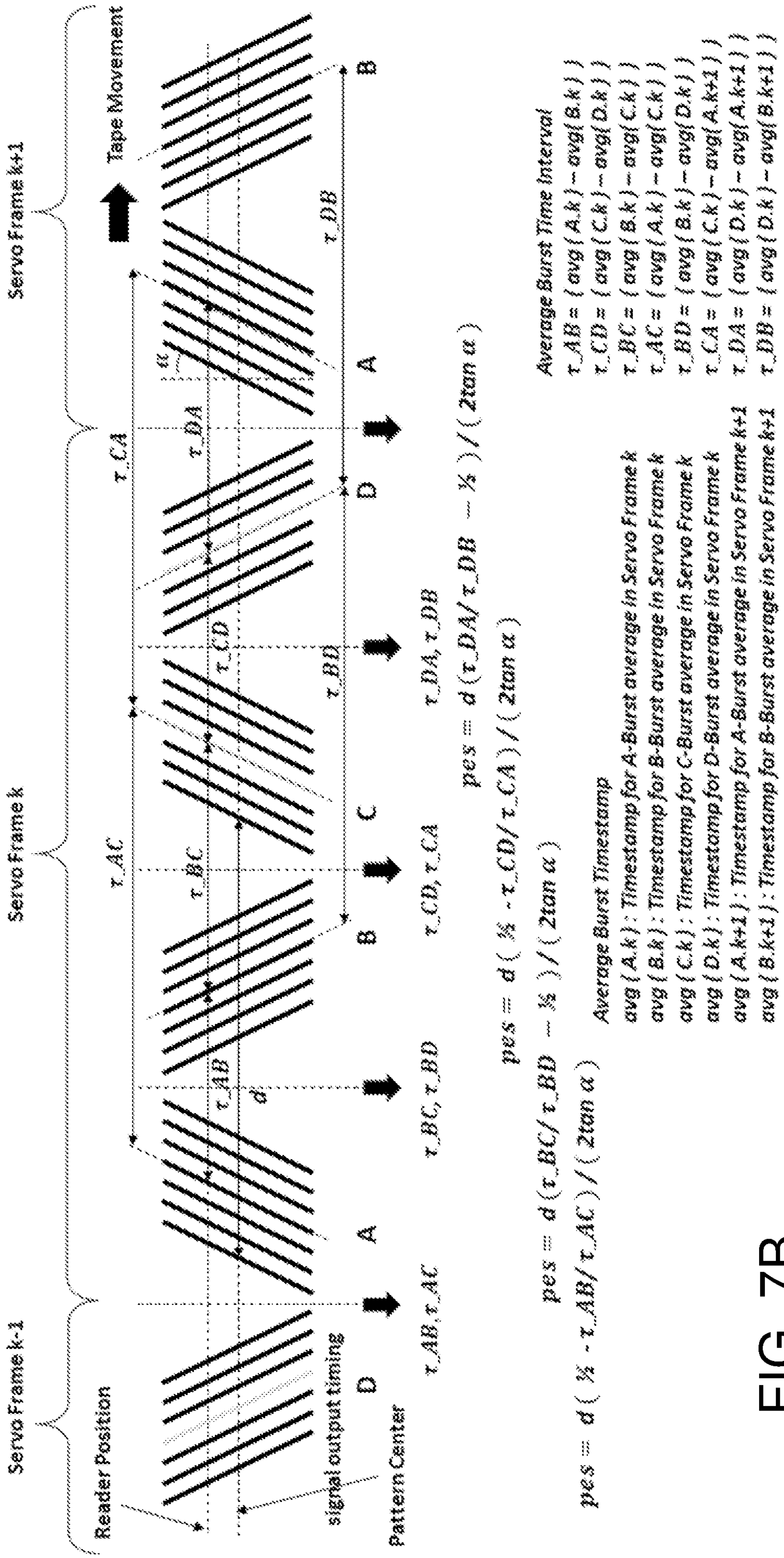

Servo Frame k-1
Servo Frame k
Servo Frame k+1
Reader Position
signal output timing
Pattern Center
Tape Movement
D
A
B
C
D
A
B
τ_AC
τ_CA
τ_AB
τ_BC
τ_CD
τ_DA
τ_BD
τ_DB
d
α
τ_AB, τ_AC
τ_BC, τ_BD
τ_CD, τ_CA
τ_DA, τ_DB
pes = d (½ - τ_AB/ τ_AC) / (2tan α)
pes = d (τ_BC/ τ_BD − ½) / (2tan α)
pes = d (½ - τ_CD/ τ_CA) / (2tan α)
pes = d (τ_DA/ τ_DB − ½) / (2tan α)
Average Burst Timestamp
avg (A.k) : Timestamp for A-Burst average in Servo Frame k
avg (B.k) : Timestamp for B-Burst average in Servo Frame k
avg (C.k) : Timestamp for C-Burst average in Servo Frame k
avg (D.k) : Timestamp for D-Burst average in Servo Frame k
avg (A.k+1) : Timestamp for A-Burst average in Servo Frame k+1
avg (B.k+1) : Timestamp for B-Burst average in Servo Frame k+1
Average Burst Time Interval
τ_AB = (avg (A.k) − avg (B.k))
τ_CD = (avg (C.k) − avg (D.k))
τ_BC = (avg (B.k) − avg (C.k))
τ_AC = (avg (A.k) − avg (C.k))
τ_BD = (avg (B.k) − avg (D.k))
τ_CA = (avg (C.k) − avg (A.k+1))
τ_DA = (avg (D.k) − avg (A.k+1))
τ_DB = (avg (D.k) − avg (B.k+1))

FIG. 7B

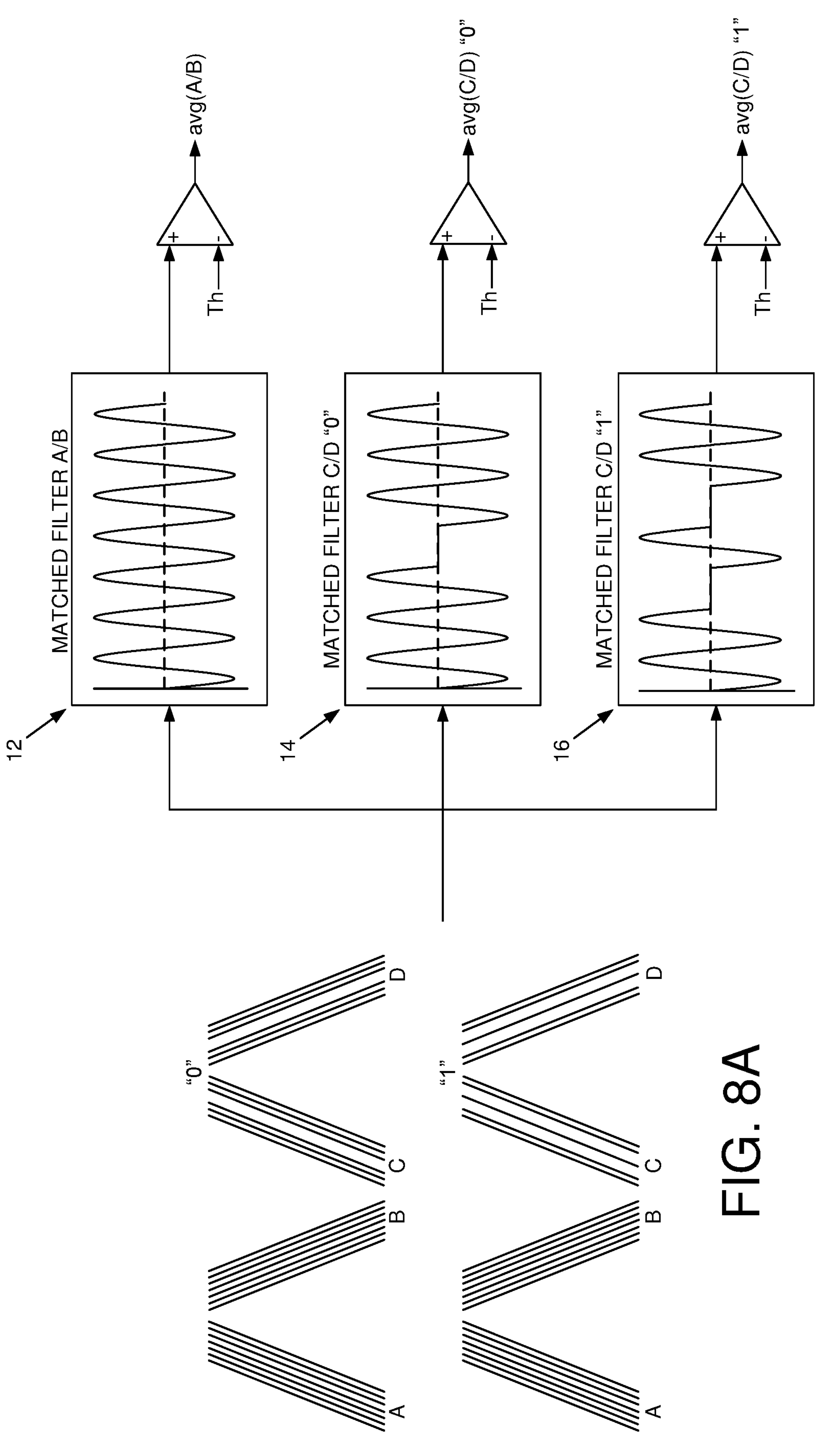

avg(A/B)
avg(C/D) "0"
avg(C/D) "1"
+
-
Th
MATCHED FILTER A/B
MATCHED FILTER C/D "0"
MATCHED FILTER C/D "1"
12
14
16
"0"
"1"
A
B
C
D

FIG. 8A

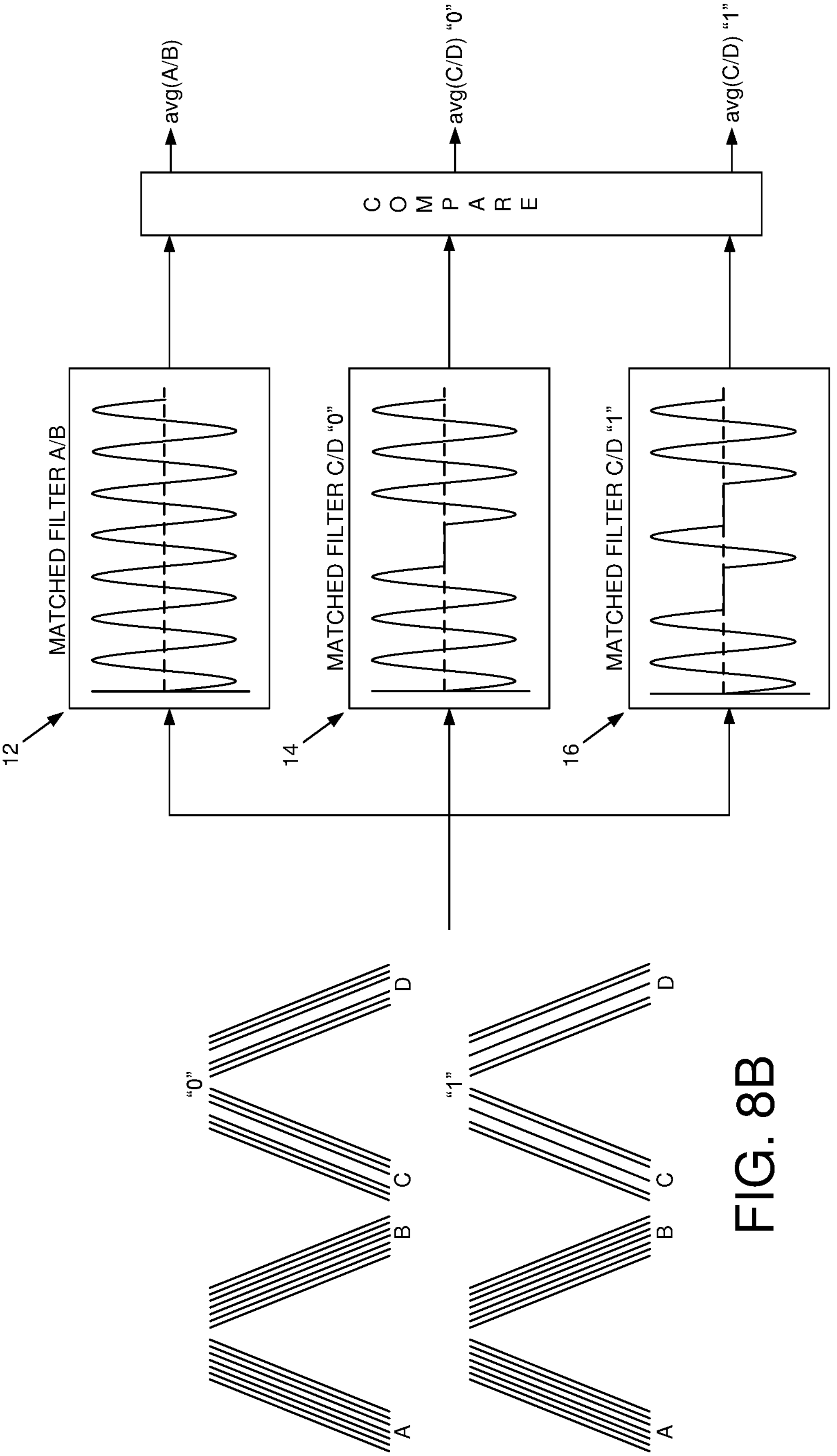

avg(A/B)
avg(C/D) "0"
avg(C/D) "1"
COMPARE
MATCHED FILTER A/B
MATCHED FILTER C/D "0"
MATCHED FILTER C/D "1"
12
14
16
"0"
"1"
A
B
C
D
A
B
C
D

FIG. 8B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2021/038154

A. CLASSIFICATION OF SUBJECT MATTER

G11B 5/55(2006.01)i; **G11B 5/008**(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)

G11B 5/55(2006.01); G11B 15/46(2006.01); G11B 21/02(2006.01); G11B 5/02(2006.01); G11B 5/56(2006.01);
G11B 5/58(2006.01); G11B 5/584(2006.01)

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
Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: magnetic tape, head, servo stripes, average time stamp, position error signal (PES)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2020-0035264 A1 (INTERNATIONAL BUSINESS MACHINES CORPORATION) 30 January 2020 (2020-01-30) paragraphs [0056]-[0065], [0073], [0100]; and figures 2-4B	1-22
A	US 2008-0100952 A1 (STEVEN G. TRABERT et al.) 01 May 2008 (2008-05-01) paragraphs [0025]-[0047]; and figures 1-9	1-22
A	US 2007-0097537 A1 (CARL R. HOERGER et al.) 03 May 2007 (2007-05-03) paragraphs [0014]-[0044]; and figures 1-7	1-22
A	US 2008-0239559 A1 (TURGUY GOKER et al.) 02 October 2008 (2008-10-02) paragraphs [0022]-[0048]; and figures 1-14	1-22
A	KR 10-2008-0089599 A (INTERNATIONAL BUSINESS MACHINES CORPORATION) 07 October 2008 (2008-10-07) paragraphs [0053]-[0147]; and figures 1, 3-16b	1-22

☐ 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
- "D" document cited by the applicant in the international application
- "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 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
21 October 2021	**22 October 2021**

Name and mailing address of the ISA/KR	Authorized officer
Korean Intellectual Property Office **189 Cheongsa-ro, Seo-gu, Daejeon** **35208, Republic of Korea**	**YANG, JEONG ROK**
Facsimile No. **+82-42-481-8578**	Telephone No. **+82-42-481-5709**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/US2021/038154

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
US	2020-0035264	A1	30 January 2020	US	10297280	B1	21 May 2019
				US	10650852	B2	12 May 2020
US	2008-0100952	A1	01 May 2008	US	7411759	B2	12 August 2008
US	2007-0097537	A1	03 May 2007	US	7289289	B2	30 October 2007
US	2008-0239559	A1	02 October 2008	EP	1975925	A1	01 October 2008
				JP	2008-243361	A	09 October 2008
				US	7477474	B2	13 January 2009
KR	10-2008-0089599	A	07 October 2008	CN	101361125	A	04 February 2009
				CN	101361125	B	12 January 2011
				EP	1984919	A1	29 October 2008
				EP	1984919	B1	05 August 2009
				JP	2009-524897	A	02 July 2009
				JP	5004969	B2	22 August 2012
				US	2007-0171565	A1	26 July 2007
				US	7245450	B1	17 July 2007
				WO	2007-085529	A1	02 August 2007