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PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Improvements in or relating to Information Storage Arrangements

5 We, WESTERN ELECTRIC COMPANY, INCORPORATED, of 195 Broadway, New York City, New York State, United States of America, a Corporation organized and existing under the laws of the State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

15 This invention relates to information storage arrangements employing a magnetic storage medium through which information may be propagated.

20 Information may be moved through a magnetic propagation medium such as a magnetic sheet of thin film in a shift register type of operation as is well known. One known arrangement comprises a thin film domain wall shift register in which a reverse magnetized domain, bounded by leading and trailing domain walls, is nucleated at an input position in the film and propagated along a first axis in the film by a step-along multi-phase propagation field. Such a domain wall device usually requires an anisotropic magnetic film where propagation of a reverse domain is either along the easy or, alternatively, along the hard axis and the domain walls bounding that reverse domain extend to the edge of the film in the direction orthogonal to the axis of propagation. Since the walls of the domain are bounded by the edge of the film, propagation of those domains is constrained to an axis along the transverse dimension of the film.

According to one aspect of this invention,

an information storage arrangement includes a film of magnetic storage material substantially isotropic in the plane of the film and having a preferred magnetization direction out of the plane of the film and capable of having single wall domains (as hereinafter defined) established therein, means for storing input information in the form of single wall domains in said film, and first means for controllably propagating said domains along a first axis in the plane of said film.

The characteristic of substantially like properties in the plane of the film permits the movement of a single wall domain controllably along transverse axes in the plane of the film by like, relatively simple propagation means.

Preferably said preferred magnetization direction is normal to the plane of the film; this permits information storage without necessitating a more complicated propagation means.

An example of a suitable isotropic material is yttrium orthoferrite.

According to another aspect of this invention an information storage arrangement includes a film of anisotropic magnetic storage material having hard and easy axes in the plane of said film and capable of having single wall domains (as hereinafter defined) established therein, means for storing input information in the form of single wall domains in said film, and first means for controllably propagating said domains along a first axis in the plane of said film.

A single wall domain differs from the reverse domains in the above-mentioned known arrangement in that the single domain wall has a shape independent of the geometry

[Price 5s. Od.]

Price 25p

of the film or, in other words, is not bounded by the edge of the film and such domains are referred to herein as single wall domains.

The invention will now be described and explained with reference to the accompanying drawings, in which:

FIGS. 1 and 6 are schematic diagrams of shift registers in accordance with one embodiment of this invention;

FIG. 2 is a schematic diagram of a propagation circuit suitable for the shift registers of FIGS. 1 and 6;

FIG. 3 is a pulse diagram provided to explain the operation of the shift register of FIG. 1;

FIGS. 4 and 5 are schematic diagrams of an input circuit for the shift registers of FIGS. 1 and 6;

FIG. 7 is a schematic diagram of a shift register in accordance with another embodiment of this invention;

FIG. 8 is a pulse diagram provided to explain the operation of the shift register of FIG. 7;

FIGS. 9 to 12 are explanatory schematic representations of a portion of the shift register of FIG. 7 showing the magnetic conditions thereof during operation;

FIGS. 13, 16 and 17 are schematic diagrams of two-dimensional shift registers; and FIGS. 14 and 15 are pulse diagrams provided to explain the operation of the two-dimensional shift register of FIG. 13.

Referring now to FIG. 1, this figure shows a schematic top view of a shift register 10 which comprises a sheet or film 11 of a material having substantially like properties in plane of the film and having a preferred magnetization direction normal to the plane of the film. Flux directed out of the paper, as viewed, normal to the plane of the sheet is represented by a plus sign; flux directed into the paper is represented by a minus sign. Sheet 11 includes a border portion 13. Flux in the border is assumed to be directed out of the plane of the sheet and thus is represented by plus signs. In the remainder of the film 11, flux is assumed directed into the plane of the sheet and thus is represented by negative signs. It is clear that a domain wall is defined between the positive and negative portions of the sheet. Sheet 11, which may be for example yttrium orthoferrite, is conveniently arranged, in a manner to be discussed later, such that the positive border 13 has an area related to the negative remaining area such that the sheet as a whole is essentially in a demagnetized condition.

Conductors P1, P2, and P3 overlie film 11. Each of conductors P1, P2, and P3 includes a series of circular loops. The loops included in conductor P1 define bit locations BL11, BL12, BL13, ... BL1n in sheet 11. The loops in conductors P2 and P3 are correspondingly positioned to define buffer

regions between bit locations in sheet 11. The conductors form a three-phase propagation circuit, each circuit including loops adjacent the loops of next adjacent propagation conductors along a single axis, as shown in FIG. 2, to move a single wall domain in a step-along manner when the conductors are pulsed consecutively as will be described later. In practice, the single wall domain occupies a space slightly larger than the conducting loop such that the next adjacent loop overlaps the domain. The space occupied by such a domain, of course, is a function of the parameters of the magnetic material and the sheet geometry in accordance with well established principles. Alternatively, the conducting loops of next adjacent propagation conductors may overlap to provide propagation. Each of conductors P1, P2 and P3 is connected between a propagation pulse source 14 and ground.

An input conductor 16 couples an input portion of sheet 11 including bit location BL11 and is connected between an input pulse source 17 and ground. Similarly, interrogate and sense conductors 18 and 19 couple bit location BL1n and are connected, respectively, between an interrogate pulse source 20 and ground and between a utilization circuit 21 and ground.

Pulse sources 14, 17 and 20, and utilization circuit 21 are connected to a control circuit 22 by means of conductors 23, 24, 25 and 26, respectively. Suitable pulse sources and control and utilization circuits may be as well known per se and accordingly will not be described in detail.

The operation of the shift register of FIG. 1 will now be described. FIG. 3 is a pulse diagram explanatory of the operation of the shift register 10 of FIG. 1. During operation, input pulse source 17 selectively applies a negative pulse (for the geometry shown) to conductor 16 to drive to a positive magnetization direction the portion of sheet 11 encompassed by that conductor. The input pulse is pulse P17 in the pulse diagram of FIG. 3 shown at time t1. Propagation conductors P1, P2 and P3 are pulsed in sequence by propagation pulse source 14 starting at a time t2 subsequent to time t1. The propagation pulses are pulses PP1, PP2 and PP3. Sources 14 and 17 are operated under the control of control circuit 22.

Initially the magnetic condition of sheet 11 is assumed to be positive in the border portion 13 and negative within the remainder of the sheet. When the input pulse P17 is applied, an area of positive magnetization appears within the initially negative area as shown in FIG. 4. The input pulse terminates permitting the later applied propagation pulse PP1 to isolate a single wall domain, i.e., a positive region, at bit location BL11 as shown in FIG. 5. In isolating such a positive region, the pulse PP1 "drives" the portion of the

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sheet surrounding that bit location to a negative magnetization as is also shown in FIG. 5. A small positive region remains extending in from the border 13 towards bit location BL11 and this region will be discussed later.

It is clear then that at time t_2 of FIG. 3 a positive region is provided at bit location BL11 in sheet 11. Such a positive region may be regarded as representative of a binary one. Had an input pulse been absent at time t_1 , no such positive region would have been formed and a binary zero would be considered stored. Regardless of the information stored, the succession of propagation pulses advances that information from one bit location to the next in three phases. The fields provided by the propagation pulses in consecutively pulsed propagation conductors operate to translate the single wall domain essentially by providing consecutively offset potential minima into which the domain "falls".

Every first propagation pulse PP1 is accompanied (or followed) by an interrogate pulse P18 under the control of control circuit 22. After $n-1$ sets of propagation pulses have been applied, at a time t_n in FIG. 3, the positive single wall domain stored at time t_1 in bit location BL11 reaches bit location BL1n. In response to the interrogate pulse applied at time t_n , bit location BL1n is driven to a negative magnetization condition (by the collapse of the domain there) inducing a pulse P19 in conductor 19 for detection by utilization circuit 21 under the control of control circuit 22. Such a pulse is indicative of a stored binary "one". Had an input pulse been absent at time t_1 , only a negligible shuttle pulse would appear at the corresponding time t_n . Thus, if an illustrative code 1011 is written (consecutively) into bit location BL11, output pulses appear in conductor 19 in the code—pulse, no pulse, pulse, pulse as consecutive propagation pulses are applied to propagation conductor P1.

The propagation direction may be reversed by reversing the propagation pulse sequence.

It is apparent, however, that the shift register just described is wasteful of useful area in the magnetic sheet since the border area 13 of sheet 11 is not used. The border area of sheet 11, however, may comprise smaller and smaller areas of sheet 11 near the input position as materials of higher and higher sheet coercive force are used. All that is required is that an area of positive (reverse) magnetization be available as a source of single wall domains as described. Ideally, the positive area need be no larger than the portion of the border and the extension thereof into the initially negative area as shown in FIG. 4. The arrangement with the larger border is shown in FIG. 1 because it is a particularly convenient geometry prepared

simply by heating sheet 11 initially, as is well known, to a temperature such that both positive and negative domains are formed in the sheet when the sheet is later cooled to room temperature. The positive domains are then removed from all areas except the border portion by providing the appropriate fields.

The inner boundary of the border portion 13 of FIG. 1 may be thought of as the path of a conductor C which closes on itself. When that conductor C is pulsed, an appropriate propagation field is provided for rearranging the domains in the magnetic sheet to provide the border configuration shown in FIG. 1. To this end, conductor C is connected between an initializing circuit 30 and ground and is operated under the control of control circuit 22 to which it is connected by means of conductor 31 as shown in FIG. 1. Alternatively, conductor C may be connected electrically in series with the propagation conductors in a manner to couple sheet 11 to provide the magnetic configuration of FIG. 1 when a propagation conductor is pulsed.

The positive border, as has been stated, permits the magnetic sheet as a whole to be in an essentially demagnetized condition. Further, the net demagnetizing field on each bit location may be reduced by distribution of a number of positive domains throughout the magnetic sheet in contradistinction to a positive border. The manner of preparing a magnetic sheet with such a distribution is analogous to that described above. It is contemplated that such positive domains may also serve as the source of positive single wall domains as described.

The described method of providing single wall domains enables a convenient supply of such domains in materials such as yttrium orthoferrite which require high fields for nucleating such domains in an initialized material. Yttrium orthoferrite requires a nucleation field in excess of 500 oersteds yet only requires about one oersted to propagate a single wall domain. The method is merely one way of supplying inputs particularly for high nucleation threshold material. For relatively low nucleation threshold materials, a nucleation field provided in a localized area of the sheet suffices. For high nucleation threshold materials, sufficiently high drives also provide single wall domains in a like manner.

The output has been described in terms of an interrogate and sense implementation. Such an output means may not always be required. The passage of single wall domains past an output position induces a voltage in a sense conductor coupled to that position for providing a detachable output therein. Also, the reflection and transmission characteristics of a single wall domain differ from the general sheet characteristics and thus may be utilized to give a conventional optical readout.

Two-dimensional operation of a shift register may be visualized as a plurality of shift registers arranged in horizontal rows, as shown in FIG. 1, in a single sheet of magnetic material. Now visualize a plurality of like registers orientated transverse, e.g. orthogonally, along vertical columns with respect to the first set of registers. A positive single wall domain at a given bit location in such a sheet then may be moved in a prescribed one of four directions.

FIG. 6 shows one such two-dimensional shift register 110. Shift register 110 includes a sheet 111 of yttrium orthoferrite having orthogonally arranged sets of propagation conductors of the type shown in FIG. 2 intersecting at bit locations BL11...BLmn. Only conductor P1 of each shift register channel is shown for simplicity. It is to be understood, however, that each channel includes conductors P1, P2 and P3 as shown in FIG. 2. An input conductor 116 is coupled to each bit location in row m of the matrix and encompasses an initialized positive area. Similarly, interrogate and sense conductors 118 and 119 are coupled to each bit location in row 1 of the matrix. It is clear that information, such as the binary word 1011, may be stored in the shift register channel of column 1, advanced serially therethrough as already described, and moved to the right, as viewed, for example in parallel, to another channel before providing indicative outputs there. Alternatively, information may be stored in the mth row in parallel at the input positions there. The information so stored may then be advanced in parallel in columns and moved serially in rows. It is clear that series or parallel operation is dependent upon whether or not the propagation conductors are pulsed individually or in parallel. The structure is symmetrical and the specific mode of information transfer and the means for effecting that transfer will be clear from the discussion of the shift register of FIG. 1. The various drivers and circuits for the embodiment of FIG. 6 may be similar to those employed in connection with the shift register of FIG. 1.

Information is moved through the magnetic sheet 111 of FIG. 6 in the simple manner described in the absence of external transfer, logic, and amplifying circuitry permitting multiple channel information shifting arrangements at greatly reduced costs. In addition, a variety of other arrangements are permitted by the simple arrangement of FIG. 6. For example, the movement of single wall domains in yttrium orthoferrite may be observed during experimentation by means of the selective reflection (Kerr effect) and transmission (Faraday effect) of polarized light. The use of polarized light in this manner not only enables an alternative read-out mode as mentioned hereinbefore but also

leads to the implementation of important new uses. It is contemplated to move a single wall domain back and forth across a sheet of material of the type described along a path similar to that traversed by an electron beam in a television tube thus providing an implementation for a variety of display devices. Alternatively, the magnetic pattern in the sheet may be observed directly through a magnetic tape viewer. This method of viewing is particularly useful because the preferred magnetization direction is out of the plane of the sheet and, accordingly, also is useful for display devices. Another contemplated use is the selective illumination of a PNP photodiode in a matrix of photodiodes by the movement of a single wall domain to an appropriate position to pass "select" light to the desired diode. It is contemplated to perform sorting and encoding operations also by separating information in one channel and inserting information from another therebetween.

The embodiments so far described have employed a yttrium orthoferrite sheet. Such a material enables complete flexibility of propagation in the plane of the sheet. That is to say, such "substantially isotropic" sheets permit propagation along n transverse axes two of which have been shown illustratively as two orthogonal axes. Thus, intersecting propagation circuits may be arranged at any angle to one another, and more than two such circuits may be employed. The property of a preferred magnetization direction substantially normal to the sheet characteristic of such materials is convenient in that it permits simple drive configurations as has been stated hereinbefore.

There are a multitude of materials having a preferred direction of magnetization out of the plane of a sheet of the material, for example, the rare earth orthoferrites, manganese bismuth, magneto plumbite, barium ferrite, and strontium ferrite. The choice of a particular material depends on practical considerations however. A practical material advantageously exhibits a low magnetization to ensure domain stability against magnetostatic fields in thin sheets of the material. In addition, a practical material exhibits a low to moderate and a uniform (or, alternatively, controlled) coercivity to domain wall motion. The material is also characterized by a nucleation field threshold for magnetization reversal in the absence of domain walls which is substantially higher than the wall motion threshold and also reasonably uniform. These properties are exhibited by the canted anti-ferromagnet yttrium orthoferrite having its C-axis normal to the plane of the sheet.

It is clear then that single wall domains that are substantially equally extended in both directions i.e., circular, can be moved so as to accomplish the desired functions in

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5 sheets of materials in which certain preferred
10 propagation directions for the domain are not
15 imposed by anisotropic effect and in which
20 the component of magnetization normal to
25 the sheet is not so large that demagnetizing
30 effects control the domain shapes. Of course,
35 materials with single wall domains of aniso-
40 tropic (non-circular) shapes can be utilized
45 by appropriately adapting the proportions of
50 the driving circuits.

The described propagation conductors pro-
vide fields in the magnetic sheet normal to
the plane of the sheet. It is not necessary
that crystalline anisotropy of the material in
the sheet be arranged in this direction. The
sheet need only be arranged to permit mag-
netization normal to the sheet. It is expected
that a sheet of isotropic material having a
sufficient thickness and/or having a suffi-
ciently low magnetization would be suitable
to this end.

The shift register arrangement so far
described have employed a magnetic sheet
which is substantially isotropic in its plane.
Other arrangements employing a magnetic
sheet which is anisotropic in its plane will
now be described.

Referring to FIG. 7, a shift register 10
comprises an electrically nonconducting aniso-
tropic magnetic field 11 and an electrically
conducting film 12 deposited on a suitable
insulating substrate 13 such as glass. Con-
ducting film 12, which may be copper, is
connected between a voltage source B, such
as a battery, and ground in a manner to pro-
vide parallel current lines therethrough. A
hairpin conductor 14 overlies film 11 and is
connected between a bipolar pulse source 16
and ground. Conductor 14 is orientated in a
direction along the hard axis thus providing
easy direction fields thereabout when pulsed.
Conducting film 12 is connected, as is clear
from the figure, in a manner to provide a
hard direction field in film 11. The hard and
easy axes of film 11 are indicated by the
double-headed arrows designated h and e,
respectively.

A nucleation conductor 17 couples film 11
at an input position also coupled by conduc-
tor 14. Conductor 17 is connected between
an input pulse source 18 and ground. A sense
conductor 20 couples film 11 at an output
position also coupled by conductor 14. Con-
ductor 20 is connected between a utilization
circuit 21 and ground.

Sources 16 and 18 and utilization circuit
21 are connected to a control circuit 22 via
conductors 23, 24 and 25, respectively. Suit-
able sources and control and utilization cir-
cuits may be as well known per se and accord-
ingly will not be described in detail.

The operation of the shift register channel
10 of FIG. 7 is simple as will be clear from
the pulse diagram shown in FIG. 8. The
current flowing on conducting film 12 of

FIG. 7 generates a bias field directed along
the hard axis from the input to the output
position in magnetic film 11. This is shown
in FIG. 8 by pulse PB initiated at a time t1.
At a time t2 in FIG. 8, a pulse P17 is pro-
vided in conductor 17 via input source 18
under the control of control circuit 22. Bi-
polar pulses +P14 and -P14 alternately are
initiated in conductor 14, via bipolar pulse
source 16, also under the control of control
circuit 22. In response, a single wall domain
is nucleated at the input position and pro-
pagated, incrementally, toward the output
position. At a later time t3, determined by
the frequency and amplitude of the bipolar
pulses on conductor 14 and by the hard direc-
tion bias field as discussed in greater detail
later, an output pulse P20 is induced in sense
conductor 20, as the domain passes there-
beneath, for detection via utilization circuit
21 under the control of control circuit 22.
An erasing bias field Me is provided in film
11 to erase single wall domains once sensed.
Such a bias is provided by well known means
(not shown).

The presence and absence of a pulse in
conductor 17 determines whether or not a
single wall domain is nucleated in the input
position. Thus, the presence and absence of
such a domain may be taken to represent a
binary one and a binary zero, respectively.
An input conveniently corresponds, in time,
to a positive pulse of the bipolar propaga-
tion pulse sequence applied to conductor 14.
The pulse on conductor 17 may even be re-
duced in amplitude such that the presence of
a positive pulse on conductor 14 is necessary
for nucleation. Be that as it may, adjacent
bit positions in film 11 are spaced apart at
least the distance a single wall domain moves
in one alternation of the pulses applied to
conductor 14. A representative stored code
1101, then, appears as shown in FIG. 9 read-
ing from right to left. The magnetization of
the film is assumed initialized in a direction
along the easy axis represented by a down-
ward directed arrow as viewed. The single
wall domain then is represented by an oval
including an upward directed arrow. The
coded word provides pulse, pulse, null, and
pulse in consecutive time intervals as con-
secutive bits pass conductor 20, for detec-
tion by utilization circuit 21.

The mechanism for moving a single wall
domain in a direction along a hard axis of
an anisotropic thin film is not completely
understood. The observed operation, however,
is accounted for in connection with FIGS.
10, 11 and 12.

FIG. 10 shows (magnified) a single wall
domain D at an input position in a film
such as film 11 of FIG. 7. The film as
shown in FIG. 10 may be thought of as film
11 viewed from beneath the film as shown in
FIG. 7. The conductor corresponding to con-

ductor 14 of FIG. 7 then would be shown partially hidden by the film. The magnetization of the film is in a first easy direction as indicated by the arrow M1 directed to the left in the figure and is seen to be opposite to the magnetization of the domain D which is in a second easy direction as indicated by the arrow M2 directed to the right. The domain D is shown bounded by the single domain wall represented by closed-curve line DW.

A hard direction (bias) field is indicated by the broken arrows MH directed upward as viewed in the figure. The hard direction field raises the left tip of the domain D and lowers the right tip of the domain as viewed in the figure. To this end, it is clear that the hard direction field (MH) and first easy direction field (M1) of the film are superposed to provide a field indicated by the broken arrow M3 directed upward and to the left in the figure. The field indicated by arrow M3 is operative on the left and right tips of domain D urging the latter into a shape aligned with the field. Thus, in the presence of the hard direction field, domain D assumes the geometry indicated by broken closed-curve line DW1 which represents the position of the bounding domain wall when a hard direction field is present. This is the condition at time t2 of FIG. 8.

Next, a positive pulse (+P14) is applied to conductor 14 providing a field directed to the right in film 11 in the position occupied by domain D. The domain D is in a position bounded by broken line DW1 of FIG. 10 shown solid in FIG. 11. The easy direction field now applied in the position of domain D superposes with the hard direction fields and with the first and second easy direction fields outside and inside the domain D respectively. The resolved fields outside the domain D are indicated by the arrow M4 directed upward and to the left in FIG. 11. The left and right tips of the domain extend and contract, respectively, changing their orientations to align with the field indicated by arrow M4. The resulting position of the domain wall of domain D is indicated by the broken closed-curve line DW2 in FIG. 11.

Curve DW2 is shown solid in FIG. 12. A negative pulse (-P14) is applied next to conductor 14 reversing the applied easy direction field in the position occupied by domain D as indicated by the curved arrow to the left on conductor 14. The resolved field now is in a direction indicated by the arrow M5, directed upward and to the left as viewed in FIG. 12, and the domain D again aligns itself with that field as indicated by the broken curves DW3 in FIG. 12.

The three arrows M3, M4, and M5, representing the hard direction and first and second easy direction fields superposed on

the film anisotropy field as described, are shown in FIG. 12. It is clear that arrow M3 represents a mean position and arrows M4 and M5 represent extreme positions to which the magnetization is rotated by the fields generated by the bipolar pulses applied to conductor 14. The initial position of the domain D as shown in FIG. 10 under the influence of a hard direction field is shown in FIG. 12 encompassed by broken curve DW1. The domain in its terminal position after a single alternation on conductor 14 is shown encompassed by broken curve DW3. A net upward displacement is represented by the distance between those two curves. The displacement has been observed to be about 2,000 angstrom units for domains having heights (up and down dimension as viewed) of from less than 1.0 mil to 3.5 mils and widths (transverse to the direction of displacement) of less than about 18 mils.

A reversal of the hard direction field provides similar displacement of the domain downward, as viewed, along the hard axis.

An understanding of the basic shift register channel as shown in FIG. 7, and the operation thereof provide a basis for an understanding of more complex arrangements. FIG. 13 shows a multiple shift register channel arrangement 30 which comprises a conductive sheet 31 and a thin magnetic film 32 arranged as shown in FIG. 7. Conductive sheet 31 is connected between a voltage source 33 and ground to provide a hard direction enabling field as already described in connection with FIG. 7. A plurality of hairpin conductors 14₁, ..., 14_n, ..., 14_n overlie film 32 and are orientated along the hard axis to provide easy direction fields in film 32 when pulsed. Conductors 14₁, ..., and 14_n are connected between a propagation pulse source 34 and ground. Input conductors 36₁, 36₂, ..., couple film 32 at input positions associated with alternate conductors 14₁, 14₃, ... in a manner shown in FIG. 7. These input positions for conductors 14₁ and 14₃ are marked by a single wall domains D1 and D2 in FIG. 13. Conductors 36₁, 36₂, ... are connected between an input source 37 and ground. An output position may be defined with respect to each channel of FIG. 13. Sense conductors 38₁, 38₂, ... shown coupled to such output positions, in only two channels for simplicity, operate to detect the single wall domains (or absence of domains) in a manner already described. Conductors 38 are connected between a utilization circuit 39 and ground.

The sources 33, 34 and 37, and utilization circuit 39 are connected to a control circuit 40 via conductors 41, 42, 43 and 44, respectively. Suitable sources and control and utilization circuits may be as well known per se and will not be described in detail.

Each of the conductors 14₁, 14₃, and 14_n defines a shift register channel which may be

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operated independently exactly as described in connection with FIG. 7, propagation source 34 providing the requisite bipolar pulses under the control of control circuit 40. The arrangement of FIG. 13, however, provides an additional flexibility. Stored domains may be moved not only upward and downward serially along the hard axis as already described but also may be moved to the left and to the right as viewed in FIG. 13, in parallel in the direction of the easy axis.

FIGS. 14 and 15 are pulse diagrams explanatory of the operation for the parallel shifting of domains to the right and to the left respectively as viewed in FIG. 13. In general, to shift to the right all information in film 31 of FIG. 13, a negative pulse is applied to odd numbered conductors 14₁, 14₃, and 14₅, followed by a positive pulse on even numbered conductors 14₂, 14₄, ..., and by a concurrent positive pulse on odd numbered conductors 14₁, 14₃, and 14₅. Operation for a movement to the left and to the right is on a two-phase basis as will become clear and, thus, even numbered hairpin conductors 14₂, 14₄, ... do not define entirely independent shift registers in this arrangement although sense conductors may be coupled thereto and outputs derived at each as is described hereinbefore.

To shift information to the right from one shift register channel to the next adjacent channel a negative pulse (see FIG. 14) is applied to, for example, conductor 14₁ followed by concurrent positive pulses on conductors 14₂ and 14₃. The negative pulse on the hairpin conductor 14₁, it is to be noted, is poled oppositely in the return path of the hairpin. Thus, fields are generated by that initial negative pulse to move the domains to the right to positions overlying the return path of hairpin conductor 14₁. The concurrent pulses on conductors 14₂ and 14₃ move the information, similarly, to positions overlying conductor 14₂. The positive pulse on conductor 14₃ trails that applied to conductor 14₂ to ensure that the information moves to positions along conductor 14₂ rather than returns to the initial positions. Information is now stored in the shift register channel defined by conductor 14₂. All shifting pulses are applied by means of propagation source 34 under the control of control circuit 40.

When information, stored serially in one channel, is moved in parallel to another channel as just described, the other channel must be unoccupied to receive the information. When viewed in this light, it is clear that corresponding bit positions in adjacent shift register channels of FIG. 13 also constitute shift register channels operated in parallel. Consider then that information is stored along the channel defined by hairpin conductor 14₁ as shown in FIG. 13 and that additional information is stored in the channel

defined by hairpin conductor 14₃ as represented by the domain D2 there. In this instance information is moved one channel to the right synchronously by applying a negative pulse to conductors 14₁ and 14₃ followed by concurrent positive pulses on conductor pairs 14₂ and 14₄, and 14₃ and 14₅, as shown in FIG. 14. It is to be understood that the fields applied are sufficient to move but not nucleate single wall domains. Accordingly, if a domain is absent in a particular position, the absence of a domain will be propagated.

To shift the information back again to the channels defined by hairpin conductors 14₁ and 14₃, concurrent negative pulses are applied similarly to conductor pairs 14₁ and 14₃ and then to 14₂ and 14₄, followed by a positive pulse applied to conductor pair 14₂ and 14₄ as indicated in FIG. 15. It is clear that the conductors 14 pulsed in pairs for such shifting may, alternatively, be connected in series. The shifting of single wall domains to the right and to the left takes place in a manner consistent with the movement of reverses domains of prior art arrangements along an easy axis. The hard direction field required herein for movement along a hard axis is not present during movement along an easy axis.

The arrangement of FIG. 13, then, not only permits the readout of separate shift register channels in parallel in a manner consistent with that described in connection with FIG. 7, but also permits information to be stored sequentially in a single channel and moved in parallel to another channel. Accordingly, a plurality of shift register channels are provided in a single magnetic film with the capability of shifting information in parallel therebetween. For example, the parallel shifting of the illustrative word 1011, shown in FIG. 13, from the channel defined by conductor 14₁ to that defined by conductor 14₃ is accomplished herein merely by the repetition of the pulses shown in FIG. 14.

The parallel shifting of information from one channel to another has been discussed in connection with the arrangement of FIG. 13. FIGS. 16 and 17 show compatible arrangements whereby individual bits (single wall domains and the absence of domains) may be shifted along a shift register channel as shown in FIG. 7 or from one channel to another as shown in FIG. 13.

If a plurality of solenoids were arranged to provide a hard direction field only along horizontal bands or sections of film 31 as viewed in FIG. 13 the shifting of individual bits in a channel is possible. The hard direction field is termed the enabling field herein because, in the absence of such a field, movement in a direction along the hard axis is inhibited. Accordingly, by controllably providing the hard direction fields along hori-

zontal bands of the magnetic films, movement is enabled along the hard axis only through a selected band. If those bands are about twice as wide as a single wall domain and overlapping (by the width of a domain) then it is possible to move single wall domains one at a time in the hard direction.

Consider FIG. 16. A thin magnetic film 51 is shown with a plurality of overlying solenoids 52. Solenoids 52 are orientated along the easy axis of film 52 between an enabling selector 50 and ground. Such solenoids are provided, conveniently, by printed circuit techniques utilizing, for example, copperclad Mylar (Registered Trade Mark). Three hairpin conductors 53, 54 and 55 are shown connected between a bipolar pulse source 56 and ground. Operation is entirely analogous to that described hereinbefore. In the absence of a hard direction field provided by activating a selected solenoid 52, bipolar pulses on a selected hairpin are inhibited from moving a domain along the hard axis. Therefore, single wall domain D3 of FIG. 16 may be moved upward for example, one position as viewed, while domain D5 remains stationary. This is accomplished by activating in succession the solenoid 52 overlying domain D3, the next adjacent overlapping solenoid 52 (upward), and then the next adjacent solenoid as bipolar pulses are applied to hairpin conductor 53. These solenoids are designated d_1 , d_2 , and d_3 , respectively. It is clear that domain D5 does not move because no hard direction field is present at its position. It is also clear that domain D4, in the channel defined by hairpin conductor 55, does not move because bipolar pulses are not applied to hairpin conductor 55. The enabling selector 50 and bipolar pulse source 56 are connected to a control circuit (not shown). Suitable pulse and control circuits may be as well known per se and will not be described in detail.

FIG. 17 shows a plurality of conductors 60₁, 62₂, ... 60_n, orientated along the easy axis of film 51 and connected between a row selector 61 and ground. The row conductors follow a crenelated pattern including portions thereof orientated along the hard axes. These last-mentioned portions are interleaved with corresponding portions of hairpin conductors 53 and 54. Such conductors (along with the hairpin conductors) operate as propagation straps to generate easy direction step-along fields on a four-phase basis in defined areas of film 51. Such operation is entirely consistent with the four-phase propagation well known per se and as described for example in copending application No. 22651/67 Serial No. 1183486. To this end, the hairpin conductors are connected to a propagation source (not shown) as well as to a bipolar pulse source shown in FIG. 16 which may include bipolar pulse source 56 for effecting hard direction translation. If the hairpin con-

ductors are connected in series, information is moved synchronously through a selected horizontal channel. If, alternatively, the hairpin conductors are arranged to be pulsed separately, asynchronous operation is possible.

The movement of a single wall domain along the hard axis of a film requires bipolar easy direction fields as has been described hereinabove. Each alternation of the easy direction field advances the domain as shown in FIGS. 10 to 12. Each domain so advanced is clear of an input position before a next adjacent bit is stored. The number of alternations required in this connection, then, depends on the dimension of the domain being moved along the hard axis. For domains having a dimension of about 0.33 mil along the hard axis, several alternations are necessary, adjacent bits being spaced one domain apart. Bit spacings are maintained, while domains are being moved between input and output positions herein.

The speed at which domains are moved along the hard axis of a film depends on the amplitude and frequency of the bipolar pulses applied to the hairpin conductors. An increase in the frequency of the bipolar pulses increases the rate at which a domain goes through the cycle depicted in FIGS. 10 to 12. If a single alternation causes an advance of 2,000 angstrom units, then the number of alternations per second determines the ultimate displacement. Frequencies of from two cycles per second to 200 megacycles provide displacement per second of from 4,000 angstrom units to 2×10^{11} angstrom units or over one meter per second. The amplitudes of the bipolar pulses are important because the amplitudes determine the extreme orientations of the fields represented by arrows M4 and M5 in FIG. 12 and thus determine the extent of the movement of the domain tips as shown in FIGS. 10 to 12. It is clear that large pulses run the risk of countering the initial easy direction magnetization along the axis of the hairpin driving the film uniformly to the hard direction therealong erasing domains and nucleating other spurious domains. But pulses just below such a level cause increased tip movement and thus lead to increased displacement per alternation. Pulses ranging from the wall motion threshold of the material to the nucleation threshold (threshold for nucleating new domains) cause displacement per cycle of from about 2,000 angstrom units to a domain width per alternation.

The amplitude of the hard direction field is also of importance in determining the rate of displacement of domains along a hard axis of a magnetic film. For a given material, the orientation of the mean field indicated by arrow M3 of FIG. 12 is determined by the amplitude of the hard direction field. The larger the field, the more nearly the

arrow M3 is aligned along the hard direction. This leads to a greater movement of the domain tips and, thus, to a greater domain displacement per alternation. Hard direction fields of from zero to the nucleation threshold provide displacements ranging from zero to a domain width per alternation.

The coercive force of the material also plays a part in determining the rate of displacement of domains. For example, in magnetic fields in which the field threshold for nucleating domains exceeds the wall motion threshold for moving the wall of those domains by a factor of about twelve, the drive currents for providing the bipolar pulses also may vary by a factor of twelve. It is clear then that the amplitude of the bipolar pulses depends on the coercive force of the material.

The advantages of such information storage arrangements may be realized from a recitation of the dimensions involved. Domains of 1×18 mils have been observed by the Kerr (optic) effect. Accordingly, hairpin conductors arranged on 15 mil centres permit an array of 500×35 bit locations per square inch of film. A considerable reduction in domain size is observed as higher coercive force materials are employed. Such a reduction, of course, permits a large increase in packing density and packing densities of the order of about 1000×100 are anticipated with increasingly higher coercive force material. Similarly, the thinner the film the smaller the possible domain size as is known to be the case also with conventional reverse domains. Consequently, by simple printed circuitry techniques high density multiple shift register channels may be provided in a single magnetic thin film and information may be moved with considerable freedom within a channel or from channel to channel in a simple manner. Movement of stored information may be controlled by a pulse programme and great latitude in such a programme is possible.

In addition to the series or parallel movement of bits in orthogonal directions in a film, adjacent words or bits in a single word may be separated, thus permitting the sorting of information. Also, bits of different words may be interchanged controllably thus permitting coding.

WHAT WE CLAIM IS:—

1. An information storage arrangement including a film of magnetic storage material substantially isotropic in the plane of the film and having a preferred magnetization direction out of the plane of the film and capable of having single wall domains (as hereinbefore defined) established therein, means for storing input information in the form of single wall domains in said film, and first means for controllably propagating said do-

main along a first axis in the plane of said film.

2. An arrangement as claimed in claim 1, wherein said preferred direction is normal to said plane.

3. An arrangement as claimed in claim 1 or 2, wherein said material comprises yttrium orthoferrite.

4. An arrangement as claimed in any preceding claim including second propagating means for controllably propagating said domains along a second axis in said film.

5. An arrangement as claimed in claim 4, wherein said first axis is transverse to said second axis.

6. An arrangement as claimed in any preceding claim and including reading means adapted to detect the presence of a single wall domain at an output position on said first axis.

7. An arrangement as claimed in any preceding claim, wherein said storing means comprises an area of reverse magnetization defining a domain wall in said film, means for extending said area in said film, and means for separating a single wall domain from said extended area.

8. An arrangement as claimed in claim 4 or 5, including means for defining in said film a plurality of first shift register channels each including bit locations, means defining in said film a plurality of second shift register channels each including bit locations, and wherein said storing means comprises means for writing input information as the presence or absence of single wall domains at input positions in desired shift register channels, and wherein said first and second propagating means are adapted to controllably propagate single wall domains from bit location to bit location in said film, and including reading means adapted to detect the presence and absence of single wall domains in output positions in said shift register channels.

9. An arrangement as claimed in claim 8, wherein each of said second shift register channels include a bit location in each of said first shift register channels.

10. An information storage arrangement including a film of anisotropic magnetic storage material having hard and easy axes in the plane of said film and capable of having single wall domains (as hereinbefore defined) established therein, means for storing input information in the form of single wall domains in said film, and first means for controllably propagating said domains along a first axis in the plane of said film.

11. An arrangement as claimed in claim 10, wherein said first means includes means for providing a magnetic field directed along said hard axis and means for providing a bipolar field directed along said easy axis.

12. An arrangement as claimed in claim



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zero to a domain width per alternation.

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In addition to the series or parallel move-
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mitting coding.

WHAT WE CLAIM IS:—

1. An information storage arrangement in-
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and having a preferred magnetization direc-
tion out of the plane of the film and capable
of having single wall domains (as herein-
before defined) established therein, means for
storing input information in the form of
single wall domains in said film, and first
means for controllably propagating said do-

main along a first axis in the plane of said
film.

2. An arrangement as claimed in claim 1,
wherein said preferred direction is normal
to said plane.

3. An arrangement as claimed in claim 1
or 2, wherein said material comprises yttrium
orthoferrite.

4. An arrangement as claimed in any pre-
ceding claim including second propagating
means for controllably propagating said do-
mains along a second axis in said film.

5. An arrangement as claimed in claim 4,
wherein said first axis is transverse to said
second axis.

6. An arrangement as claimed in any pre-
ceding claim and including reading means
adapted to detect the presence of a single
wall domain at an output position on said
first axis.

7. An arrangement as claimed in any pre-
ceding claim, wherein said storing means
comprises an area of reverse magnetization
defining a domain wall in said film, means
for extending said area in said film, and
means for separating a single wall domain
from said extended area.

8. An arrangement as claimed in claim 4
or 5, including means for defining in said
film a plurality of first shift register channels
each including bit locations, means defining
in said film a plurality of second shift regis-
ter channels each including bit locations, and
wherein said storing means comprises means
for writing input information as the pre-
sence or absence of single wall domains at
input positions in desired shift register
channels, and wherein said first and second
propagating means are adapted to controllably
propagate single wall domains from bit loca-
tion to bit location in said film, and includ-
ing reading means adapted to detect the
presence and absence of single wall domains
in output positions in said shift register
channels.

9. An arrangement as claimed in claim 8,
wherein each of said second shift register
channels include a bit location in each of said
first shift register channels.

10. An information storage arrangement
including a film of anisotropic magnetic
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in the plane of said film and capable of hav-
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input information in the form of single wall
domains in said film, and first means for con-
trollably propagating said domains along a
first axis in the plane of said film.

11. An arrangement as claimed in claim
10, wherein said first means includes means
for providing a magnetic field directed along
said hard axis and means for providing a
bipolar field directed along said easy axis.

12. An arrangement as claimed in claim

11, wherein said field directed along said hard axis is substantially uniform in said film.

13. An arrangement as claimed in claim 11, wherein said means for providing said field along said hard axis is segmented so that said field can be provided along a band or bands in said film at will.

14. An arrangement as claimed in any one of claims 10 to 13, including means for controllably propagating said single wall domains in said film along said easy axis.

15. An arrangement as claimed in any one of claims 11 to 14, wherein said means for providing said bipolar field includes a plurality of hairpin conductors coupled to said film and orientated along said hard axis and defining channels in said film.

16. An arrangement as claimed in any one of claims 11 to 14, wherein said means for providing a bipolar field includes a plurality of hairpin conductors coupled to said film and orientated along said hard axis and defining channels in said film, and means for selectively providing bipolar pulses in said conductors to provide said bipolar field along one or more of said channels.

17. An arrangement as claimed in claim 15 or 16, including means for selectively moving said domains in parallel from one channel to another.

18. An arrangement as claimed in claim 14, wherein said means for propagating said single wall domains along said easy axis comprises interleaved conductors coupled to said film so that domains can be propagated when said conductors are pulsed in a multiphase manner.

19. An arrangement as claimed in any one of claims 10 to 18, including reading means adapted to detect the presence of a single wall domain at an output position.

20. An arrangement as claimed in any one of claims 6, 8, 9 or 19, wherein said or each reading means is optical and is adapted to co-operate with a source of polarized light.

21. An arrangement as claimed in any one of claims 6, 8, 9 or 19, wherein said or each reading means comprises a magnetic tape viewer.

22. Information storage arrangements substantially as herein described and explained with reference to the accompanying drawings.

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