United States Patent

Copeland, III

[15] **3,668,667**

[45] **June 6, 1972**

[54] MULTILEVEL DOMAIN PROPAGATION ARRANGEMENT

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[52] **U.S. Cl.** .....**340/174 TF**

[51] **Int. Cl.** **G11c 19/00,** G11c 11/14

[58] **Field of Search** .....340/174 TF

[56] **References Cited**

UNITED STATES PATENTS

3,516,077	6/1970	Bobeck et al.	340/174 TF
3,553,661	1/1971	Hadden, Jr.	340/174 TF

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[57] **ABSTRACT**

A multilevel coding arrangement for a multistage single wall domain propagation channel is provided by a number of parallel magnetically soft rails adjacent a sheet in which single wall domains can be moved. The rails define laterally displaced stable positions for the domains, n rails defining $n + 2$ domain positions in each stage in the domain channel.

9 Claims, 5 Drawing Figures

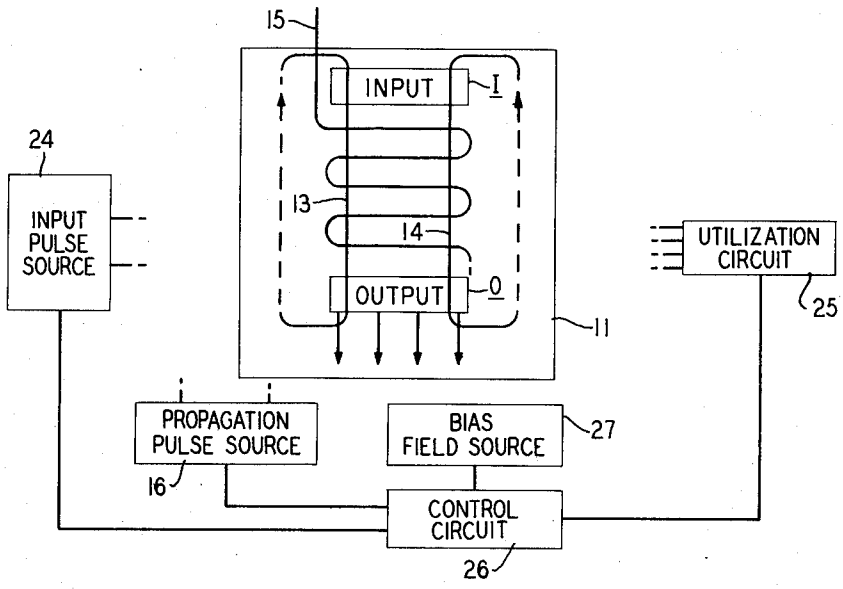


FIG. 1

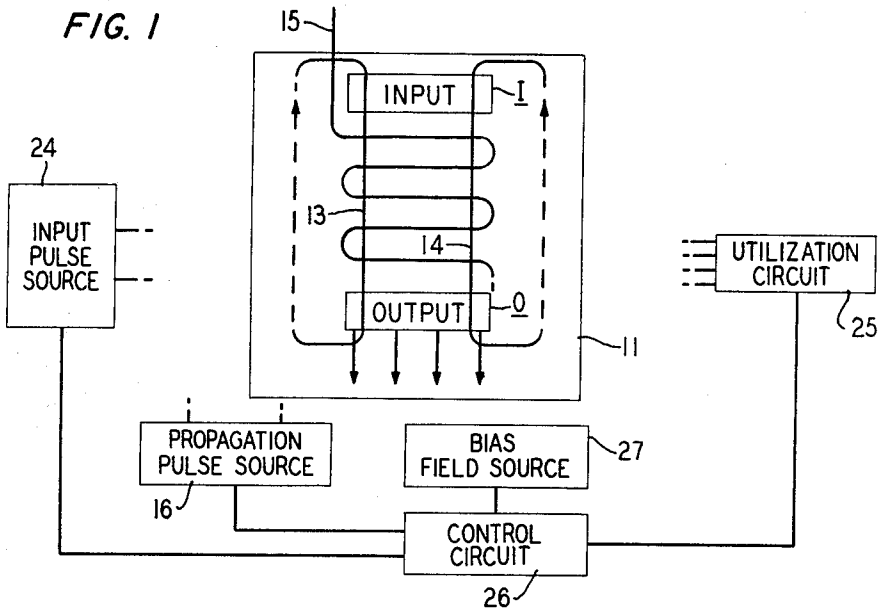


FIG. 2

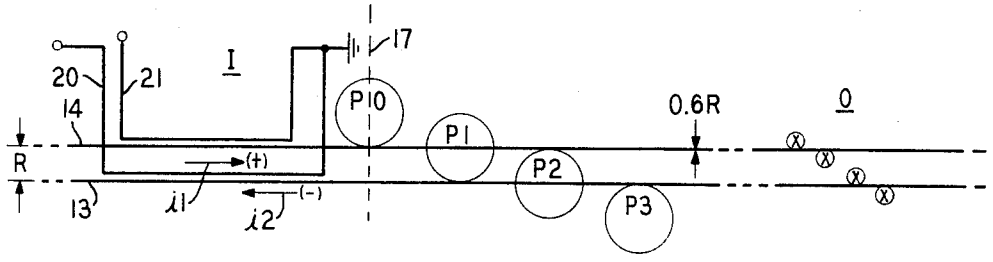
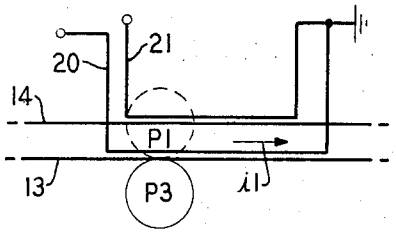


FIG. 3



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FIG. 4

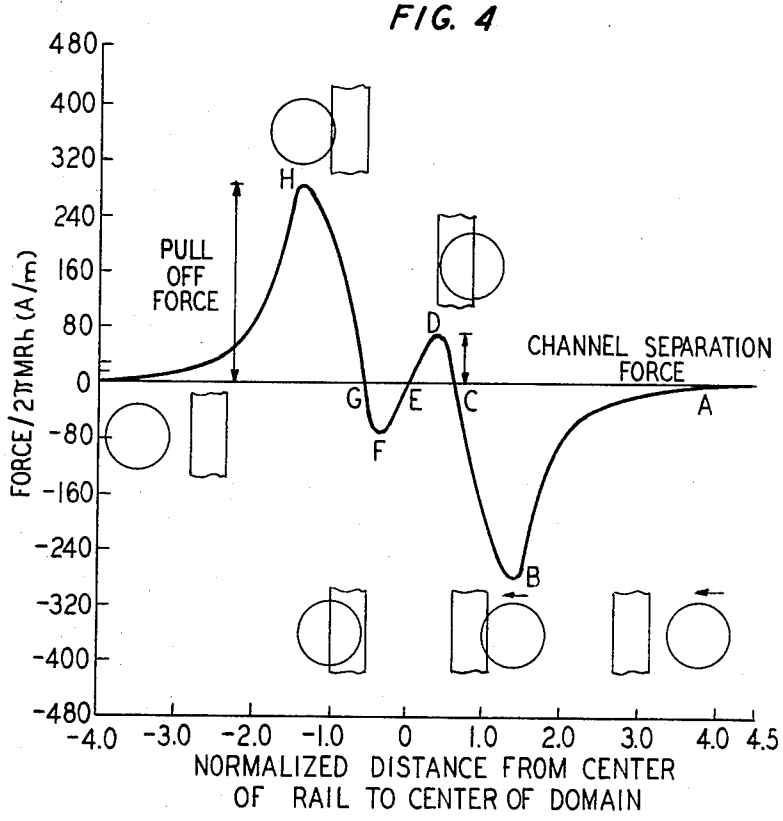
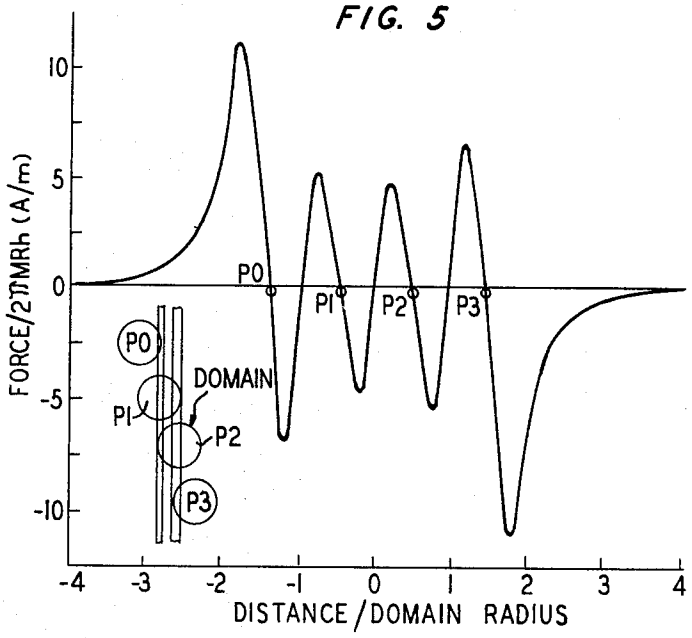

480
400
320
240
160
80
0
-80
-160
-240
-320
-400
-480
FORCE/2πMRh (A/m)
PULL OFF FORCE
H
D
T
CHANNEL SEPARATION FORCE
G
E
C
A
F
B
-4.0 -3.0 -2.0 -1.0 0 1.0 2.0 3.0 4.0 4.5
NORMALIZED DISTANCE FROM CENTER OF RAIL TO CENTER OF DOMAIN

FIG. 5


10
5
0
-5
-10
FORCE/2πMRh (A/m)
P0
P1
P2
P3
DOMAIN
-4 -3 -2 -1 0 1 2 3 4
DISTANCE/DOMAIN RADIUS

MULTILEVEL DOMAIN PROPAGATION ARRANGEMENT

FIELD OF THE INVENTION

This invention relates to data processing arrangements, particularly arrangements which employ single wall domain propagation devices.

BACKGROUND OF THE INVENTION

A single wall domain is a magnetic domain encompassed by a single domain wall which closes on itself in the plane of the medium in which it moves. Such a domain is a stable, self-contained entity free to move anywhere in the plane of the medium in response to offset attracting magnetic fields.

Magnetic fields for moving domains are often provided by an array of conductors pulsed individually by external drivers. The shape of the conductors is dictated by the shape of the domain and by the material parameters. Most materials suitable for the movement of single wall domains exhibit a preferred direction of magnetization normal to the plane of movement and are magnetically isotropic in the plane. Conductors suitable for domain movement in such materials are shaped as conductor loops providing magnetic fields in first and second directions along an axis also normal to the plane. By pulsing a succession of conductors of the array consecutively offset from the position of a domain, domain movement is realized. In practice, the conductors are interconnected serially in three sets to provide a familiar three-phase shift register operation. The use of single wall domains in such a manner is disclosed in U.S. Pat. No. 3,460,116 of A. H. Bobeck, U. F. Gianola, R. C. Sherwood, and W. Shockley, issued Aug. 5, 1969.

My copending application Ser. No. 49,273, filed June 24, 1970, describes an alternative multistage domain propagation arrangement in which domains move from stage to stage along a magnetically soft rail between input and output stages. The rail has a geometry to define a stable position for a domain to either side thereof at each stage permitting a domain to one side of the rail to represent a binary zero and a domain to the other side to represent a binary one.

BRIEF DESCRIPTION OF THE INVENTION

The present invention is based on the realization that a plurality of magnetically soft rails arranged in parallel on the surface of a sheet of magnetic material defines a set of laterally displaced stable positions for a domain at each stage. Such a multirail arrangement permits a coding arrangement of an order higher than binary. In an illustrative embodiment, two rails are employed to define four stable, laterally disposed positions for a domain at each stage. A domain at an input stage is moved to one of four stable laterally disposed positions at that stage for movement to an output stage. Four detectors at the output stage indicate the coded values represented.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a schematic illustration of a multilevel code arrangement in accordance with this invention;

FIGS. **2** and **3** are schematic illustrations of portions of the arrangement of FIG. **1** showing the magnetic conditions thereof during operation; and

FIGS. **4** and **5** are graphs showing the stability conditions for laterally disposed domain positions defined in the arrangement of FIG. **1** as a function of force.

DETAILED DESCRIPTION

FIG. **1** shows a domain propagation channel arrangement in accordance with this invention. The arrangement includes a sheet of magnetic material **11** in which single wall domains can be moved. An illustrative arrangement of two magnetically soft rails **13** and **14** are shown adjacent a surface of sheet **11**.

The rails may be deposited on the surface of the sheet directly over, for example, a thin chromium spacing film or may be deposited on glass and juxtaposed with the surface. Each rail is indicated to form a closed loop geometry signifying that information is recirculating about the domain channel defined by the loops and domain patterns representing that information are neither generated nor annihilated in the illustrative system.

The channel is divided into a sequence of stages by a pair of serpentine electrical conductors offset from one another and driven in the alternative as disclosed in my above-mentioned copending application. For purposes of this description, the serpentine conductors are represented by a single serpentine line **15**. Each of the conductors represented by line **15** is connected between a propagation pulse source **16** and ground as indicated in FIG. **1**. The serpentine geometry of line **15** forms a repetitive pattern along rails **13** and **14** which defines stages along the axes of the rails. One of these stages is selected as an input stage, another as an output stage. The input and output stages are indicated by blocks I and O respectively as shown in FIG. **1**.

The illustrative two rail embodiment defines for each stage four ($n+2$ where $n > 1$ is the number of rails) positions which are laterally disposed with respect to one another with reference to the axes of the rails. FIG. **2** shows these four positions for a representative stage. The positions for the representative stage are actually defined along broken line **17** in FIG. **2** but are shown as circles in consecutive positions for illustrative purposes. It is to be understood that the circles represent only the lateral displacement of domains, one from the other, in a single stage and do not represent consecutive positions for a domain in consecutive stages along the axes of the rails in FIG. **2**.

The four possible positions for a domain in a stage are designated **P0**, **P1**, **P2**, and **P3** in FIG. **2**. Once a domain is in one of the laterally displaced positions it is advanced along the associated rail, as the propagation pulses are applied, without changing its position relative to the rail. In the illustrative embodiment, such a domain is recirculated continuously passing the input position I at which the domain position can be changed if desired and output position **0** at which the domain position is detected.

The illustrative input arrangement comprises two electrical conductors **20** and **21** associated with rails **13** and **14** respectively as shown in FIG. **2**. Each of the conductors serves to move a domain to one side or the other thereof depending on the polarity of the current applied to it. If, for example, the magnetization of a domain is towards the viewer in FIG. **2**, a current in the direction of arrow *i***1** (+) in conductor **20** moves a domain in position **P3** to position **P1** as shown in FIG. **3** whereas a reversal in polarity causes the opposite movement.

In a simple mode of operation, the input arrangement is operated to move domains to a reference position **P0**. Accordingly, a current in the direction of arrow *i***1** (+) is provided in for example conductor **20** ensuring that no domain in position **P3** passes the input at a (lateral) position where a pulse in conductor **21** would have negligible affect on it. Thereafter, conductors **21** and **20** are pulsed in coded fashion to establish a selected position for a domain in each stage. Table I establishes the input code for selecting domain positions:

TABLE I

Position Occupied by Domain	When Conductor **21** is First Pulsed as Follows	And then Conductor **20** is Pulsed as Follows
P0	+	No pulse
P1	−	+
P2	−	No pulse
P3	−	−

Conductors **20** and **21** are connected between an input pulse source **24** of FIG. **1** and ground.

It may be recognized that a four-level coding system as illustrated provides a numbering system to the base four where successive domains can represent multiples of 4^3, 4^2, 4^1, 4^0 or −64, 16, 4, 1 which allows each domain to represent twice as much information as schemes where each domain represents a binary number. For example, to store the number 45 in a binary organization requires six domain positions (101101) along a single rail whereas in the illustrative four-level coding arrangement only three domain positions are required to store the same number ($45 = 231 = 2.4^2 + 3.4^1 + 1.4^0$) in a two rail system (viz., **P2**, **P3**, **P1** of FIG. **2**) in accordance with this invention.

The propagation operation advances domains, so positioned, to the output stage **0**. Conveniently, a Hall type detector of the type disclosed, for example, in copending application Ser. No. 882,900, filed Dec. 8, 1969 for W. Strauss, now U.S. Pat. No. 3,609,720, issued Sept. 28, 1971, is placed to detect the presence of a domain in each of the code positions. In practice, the positions of the devices are staggered as indicated by the encircled X marks in FIG. **2**. Such devices are connected to a utilization circuit **25** as indicated in FIG. **1**.

Sources **16** and **24** and circuit **25** are connected to a control circuit **26** for synchronization and control. The various sources and circuits herein may be any such elements capable of operating in accordance with this invention.

The diameter of a domain is maintained at a prescribed value by a bias field in a familiar manner. A source of such a field is represented by block **27** so designated in FIG. **1**.

The width of rails **13** and **14** as well as the separation therebetween is shown in FIG. **2** in terms of a domain radius. Illustratively, the rails are on centers one radius (R) apart and are **0.6**R wide.

The stability of a position to either side of a rail as disclosed in my copending application is summarized in connection with FIG. **4**. The figure shows a plot of the normalized force $F/2\pi MRh$ (amperes per meter) exerted by a magnetically soft (permalloy) rail of normalized width 1.0 (i.e., the domain radius for a domain having a radius equal to the thickness, h, of the wafer) where M is the magnetization of the material in webers per meter square. A top view of the domain and rail are shown at various points along the graph to demonstrate the position of the domain with respect to the rail at those points. It is clear that two stable points, G and C, exist for a domain with respect to the rail. A domain, initially at A, for example, experiences a maximum force (point B) pulling it toward C. The coercivity of the material of sheet **11** is assumed negligible so that it is not an important factor in preventing a domain from reaching C. In practice this is the case. Once the domain reaches C, an external force is required to move it to G. This external force is called the "channel separation" force. In order to pull a domain free of a rail, a large external force is necessary as shown at H. This force is called the "pull off" force.

The force calculation is dependent on the sum of the forces acting on the two edges of the permalloy rail and thus is a function of the rail width. It can be shown that there is a rail width at which the channel separation force is a maximum and a width at which two stable positions are no longer defined by a rail.

The two rails of FIG. **2** are placed sufficiently close together such that all the positions **P0**, **P1**, **P2**, and **P3** of FIG. **2** exist. This is clear from a similar slot of force versus distance shown for a two rail system in FIG. **5**. It is important to note that the positions **P1** and **P2** are stable because when a domain occupies a stable position with respect to a first rail, the center of that domain is over the second of the rails and experiences no net force because of that second rail.

The invention has been described in terms of a two rail system where four lateral positions are defined thereby in each stage. It should be apparent that additional rails define additional stable positions. If more than two rails are employed, however, each additional rail defines only a single additional stable lateral position for each stage, n rails defining $n+2$ stable positions (where $n > 1$).

Like results are achieved when grooves in sheet **11** define the rails as, for example, rails **13** and **14** of FIG. **2**.

Not only is coding flexibility apparent in the arrangement of FIG. **1**, but a significant gain in packing density is achieved in accordance with this invention. For example, if we assume a spacing of two domain diameters between adjacent domains along a given rail and three domain diameters between domains in adjacent rails, a six domain diameter squared (6 D^2) area is necessary for each storage area. If a single rail system is used, two domain positions are defined in that storage area. This leads to a packing density of one binary bit per 6 D^2 area. If two rails are employed, on the other hand, the area for storage is increased to 8 D^2 but the information stored is equivalent to two binary bits. Therefore, a storage density of one position per 4 D^2 area results, an increase by a factor of 1.5.

What has been described is considered merely illustrative of the principles of this invention. Accordingly, various alternatives may be devised in accordance with those principles within the spirit and scope of this invention.

What is claimed is:

1. A domain propagation arrangement comprising a sheet of magnetic material in which single wall domains can be moved, $n > 1$ rails energy coupled to and defining a propagation channel in said sheet, means for generating repetitive magnetic field patterns for moving domains from stage to stage simultaneously along a first or second side of each of said rails from input to output stages in said channels, said rails having a geometry and being disposed to define $n + 2$ stable positions for domains in each of said stages.

2. A domain propagation arrangement in accordance with claim **1** including means for moving a domain to a selected one of said $n+2$ positions in said input stage and means for detecting the one of said $n+2$ positions occupied by a domain at said output stage.

3. A domain propagation arrangement in accordance with claim **1** wherein said rails comprise magnetically soft films disposed in parallel between said input and output stages.

4. An arrangement in accordance with claim **1** wherein said rails comprise grooves in the surface of said sheet disposed in parallel between said input and output stages.

5. An arrangement in accordance with claim **2** wherein each of said rails forms a closed loop for recirculating information.

6. An arrangement in accordance with claim **3** wherein n is 2.

7. An arrangement in accordance with claim **6** wherein said two rails are spaced apart a distance such that a domain therebetween in a stable position with respect to a first of said rails overlies the second of said rails such that the latter applies only a negligible force on said domain.

8. An arrangement in accordance with claim **7** wherein said domain has a diameter of 2R and the distance between the centers of said rails is R.

9. A multilevel magnetic domain logic arrangement comprising a sheet of magnetic material in which single wall domains can be moved, a plurality of magnetically soft overlay rails juxtaposed with a surface of said sheet, means for generating a repetitive magnetic field pattern along said rails in a manner to move domains from stage to stage therealong between input and output stages, each of said rails having a geometry for defining first and second laterally disposed stable positions for a domain in each of said stages, said rails being disposed with respect to one another in a manner to define a set of laterally displaced stable positions for a domain in each of said stages, means for moving domains to a selected one of said set of positions defined by said plurality of rails at said input stage, and means for detecting the presence and absence of domains in ones of said set of positions at said output stage.

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