

Nov. 24, 1970

R. H. MORROW ET AL
SINGLE WALL DOMAIN APPARATUS HAVING INTERSECTING
PROPAGATION CHANNELS

3,543,255

Filed June 18, 1969

5 Sheets-Sheet 2

FIG. 2

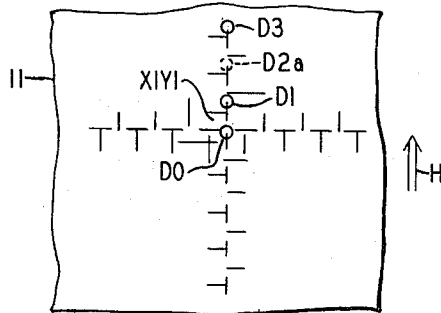


FIG. 6

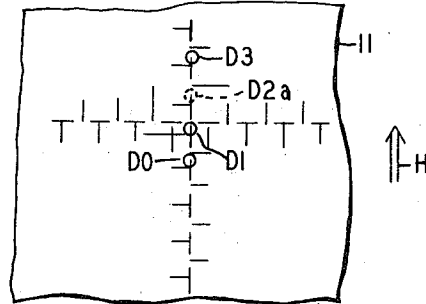


FIG. 3

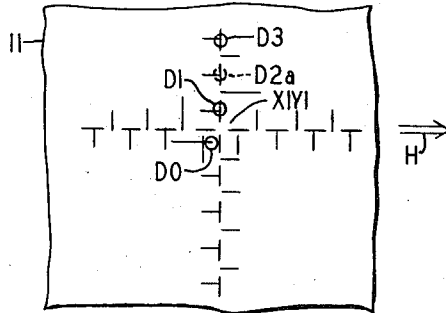


FIG. 7

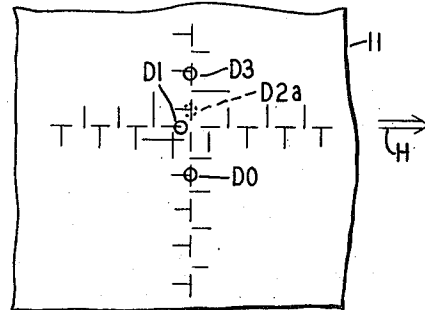


FIG. 4

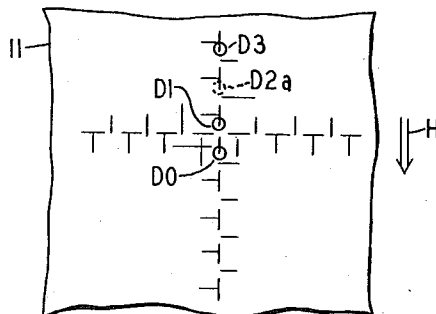


FIG. 8

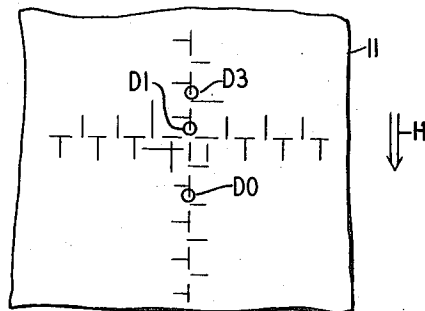


FIG. 5

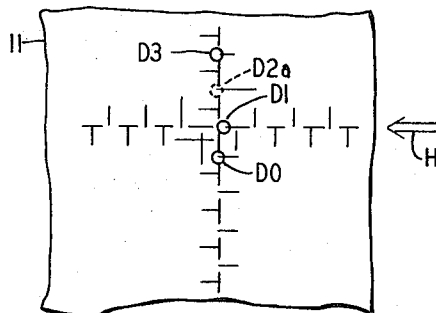
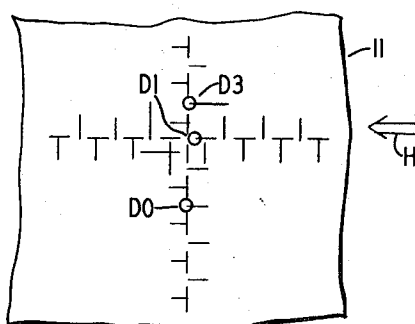


FIG. 9



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FIG. 10

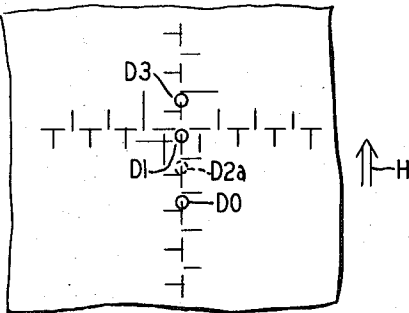


FIG. 14

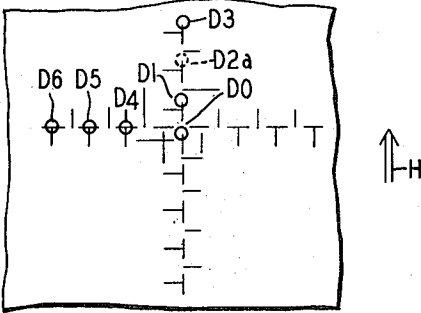


FIG. 11

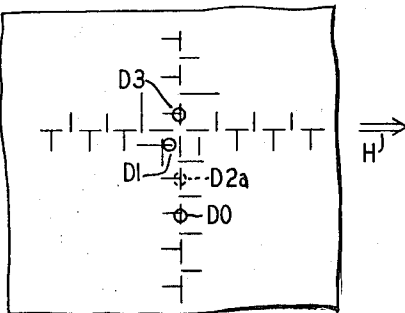


FIG. 15

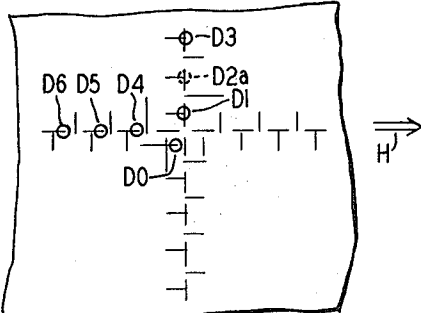


FIG. 12

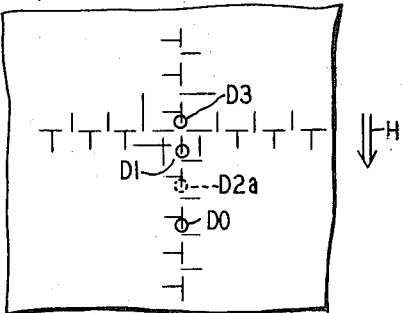


FIG. 16

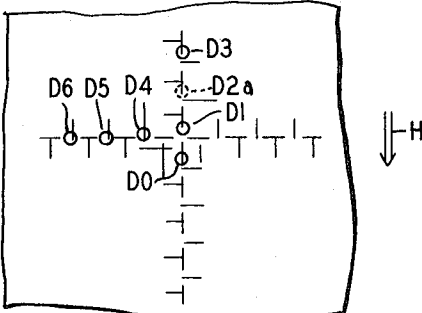


FIG. 13

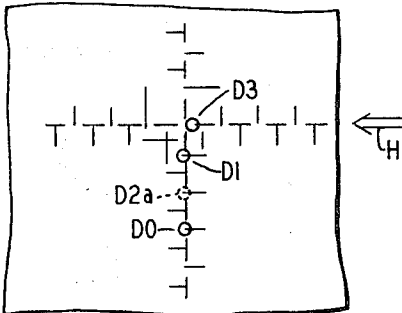
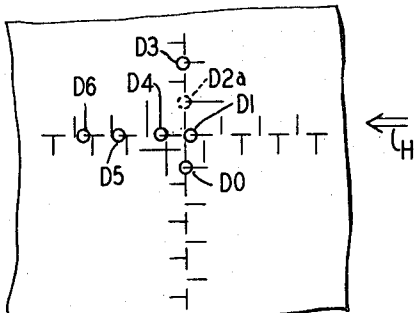


FIG. 17



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FIG. 18

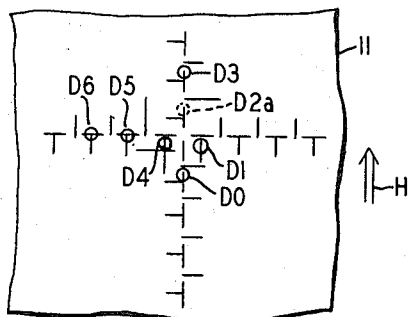


FIG. 22

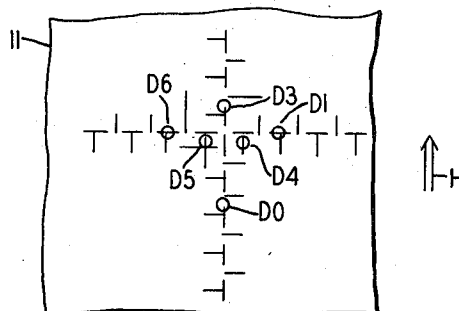


FIG. 19

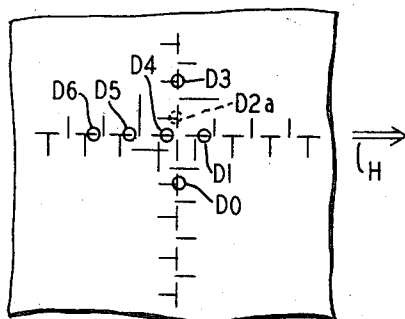


FIG. 23

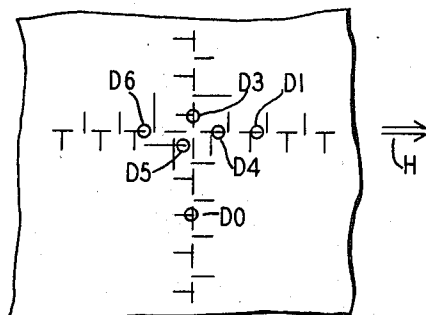


FIG. 20

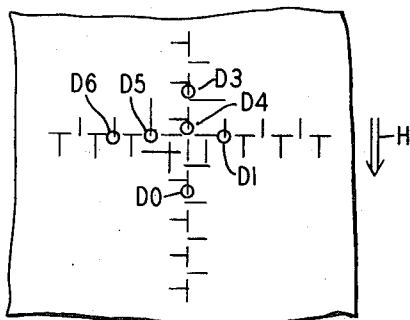


FIG. 24

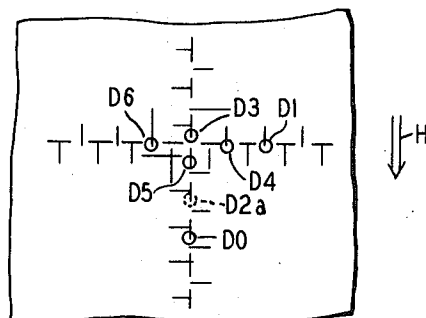


FIG. 21

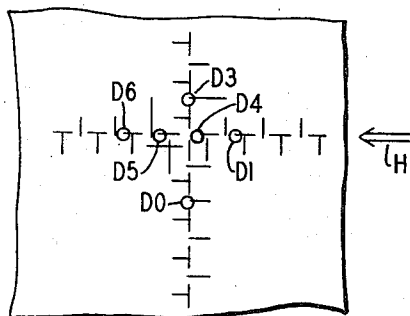
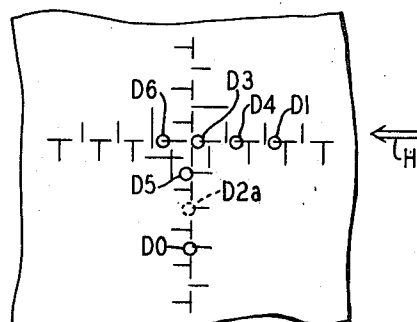


FIG. 25



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FIG. 26

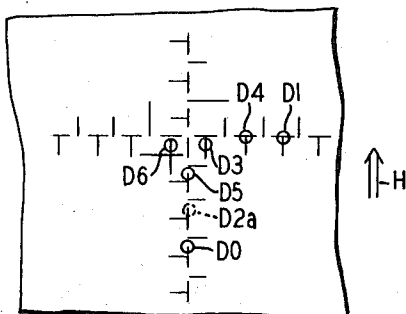


FIG. 27

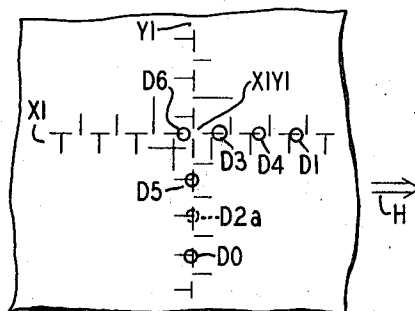


FIG. 28

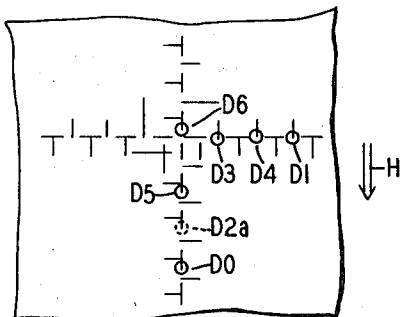


FIG. 29

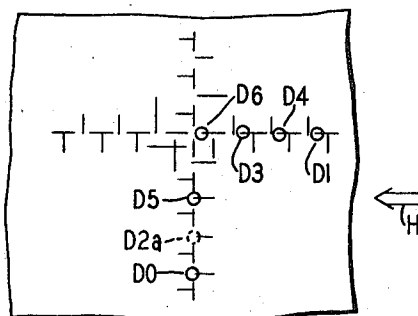


FIG. 30

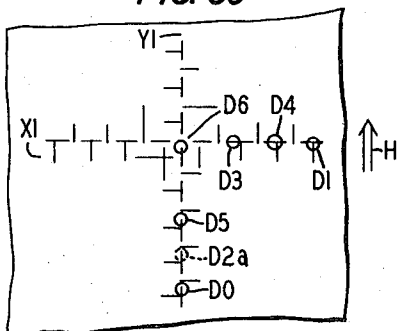
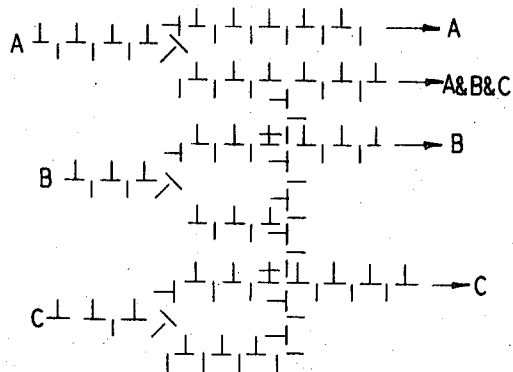


FIG. 31



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SINGLE WALL DOMAIN APPARATUS HAVING INTERSECTING PROPAGATION CHANNELS

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Int. Cl. G11c 11/14, 19/00

U.S. Cl. 340—174

9 Claims

ABSTRACT OF THE DISCLOSURE

Propagation channels for single wall domains are defined in a magnetic sheet by magnetically soft overlays in which attracting magnetic poles move in response to reorienting in-plane fields. Information in two channels is shown to pass intersections between the channels synchronously without destructive interference if the intersection is properly constructed.

FIELD OF THE INVENTION

This invention relates to data processing arrangements and, more particularly, to such arrangements comprising domain propagation devices.

BACKGROUND OF THE INVENTION

Domain propagation devices are well known in the art. In most known domain propagation devices, a reverse-magnetized domain, having spaced apart leading and trailing domain walls, is moved controllably in a channel structured to prevent lateral motion of the domain. The Bell System Technical Journal (BSTJ), volume XLVI, No. 8, October 1967, at page 1901 et seq., on the other hand, describes a domain which is (self) bounded by a single domain wall and is free to move in the plane of the sheet. Movement in the latter case is in response to an offset structured magnetic field (gradient) which displaces the domain in the absence of uncontrolled expansion.

A typical magnetic sheet in which single wall domains are moved comprises, for example, a rare earth orthoferrite or a strontium or barium ferrite. The domains assume the shape of circles in the plane of a sheet of these materials. The sheets are characterized by a preferred direction of magnetization normal to the sheet, flux in a first direction along that normal being considered negative (—) and flux in a second direction being considered positive (+). A convenient convention is to represent a single wall domain in such a sheet as an encircled plus sign where the circle represents the encompassing single wall of the domain. In connection with the ensuing discussion, the plus sign is omitted and the domain is represented solely as a circle.

There are a variety of techniques for moving single wall domains. One, illustrated in the above-mentioned BSTJ article, comprises offset conductor loops pulsed in sequence to attract domains to next consecutive positions. This technique permits a high degree of control over individual domains. But the current carrying requirements of such conductors make it difficult to take full advantage of the resolution capabilities of photolithographic techniques. Consequently, it is difficult to realize the minute dimensions required to manipulate, for example, domains of the order of microns.

Another technique for moving single wall domains employs a structured magnetically soft overlay on the sheet in which single wall domains are moved. The overlay generates attracting magnetic poles which move in the overlay in response to reorienting in-plane fields. The poles attract domains along a predictable path determined

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by the geometry of the overlay pattern and the consecutive orientations of the field. This technique has the virtue that the overlay has no current carrying requirements and so takes full advantage of high resolution capability of photolithographic techniques and can be adapted for manipulating domains of minute size. The technique also permits the movement of all domains in a sheet without discrete wiring connections at the expense of selective movement of domains.

It has been found desirable to procure a degree of selectivity in the propagation technique in which overlays are used in order to permit various logic operations to be carried out. Moreover, it has been found that the geometry of the overlay is the key to achieving the desired selectivity. Fanout and AND and OR operations have been achieved by variations in overlay geometry.

It is an object of this invention to provide a domain propagation device in which domain propagation channels intersect one another in a manner to permit information moving synchronously in the channels to pass through the intersection without destructive interference.

BRIEF DESCRIPTION OF THE INVENTION

A pattern of four magnetically soft thin film rectangles (bars) disposed on imaginary horizontal and vertical axes symmetrically with respect to the origin of those two axes defines an intersection for circulating a single wall domain in a magnetic substrate in response to a rotating in-plane magnetic field. Patterns of single wall domains, representative of information, are moved in the substrate along propagation channels defined by bar and T-shaped magnetically soft thin film overlays aligned with those axes as well as with the bars at the origin.

The position occupied by a domain in each instance is associated with the end of each portion of a bar or T-shaped overlay which has its long dimension aligned with the in-plane field, assuming a compatible direction of magnetization within the domain. As the in-plane field rotates to align with the next adjacent overlay portion, poles generated there in response to that field attract the domain. Domain patterns, so moved, introduce domains into the intersection in accordance with the information represented.

A domain moved into such an intersection and not intersected with by another domain continues to circulate in response to reorientations of the in-plane field. On the other hand, a subsequent domain propagating toward the intersection in one of the channels replaces the circulating domain. The circulating domain, in turn, continues along the channel in which its replacement had been propagated. A modification of the bar and T-shaped overlay adjacent the bars defining the intersection permits information to move synchronously in two channels through such an intersection without destructive interference thus providing an information "crossover."

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is an illustration of a domain propagation circuit including crossovers in accordance with this invention;

FIGS. 2 through 30 are illustrations of a representative crossover of FIG. 1 showing the magnetic conditions therein during operation; and

FIG. 31 is an illustration of an alternative domain propagation circuit in accordance with this invention.

DETAILED DESCRIPTION

FIG. 1 shows a domain propagation arrangement 10 including crossovers in accordance with this invention. Illustratively, four propagation channels X1, X2, Y1 and Y2 are shown forming intersections X1Y1, X1Y2, X2Y1,

and X2Y2 therebetween. The channels are defined illustratively by bar and T-shaped magnetically soft overlays 12 as disclosed in copending application Ser. No. 732,705, filed May 28, 1968 for A. H. Bobeck. Domains are moved along the pattern of overlays in response to rotating in-plane fields in a manner consistent with the description above. Block 14 in FIG. 1 represents the source of such an in-plane field.

Domains are introduced selectively into the various channels illustratively by means of magnetically soft discs IX1, IX2, IY1 and IY2 as disclosed, for example, in copending application Ser. No. 756,210, filed Aug. 7, 1968 for A. J. Perneski in response to permutations in the in-plane field amplitude. This input mechanism is made selective by an additional winding (not shown) for each disc for providing a localized in-plane field there when pulsed. This added field augments the reorienting in-plane field to provide an input. Block 15 represents an input driver adapted for this purpose.

Domains are detected illustratively by familiar output loops OX1, OX2, OY1, and OY2, each of which is connected between a detector 16 and ground.

Drivers 14 and 15 and detector 16 operate under the control of a control circuit 17. The various drivers and circuits may be any such elements capable of operating in accordance with this invention.

A variety of techniques for selectively generating, propagating and detecting single wall domains are known in the art and well understood. The illustrative input and output configurations are merely representative of ones of these techniques all of which are adaptable in accordance with this invention. For example, the illustrative domain propagation arrangement employs magnetically soft overlays in which poles move in response to a rotating in-plane field. A crossover in accordance with this invention also employs such a technique. Since domain propagation in this manner is described in the above-mentioned application of Bobeck, we may direct our attention primarily to the intersection of two propagation channels defined by overlays. We will merely assume that domains are provided, propagated and detected by the representative implementations without further description.

Consider a familiar situation in which data streams are propagating along channels which are here taken to intersect. For example, consider the information 101 represented by a domain, the absence of a domain, and a domain respectively moving downward along channel Y1 in FIG. 1. The utility of a crossover arrangement in accordance with this invention is demonstrated by a showing that the information 101 moves through a representative intersection X1Y1 of FIG. 1 at the same time information moves to the right along channel X1 as viewed in FIG. 1.

FIG. 2 shows an enlarged view of the intersection or crossover X1Y1 of FIG. 1. The information is represented by domains D1, D2a, D3 as shown; "domain" (or circle) D2a, of course, is broken to illustrate that a domain is really absent in that position. The broken circle representation serves as an expedient to facilitate the description. For the assumed initial disposition of information with respect to the overlay pattern, an upward directed in-plane field, represented by arrow H in FIG. 2, is required. Positive poles are generated at the terminus of of each segment of the overlay having its long dimension aligned with field H.

Our convention calls for domains to be attracted to positive poles. It must be appreciated, nevertheless, that in practice, the magnetization direction of the domain and the surface of sheet 11 against which the overlay is disposed determines the polarity of field for realizing the action to be described immediately hereafter.

Field H is assumed to be rotating clockwise. FIGS. 2 through 13 show the consecutive positions of the domains representing information in channel Y1 as field H rotates when information is absent in channel X1. The field can

be seen to make three rotations in the period represented by the figures.

Initially, as shown in FIG. 2, a domain D0 is assumed to be present in the intersection. This domain will be seen to replace the first information-representing domain which enters the intersection. The last information-representing domain to enter the intersection, in turn, remains in the intersection to serve the function of domain D0 for next consecutive information.

In the absence of incoming information, domain D0 merely recirculates at the intersection following the changing pole patterns in response to the rotating field. When information is propagated into the intersection, on the other hand, domain D0 does otherwise.

FIG. 2 shows field H oriented upward. Domain D1 is shown disposed to enter the intersection. FIG. 3 shows the field oriented to the right. Domain D1 is moved, in response, to a position to repel domain D0, an interaction analogous to that exhibited by like-charged pith balls. The position to which domain D0 would move normally in the absence of domain D1 is now denied to it because of that repelling force and domain D0 moves downward to an alternate position shown in FIG. 3. Domain D3 and absent domain D2a move downward as shown.

In FIG. 4, field H is shown directed downward. Domain D1 has now entered the intersection. Domain D0 is moved downward well out of the intersection; D2a and D3 are moved downward as shown. It is important to note that the information represented initially by domain D1 is now represented by domain D0 and is in a position which corresponds to that which it would occupy only after one additional rotation of the in-plane field in the absence of the intersection with a circulating "dummy" domain. In other words, the position of the information represented by a domain entering a crossover herein is advanced one cycle.

Domain D1 now starts to circulate at the intersection as the field rotates to the left as shown in FIG. 5. Information represented by D0, D2a and D3 moves downward as viewed.

FIG. 6 shows the field returned to its assumed initial orientation. Domain D1 is still recirculating at the intersection. But now an absence of a domain is entering the intersection. No interaction occurs and domain D1 continues to circulate moving closer to the position of D2a as field H rotates to the right as viewed in FIG. 7. Domain D1 finally occupies the next normal position of D2a when the field is directed downward as shown in FIG. 8. Because domain D1 was not expelled from the intersection, a gap equivalent to an absence of a domain occurs between the positions of domains D0 and D1 as shown in FIG. 8. This gap will be designated D2a when the continuity of the information flow is reestablished below. Once again the position of information is seen to be advanced one full cycle.

FIGS. 9 and 10 show the field directed to the left and upward respectively. Domains D0 and D3 have moved downward and domain D1 continues to circulate as viewed.

When the field H rotates to the right as shown in FIG. 11, domain D1 is prevented from moving to its normal recirculating position by the presence of domain D3 and, consequently, moves instead to the position shown in that figure. Domain D1 is now free of the intersection reestablishing the information format 101 as is perhaps more clear from FIG. 12. The absence of a domain (D2a) is once again designated in FIGS. 11 and 12 for consistency.

FIG. 13 shows the field directed to the left. Domain D3 now circulates at the intersection, as did domain D0 before it, while the information represented by domain D0, absence of a domain D2a and domain D1 is advanced downward as viewed. It is clear that the information passes the intersection but is represented by domain symbols with different designations after it so passes. It

is also clear that the position of the information is advanced one full cycle.

An analogous operation accounts for the independent advance of information from left to right along channel X1 as may be appreciated by rotating FIG. 2 ninety degrees counterclockwise aligning channel Y1 along the horizontal axis.

Now we are in a position to consider the movement of illustrative information 101 downward along channel Y1 at the same time information moves to the right along channel X1. We will assume that information 111 is moving along channel X1 for illustrative purposes. FIGS. 14 through 25 show the consecutive positions for the information in channel X1.

The information in channel Y1 moves in a manner slightly modified from that already described above and is repeated in FIGS. 14 through 25 to illustrate the modifying interactions which permit the information to cross over at the intersection. The information in channel X1 is represented by domains D4, D5 and D6.

The description is initiated with the field H directed upward as shown in FIG. 14. Domains D4, D5 and D6 are in consecutive positions associated with the tips of overlays aligned with the field. The positions assumed by D0, D1, D2a and D3 are as shown in FIG. 2.

FIG. 15 shows the field H directed to the right. Domain D0 moves downward due to the presence of domain D1 as was the situation in FIG. 3. As can be seen from FIG. 16, domains in the Y1 channel continue to move as was the case in FIG. 4 while, now, domains D4, D5 and D6 move to the right as viewed. Domain D1 is now in the intersection.

FIG. 17 shows field H rotated to the left. Domain D1 is circulating as was the case in FIG. 5. Domain D0 is free of the intersection and domain D4 is approaching the intersection. It is helpful to note that the geometry of the overlay pattern is such that rotating in-plane field introduces information into the intersection from the X1 channel ninety degrees ahead of the information introduced from the Y1 channel. This is clear from a comparison of the positions of D2a and D4 in FIGS. 17 through 20.

As the field reorients upward as shown in FIG. 18, the presence of domain D4 denies domain D1 its normal next "circulating" position as shown for it in FIG. 6. The remaining information moves normally as can be seen. When field H assumes its next orientation to the right as shown in FIG. 19, domain D1 is free of the intersection. Domain D4 is now in the intersection.

FIG. 2 shows the field directed downward. Domain D4 and the absence of domain D2a (not shown) occupy the same position. This, of course, signifies that in this instance no domain is present in the Y1 channel to prevent domain D4 from circulating as the field rotates to the left as shown in FIG. 21. Domain D5 now approaches the intersection.

The situation illustrated in FIG. 18 now repeats as shown in FIG. 22 as the field again rotates upward. To be specific, the presence of domain D5 now denies domain D4 its next normal circulating position and the latter domain is free of the intersection. By the same token, domain D5 is denied entrance to the intersection by domain D3 as shown in FIG. 23 as field H (ninety degrees later) reorients to the right as viewed occupying the position occupied by domain D1 in FIG. 11 instead.

FIG. 24 shows the field directed downward. Domain D5 is now free of the intersection moving downward in the vertical channel. Information in that channel is now reconstituted and the representation of the absence of a domain (D2a) is once again added.

FIGS. 25 and 26 again show that domain D6 denies domain D3 its next normal circulating position in the intersection as the field reorients first to the left and then upward as viewed. In this instance, however, no

additional information is moving downward into the intersection along channel Y1. Consequently, when field H reorients to the right as shown in FIG. 27, domain D3 moves to the right along channel X1 and domain D6 now enters the intersection.

The next complete rotation of field H is depicted in FIGS. 28 through 30. The information in channel Y1, 101, can be seen to be represented by domain D0, absence of a domain D2a and domain D5. The information, 111, in channel X1 can be seen to be represented by domains D1, D4 and D3. Domain D6 continues to recirculate in the intersection serving the initial function of domain D0 for next consecutive information.

Information has been shown to pass representative intersection X1Y1 in two directions simultaneously without destructive interference. Our objective has been realized.

The crossover, of course, permits a degree of freedom in overlay geometry when complex functions are to be implemented. It may in some instances merely permit a relatively simple overlay pattern to be achieved where a more complicated pattern might provide the same function. A gain in packing density may accompany the simplicity so permitted. On the other hand, certain functions cannot be realized without crossovers and in these instances a crossover in accordance with this invention is a necessity not just a convenience.

FIG. 31, for example, shows an overlay pattern for a magnetic sheet (not shown) where domains are introduced selectively at A, B, and C (to the left as viewed) and are routed normally through the upper associated propagation channel, as viewed, under the control of switches as described in copending application Ser. No. 759,337, filed Sept. 12, 1968 for A. J. Perneski. If it is desired to provide all the information (A, B and C) in sequence in one channel, the information in each channel is rerouted to the associated lower channel in each instance for collection at A and B and C to the right as viewed. Crossovers are necessary in such a circuit and each such crossover functions as described above.

To ensure crossover operation in accordance with this invention, the overlay is dimensioned to provide attracting fields of appropriate strength. When decisions are made, that is to say, when domains interact at an intersection, a situation resembling a race condition prevails. Consequently, the overlay geometry particularly at an intersection is important. Typically, for domains in a two mil thick orthoferrite platelet having diameters of 1.5 mils, bars and T-shaped overlays are 1 x 5 and 1 x 5 x 5 mils respectively. In some instances the base of a T-shaped overlay may be spaced apart from the associated top. This is to provide less attraction for a domain by causing the domain to pass an air gap before it comes to rest on the poles at the end of that base when the field is appropriately aligned. A typical sheet 11 comprises samarium-terbium orthoferrite having a coercive force of 0.1 oersted or less. A suitable overlay is a 6,000 angstrom units thick permalloy layer having a magnetic remanence of 10,000 gauss. Constant domain diameters during operation are insured by a bias field supplied by a familiar source represented by block 40 of FIG. 1. Typically, the bias field for the arrangement described is 50 oersteds and is in a direction to contract domains as is well understood.

What has been described is considered merely illustrative of the principles of this invention. Accordingly, numerous and other arrangements according to those principles may be devised by one skilled in the art without departing from the spirit and scope of this invention.

What is claimed is:

1. Apparatus comprising a magnetic sheet in which single wall domains can be moved, means for defining in said sheet first and second channels for single wall domains in response to a reorienting in-plane field, and means for defining a crossover between said first and second

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channels, said last-mentioned means including means for circulating a first single wall domain responsive to a reorienting in-plane field in the absence of a second single wall domain entering said crossover and for circulating said second domain and advancing said first domain along the one of said first or second channels along which said second domain entered said crossover.

2. Apparatus in accordance with claim 1 also including means for providing a reorienting in-plane field and means for selectively introducing single wall domains at input positions in said first and second channels.

3. Apparatus in accordance with claim 2 wherein said means for defining first and second channels comprises a magnetically soft overlay in which magnetic poles move in response to said reorienting in-plane field.

4. Apparatus in accordance with claim 3 wherein said overlay comprises bar and T-shaped patterns and said in-plane field reorients by rotation.

5. Apparatus in accordance with claim 4 wherein said crossover comprises four radially oriented thin film bars disposed at 90 degrees to one another.

6. Apparatus in accordance with claim 5 wherein said crossover also includes bar and T-shaped overlays disposed to accept domains denied entrance to said crossover or expelled from said crossover by the presence of other domains.

7. Apparatus comprising a magnetic sheet in which patterns of single wall domains representative of information

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can be moved, means for defining in said sheet a plurality of domain propagation channels having intersections therebetween and means for defining at said intersections information crossovers responsive to a reorienting in-plane field.

8. Apparatus in accordance with claim 7 wherein said means for defining a plurality of domain propagation channels comprises magnetically soft overlay patterns in which magnetic poles move responsive to said reorienting in-plane field.

9. Apparatus in accordance with claim 8 wherein said crossover comprises spaced apart magnetically soft overlay elements in a pattern at each of said intersections for circulating a first domain in said intersection in the absence of a second domain in response to said reorienting in-plane field and for circulating said second domain and advancing said first domain along the one of said channels from which said second domain entered said intersection.

References Cited

UNITED STATES PATENTS

3,191,054	6/1965	Ghisler et al.	340—174 X
3,460,116	8/1969	Boback et al.	340—174

STANLEY M. URYNOWICZ, JR., Primary Examiner