Deposited Magnetic Films as Logic Elements*

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THE USE of thin magnetic films as storage elements is well known. Several papers on the subject have appeared in the literature, particularly in recent years[1]. Less emphasized, perhaps, is the use of magnetic films as logic elements. The authors' study in this area has revealed that film elements are both flexible and versatile as logic devices.

This paper describes two modes of film-core operation, namely reversible-rotation and saturable-transformer action, as they pertain to a particular circuit. Also described are certain principles of array logic. These principles involve writing multiple copies of a word in a film-core array. Then, by the proper arrangement and selection of sense lines linking parts of these copies, some desired result is obtained from the array. This approach makes it possible to perform in one or two clock periods operations that have previously required many clock periods. The application of magnetic films as logic elements is illustrated by a scale-factoring device whose function is to find the most significant digit in a binary word, shift that word to the left until the most significant digit is in a position immediately to the right of the position reserved for the sign bit, and record the number of places shifted in an auxiliary register. The methods and advantages of accomplishing these operations with deposited magnetic film-cores are given in detail in the paper.

In some of the subsystem designs investigated, where comparisons between film-element logic and its conventional counterparts were made, definite reductions in both the required number of semiconductor components and the operating time were observed. For instance, throughout all of the designs, the use of separate NOT elements was easily avoided by appropriate wiring and biasing of film cores. Use of separate OR elements may also be eliminated by appropriate wiring between film elements. This principle and the component savings it produces are illustrated by the encoder that is described in this paper (as part of the scale-factoring device). By interconnecting film elements to form functional logic arrays (such as the shift matrix described below), great gains in speed of entire sequences may often be realized. These logic advantages — together with such properties as small size, high reliability, low power requirements, relative insensitivity to environment, and low cost — make magnetic film elements very desirable as logic devices.

LOGICAL PROPERTIES OF FILM ELEMENTS

This section introduces those logical properties of film elements that are used in the scale-factoring device. Specifically, these four ways of using the logical properties of film elements are described:

a. AND logic using the reversible-rotation mode of operation;
b. AND logic using the saturable-transformer mode of operation;
c. Inverter logic using the saturable transformer mode of operation;
d. Functional array logic.

AND *Logic* (*Reversible-Rotation Mode*)

Fig. 1 illustrates a method of obtaining AND logic using a film element in the reversible-rotation mode of operation. If inputs to such a film element are x and y, respectively, then the output is xy, as shown.

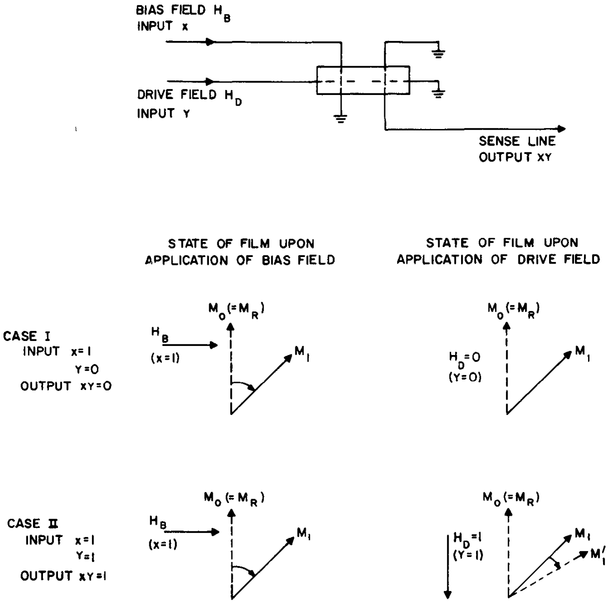

Fig. 1—AND logic (reversible-rotation mode).

The "0" state of the film core, represented by the magnetization vector M_O, is made to correspond to the remanent state of the film core, M_R. A bias field, H_B, transverse to M_O, corresponding to the logical input x, rotates the vector M_O through an angle to a

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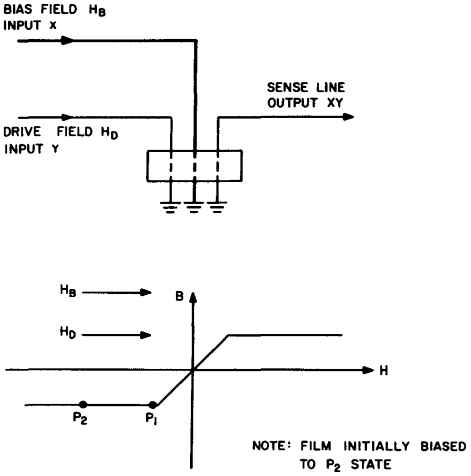
[1] A list of references on this subject appears in an article by A. J. Kolk and J. T. Doherty, "Thin Magnetic Films for Computer Applications," *Datamation*, vol. 5. pp. 8-12; September/October, 1959.

position shown as M_1. Subsequent application of a drive field, H_D, corresponding to a logical input *y*, in a direction antiparallel to the vector M_O, further rotates the vector M_1, altering the state of the film core to M'_1. (In the reversible rotation mode of operation, application of bias field H_B and drive field H_D is time-sequenced so that the biasing precedes the driving.) Change of the magnetization of the film core from state M_1 to M'_1 induces a voltage on the sense line, corresponding to a logical output of "1". No output is obtained unless both the bias field H_B and the drive field H_D are present, as illustrated by the vector diagrams in Fig. 1. Logically, then, the output xy is "1" only if inputs x and y are both "1".

AND *Logic (Saturable-Transformer Mode)*

Fig. 2 illustrates a method of obtaining AND logic using the film core as a saturable transformer. In this mode of operation, the film core is initially biased to one of its remanent states of magnetization in the hard direction. Its state is then caused to change or not to change in a direction of high permeability, depending upon certain control conditions.



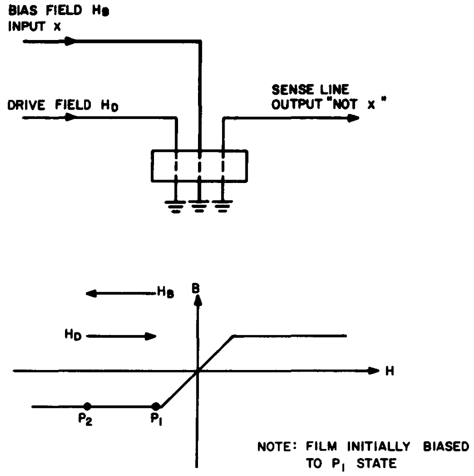
NOTE: FILM INITIALLY BIASED TO P_2 STATE

Fig. 2—AND logic (saturable-transformer mode)

Fig. 2 shows the film core as initially biased to the P_2 state. (Means of effecting this initial bias are not shown in the figure.) A bias field H_B, corresponding to logical input x, further biases the film core to state P_1. Application of a drive field H_D, corresponding to logical input y, then causes a change in the state of the film core. This change is in the steep region of the B–H diagram, so that an output voltage is induced in the sense line. This voltage corresponds to a logical output of x AND y. A "1" output is obtained only if the bias field H_B and the drive field H_D are both present.

Inverter Logic (Saturable-Transformer Mode)

Fig. 3 shows a simple method of obtaining logical inversion (*i.e.*, negation) using a film core in the saturable-transformer mode of operation. The film core shown in the figure is initially biased to the P_1 state. (Means of effecting this bias are not shown in the figure.) A bias field H_B, corresponding to logical input x, biases the film to the P_2 state. Application of a drive field H_D, in a direction opposite to the bias field, then merely biases the film core toward P_1. It is, however, not of sufficient strength to drive the film core into the steep portion of the B–H curve. Consequently no voltage is induced on the sense winding; this corresponds to a NOT x logical output. If, on the other hand, the bias field H_B were absent, meaning a NOT x input, the film core would remain in its original biased state at P_1. Application of a drive field H_D would then induce a voltage on the sense winding which would correspond to output x.



NOTE: FILM INITIALLY BIASED TO P_1 STATE

Fig. 3—Inverter logic (saturable-transformer mode).

Functional-Array Logic

A very powerful feature of magnetic film elements is their adaptability to a technique of logic described as *functional-array logic*. Use of this technique results in a great saving in time for many operations that may be sequential in nature. An example of a sequential operation is a shifting operation where the total time to shift a number is dependent upon the number of shifts required. The accomplishment of shifting by functional-array logic is explained in detail in this paper. In general functional-array logic may be thought of as an arrangement of information in an array based upon an input word or bit configuration for the purpose of accomplishing a specific logical operation in one step.

In the preceding sections on the saturable-transformer and reversible-rotation modes of operation, the logic of the individual films was presented. Because of their size, it is possible to assemble these film elements in compact arrays and to bias and drive many film elements simultaneously without appreciable time delays or power losses. One such arrangement is illustrated in Fig. 4, which is an

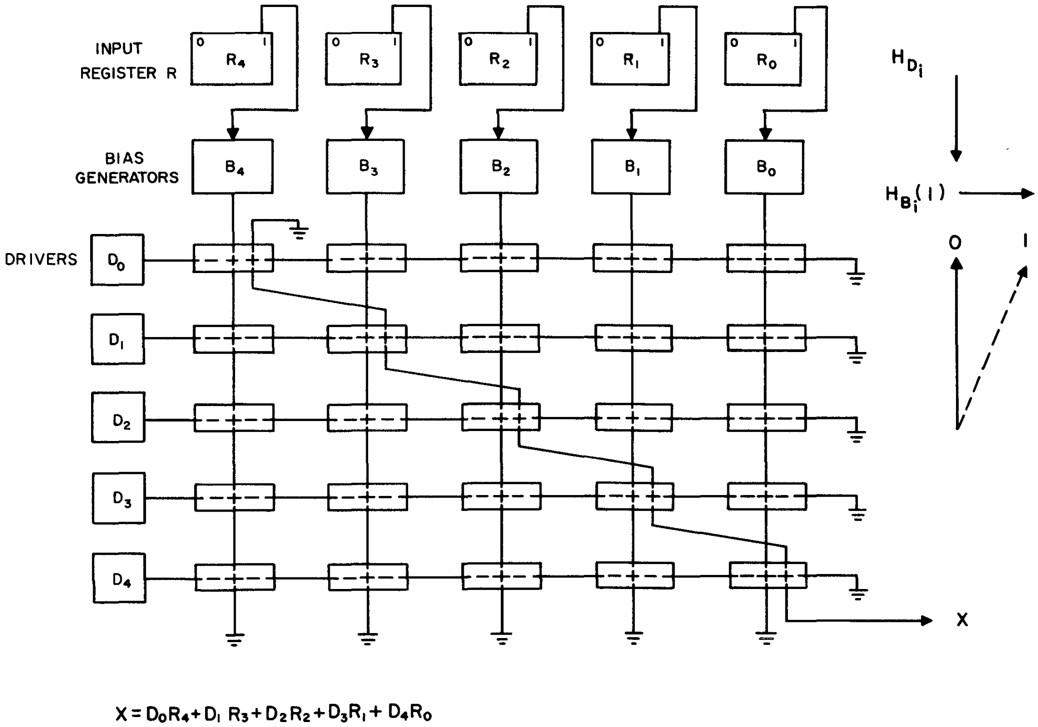


Fig. 4—(a) Film magnetization directions. (b) An example of functional-array logic.

example extracted from one of the arrays to be presented in a later section.

The function of this array is to sense for an information bit in a position within the input word. The input word is contained in the input register R, and each of the bias generators (B_0–B_4) supplies a bias field to the film element below it if the corresponding input-register stage (R_0–R_4, respectively) contains a "1". This bias field rotates the magnetic vector to the "1" position as indicated in Fig. 4(a). If a drive field $\mathrm{H_D}$ is applied to a film core thus rotated, an output is induced on a sense line linking that film core.

If driver D_0 is energized after the array is biased, and there is a "1" in input register-stage R_4, an output is obtained on the sense-line X. This simple arrangement could be used as a sign test. The other drivers, D_1–D_4, could also be initiated singly to determine whether input register stages R_3–R_0, respectively, contain binary "1"s. Another way of using the same functional array depends on initiating all drivers simultaneously so that a "0" output indicates that the input world is all "0"s. Various effects can be produced with functional arrays by varying the wiring of the sense, drive, and bias lines. Applications of two of these effects are discussed under "Circuit Descriptions."

Circuit Functions

The logical operation that will be described to illustrate the utilization of magnetic film elements is that of scale factoring of a data word. In certain number representations this operation is also referred to as "normalizing a number." In both scale factoring and normalizing, a binary word is examined to determine the location of its most significant information bit. The entire word is shifted until this bit is in the highest order non-sign position, and the amount of this shift is stored in an auxiliary register. If the word is given in a complement representation, such as one's or two's complement, the operation is referred to as the process of scale factoring. On the other hand, if the word is represented in the sign and magnitude form, the operation is referred to as normalizing.

For the purposes of this description the one's complement representation is used. It follows that the leftmost bit of a binary word is the sign bit; "1" for negative numbers and "0" for positive numbers. Therefore the most significant information bit is the leftmost "0" for negative numbers and the leftmost "1" for positive numbers.

Circuit Descriptions

The scale-factoring operation consists of three separate operations that are first treated separately in the description that follows and then integrated into one unit in the last portion. The three operations and the order in which they are presented are as follows:

a. Location of highest-order information bit;
b. Shifting;
c. Encoding the amount of shift.

Location of Highest-Order Information Bit

In conventional logic circuits, the process of determining the location of the highest significant information bit of a binary word is a time-consuming operation. The method normally used depends on shifting the binary word one position at a time in the direction of most significance. After each shifting operation, a check is made for a difference between the sign bit and the bit occupying the most significant position. If the bits are alike, the word is shifted again and the check repeated. The first time that the bits are found to be unlike, the word is in its proper position. The amount of shift that has been accomplished is then read from a counter that has been counting the number of shifts. The number of sequential steps and therefore the time for this operation can be large, especially where the word size is large and the highest order information bit appears in one of the lower order positions.

In the preliminary section on functional-array logic, it was shown that logical operations could be performed using functional arrays. An array of this type is illustrated in Fig. 5; its function is to determine the most significant information bit in the word "00010". The word is arranged in a 5 × 5 bit array such that one row contains a negative copy of the word and four rows contain positive copies of the word. Sense lines S_0–S_3 are arranged in such a manner that they couple one bit in the negative row and one bit in each column to the left of that position. The figure shows that one and only one sense line may link bits that are all in the "0" state and that this sense line has a direct relationship to the location of the most significant information bit. The sense lines to the left of this position will always link a bit in the "1" state because of the negative row, and the sense lines to the right will always link a bit in the "1" state because of the column immediately below the highest-order "0" in the negative row. In the example of Figure 5, sense line S_2 is the only sense line linking bits that are all in the "0" state. This condition dictates that a shift of two positions is required to properly scale the number "00010". If the number had been "001XX", it could be shown by similar means that sense line S_1 would be the only one linking bits all in the zero state, and the corresponding scaling shift would be one.

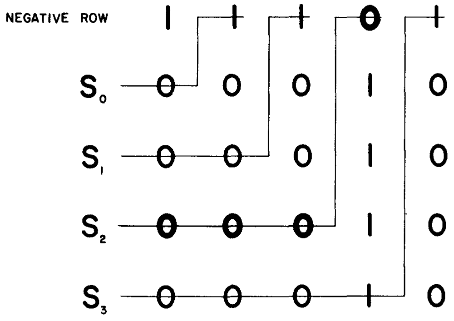


Fig. 5—Functional array for determining most significant information bit.

A method of implementing this logic with film elements is illustrated in Fig. 6. The number to be scaled is located in the input register, stages R_0–R_4. If any stage of the input register contains a binary "1", it will initiate one of the corresponding bias generators B_0–B_4. The function of the bias generators is to supply a field transverse to the remanent state of the films linked by its output line. This field is represented by vectors $H_B(1)$ in Figs. 6(a) and 6(b). After the films in the array have been appropriately biased by the bias generators B_0–B_4 and B_p, the action of which will be explained later, the film elements are driven by drive generator D. This driver links all films in the array and supplies a field that is antiparallel to the remanent state of the film cores, but not of sufficient magnitude to completely switch the film core with no other applied fields. This field is identified by vectors H_D in Figs. 6(a) and 6(b).

Referring to Fig. 6(a) and 6(b), the effects of the bias and drive fields are shown for the various rows of films in the array. A permanent bias field — represented by vector H_{BP} in Fig. 6(a) — is applied to all film elements in the first or negative row of films, where it is desired that a negative copy of the word be represented. This field has the effect of rotating the magnetic state vector away from the remanent direction of magnetization so that, without the application of another biasing field by one of the bias generators B_0–B_4, an output would be obtained on sense lines linking these film elements when drive field H_D is applied. If a field is applied by one of the bias generators, the magnetic state vector is rotated back into alignment with the remanent direction, so that no output is produced on sense lines linking these film elements when drive field H_D is applied. Therefore, in the first row, (1) no output is obtained on any sense line that links a biased film element if there is a "1" in the corresponding input register, and (2) an output is obtained if there is a "0" in the input register. Thus the action of the permanent bias generator B_p produces a negative copy of the input word in the first row. Examination of Fig. 6(b) for the remaining rows shows that the converse conditions apply; *i.e.*, a "0" output is obtained on a sense line linking a film element associated with a register containing a "0", and a "1" output is obtained on a sense line linking a film element associated with a register containing a "1".

The array of Fig. 6 is arranged in the manner described in the example of Fig. 5. A signal to indicate the amount of shift required is obtained by the use of inverters that terminate each sense line. Since only one sense line will have zero signal induced on it, only one inverter will have an output signal. Because a zero

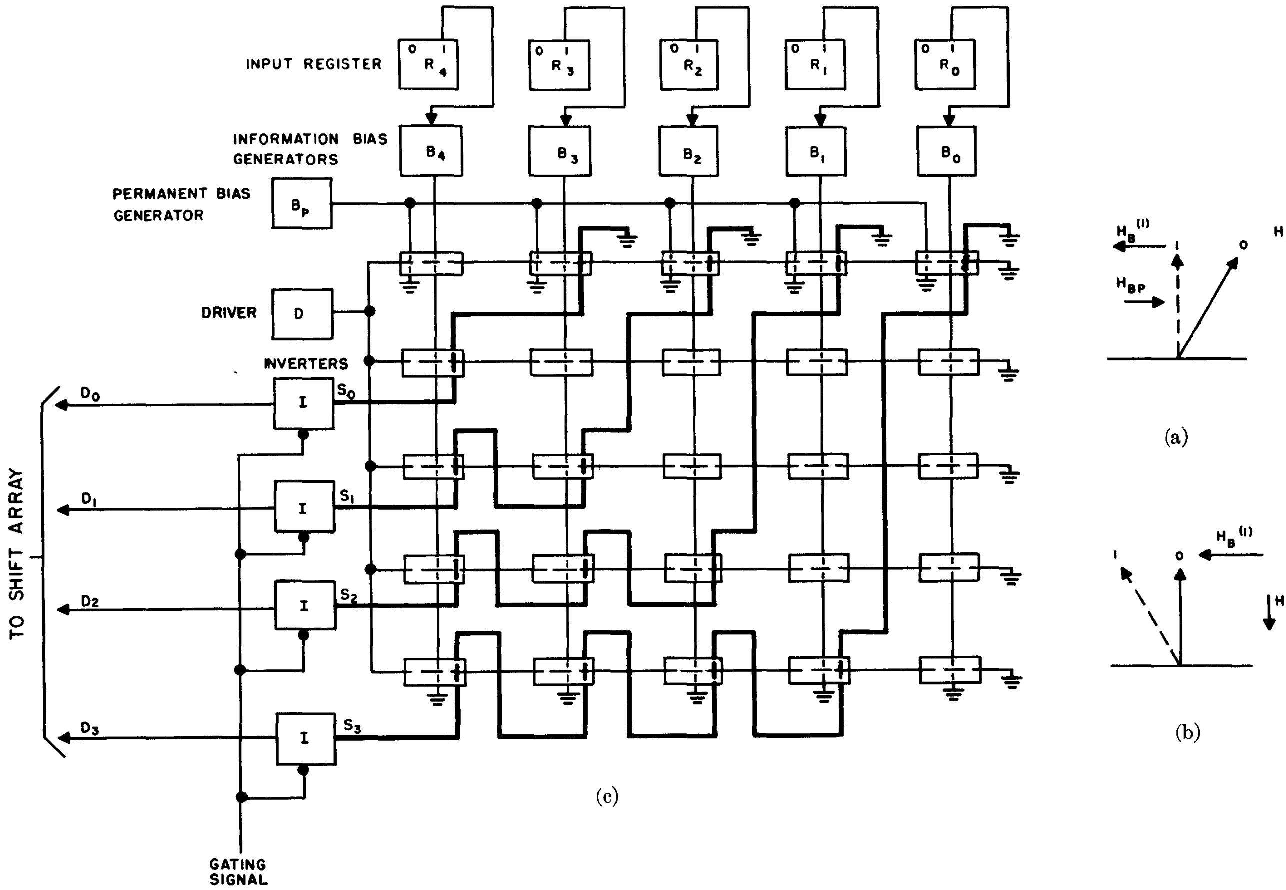


Fig. 6—(a) Film magnetization directions of Row 1 (negative row) for zero bias. (b) Film magnetization directions of Rows 2–5 for zero bias. (c) Network for determining most significant information bit.

or null signal is used to the inverters, the inverters are necessarily gated as indicated in Fig. 6.

Shifting

For shifting operations, it is also desirable to be able to shift a word an arbitrary number of positions in a time not dependent upon the number of positions shifted. Here again functional arrays are readily applicable. An array for accomplishing the left-shifting of a word two positions is illustrated in Fig. 7. As in the example of Fig. 5, the word "00010" is used. Five copies of the word are represented in the array, and sense lines are diagonally drawn through the array as shown in Fig. 7.

Shifting in this array is accomplished by transferring a selected row of bits via the sense lines to the output register. In the example of Fig. 7, an open-ended left shift of two is obtained by selecting the third row and transferring the bits via sense lines S_2, S_3, and S_4 to the output register. Similarly, other shifts can be obtained from the same array by selecting other rows. If, for example, row 1 is selected, a shift of zero is obtained; if row 5 is selected, a shift of four is obtained.

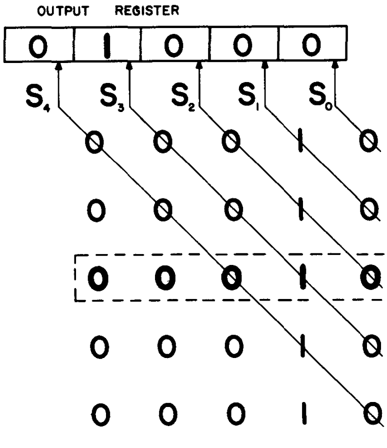


Fig. 7—Functional array for left-shifting a word.

The circuit of Fig. 8 illustrates a film-element array for the execution of left shifts. The word to be shifted is originally in the input register R_0–R_4, and bias generators B_0B_4 are initiated if there is a "1" in the corresponding input register. The bias generators supply a field transverse to the remanent magnetization direction. This field rotates the magnetic state vector in each film element away from the remanent direction so that a drive pulse applied antiparallel to

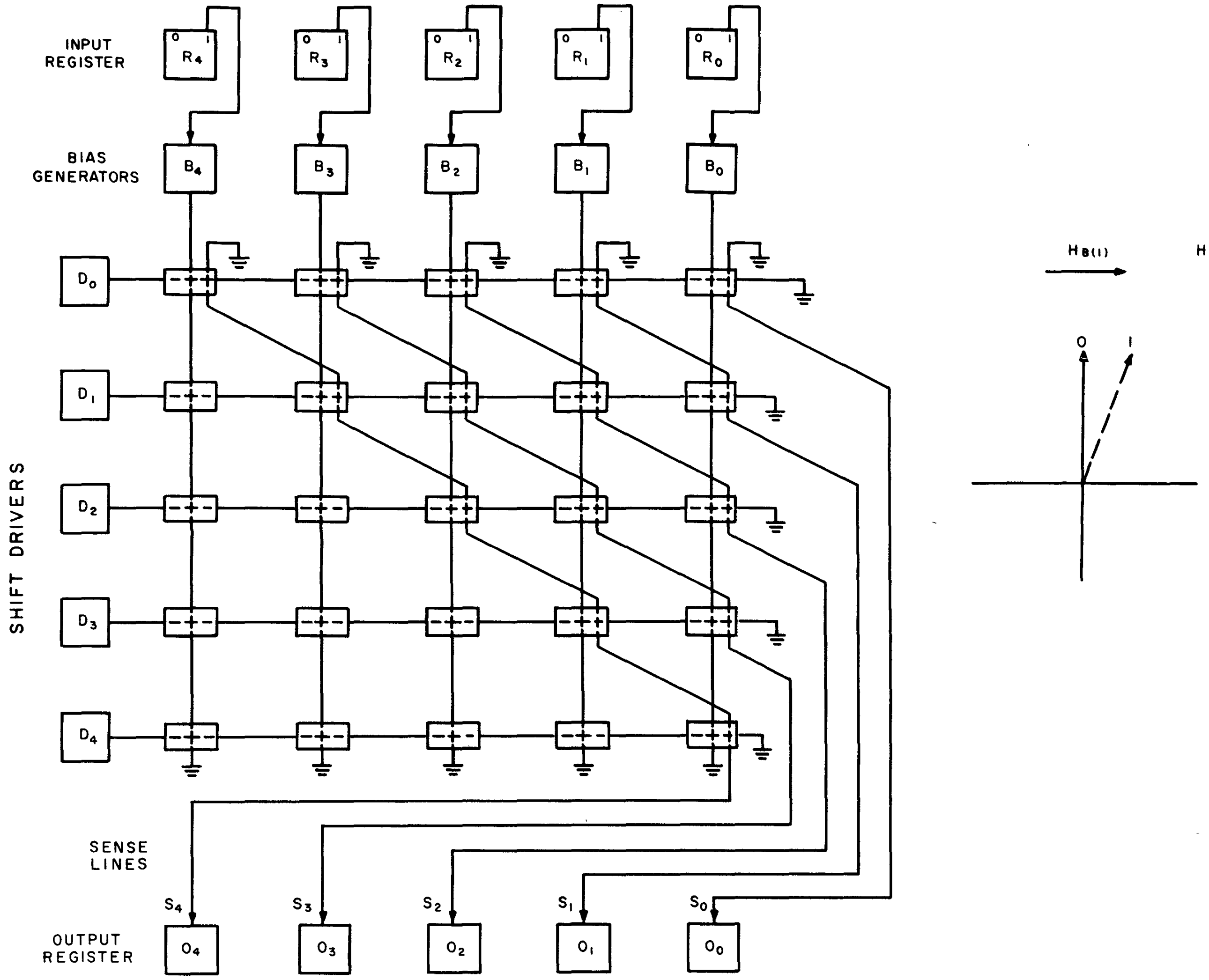


Fig. 8—(a) Film magnetization directions. (b) Network for left-shifting operation.

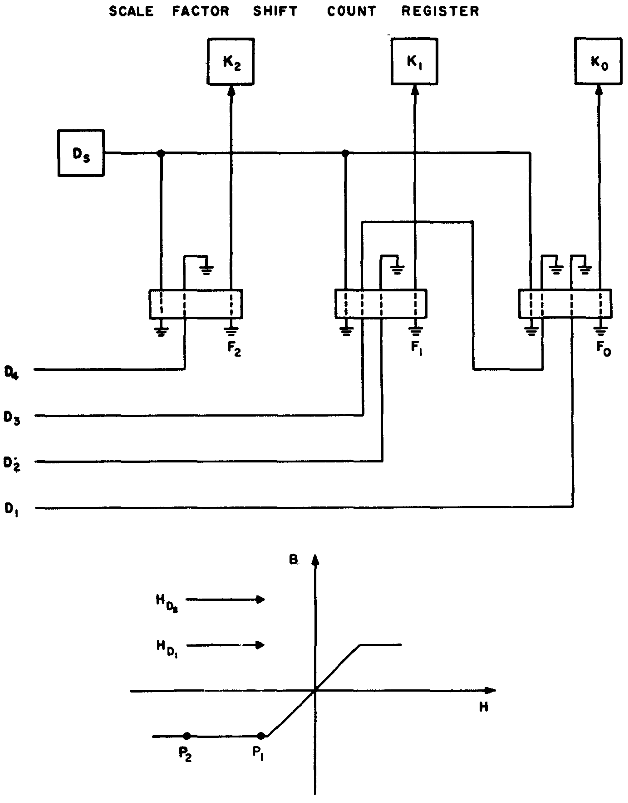
the remanent direction produces an output on a sense line linking that film element. The bias field is represented by vector H_B (1) in Fig. 8(a), and the drive field is represented by vector H_{D_i}. To implement a shift of from zero to four in this array, one of the shift drivers, D_0 to D_4, respectively, is initiated, and the corresponding row of films is supplied with a drive or interrogation pulse. The sense lines linking the film elements in the interrogated row will have an output signal only where the film element linked is initially biased away from the remanent state. These sense-line signals are coupled to the stages of the output register and the resulting word is in its shifted position.

Encoding

In a preceding paragraph the amount of shift was determined by locating the position of the most significant bit in a word. This shift count appeared as a unique signal on one of the lines D_0–D_3, as shown in Fig. 6. In many applications it is desirable to store this signal as a binary number. This requires a "one-to-many" translation. An encoder is a device for accomplishing this result.

Physically, a signal representing the number is applied to the encoder input. The output from the encoder then appears as one or more signals, corresponding to the respective "1" bits of the binary representation of the given number. For example, the number "13" would be encoded as "1101" with signals from the output of the encoder setting corresponding stages 3, 2 and 0 of a four-bit encoder register.

Fig. 9 shows a three-bit magnetic film encoder with its associated register. Inputs to the encoder are shown as D_1, D_2, D_3 and D_4, corresponding to shift counts of 1, 2, 3 and 4, respectively. (Note that only one of these inputs is active at any given time.) The output from the encoder appears in the scale-factor shift-count register, stages K_2, K_1, K_0. Film elements F_0, F_1 and F_2 act as AND gates operating in the saturable-transformer mode, as described previously.



NOTE: ALL FILMS INITIALLY BIASED TO P_2 STATE.

Fig. 9—Scale-factor shift-count encoder.

All three film cores are initially biased to the P_2 state. The input lines are so wired that lines D_1, D_2 and D_4 link film elements F_0, F_1 and F_2, respectively, while line D_3 links both film elements F_0 and F_1. A field H_{D_i}, corresponding to a D_i input, biases the film element (or elements) that it links to the P_1 state. The drive generator D_s subsequently supplies a drive field H_{D_s} to all the films. Any film element that is in the P_1 state therefore produces an output signal on its respective sense line. This output then sets the corresponding scale-factor shift-count register stage to "1".

In the example used to illustrate the scale-factoring operation, where the shift count was 2, a field H_{D_2}, corresponding to input D_2, biases the film element F_1 to the P_1 state. Subsequent application of drive field H_{D_s} then produces an output on the sense line of film element F_1, and thereby sets scale-factor shift-count register stage K_1 to "1". Film elements F_0 and F_2 do not have outputs because their states are unaltered, having remained at P_2. Consequently, the scale-factor shift-count register reads "010", which is the binary representation of 2.

COMBINED CIRCUIT OPERATION

Circuit Operation

Fig. 10 is a composite drawing incorporating the circuit for determining the highest-order information bit with the circuit required for shifting. Since both of these arrays utilize the same mode of operation, namely, reversible-rotation, it is possible to combine them in the same array and use the same bias generators. Inspection of Figs. 6 and 8 reveals that certain film elements in each array are not used in the performance of the logic operation. These unused film elements are not included in the combined array of Fig. 10.

The operation of the circuit is divided into two major sequences: determination of the highest-order information bit, and the shifting operation, with the encoding being accomplished during the shifting operation. After the array has been biased, the first sequence is initiated by driver $\underset{-}{D}$, which supplies a drive field to the film elements in the highest-order information-bit-determination portion of the array. These film elements are linked by sense lines S_1–S_4. These sense lines are coupled to the shift driver inverters D_0–D_3. Since a zero output on one of the sense lines is the required signal to the shift driver inverter, these drivers must necessarily be gated. The output of drivers D_0–D_3 is used to drive the film elements in the shift array and encoding network. The operation of the shift and encoding circuits is as described above.

In the example of Fig. 5, a positive number is used for illustration. If the same approach is applied to a negative number, *i.e.*, the complement in the first row and the number itself in the remaining rows, there is not a unique method of determining the location of the highest-order information bit. If, however, the negative number itself is placed in the first row and its complement, or the positive copy, in the remaining rows, the previous rules apply. It follows that some form of gating between the input register stages and the bias generators is necessary. Similarly, since the information in the shift array is in its complement form for negative numbers, some form of gating between the shift array and the output register is necessary. The conditional complementer circuits shown within the dotted line enclosures of Fig. 10 accomplish these gating functions.

If the number originally in the input register is negative, R_4 is "1", and the R or negative generator drives the row of P_1 saturable-transformer film elements in both conditional-complementer networks. These P_1 film elements act as AND inverters (*i.e.*, Sheffer-stroke functions) in both networks and complement the information supplied to the bias generators for the array and again recomplement the information from the array for the proper output representation. If the number in the input register is positive, R_4 is "0", and the $\bar{R}$ or positive generator drives the P_2 row of film elements in the conditional-complementer networks. These film elements are AND gates and allow the information to be transferred

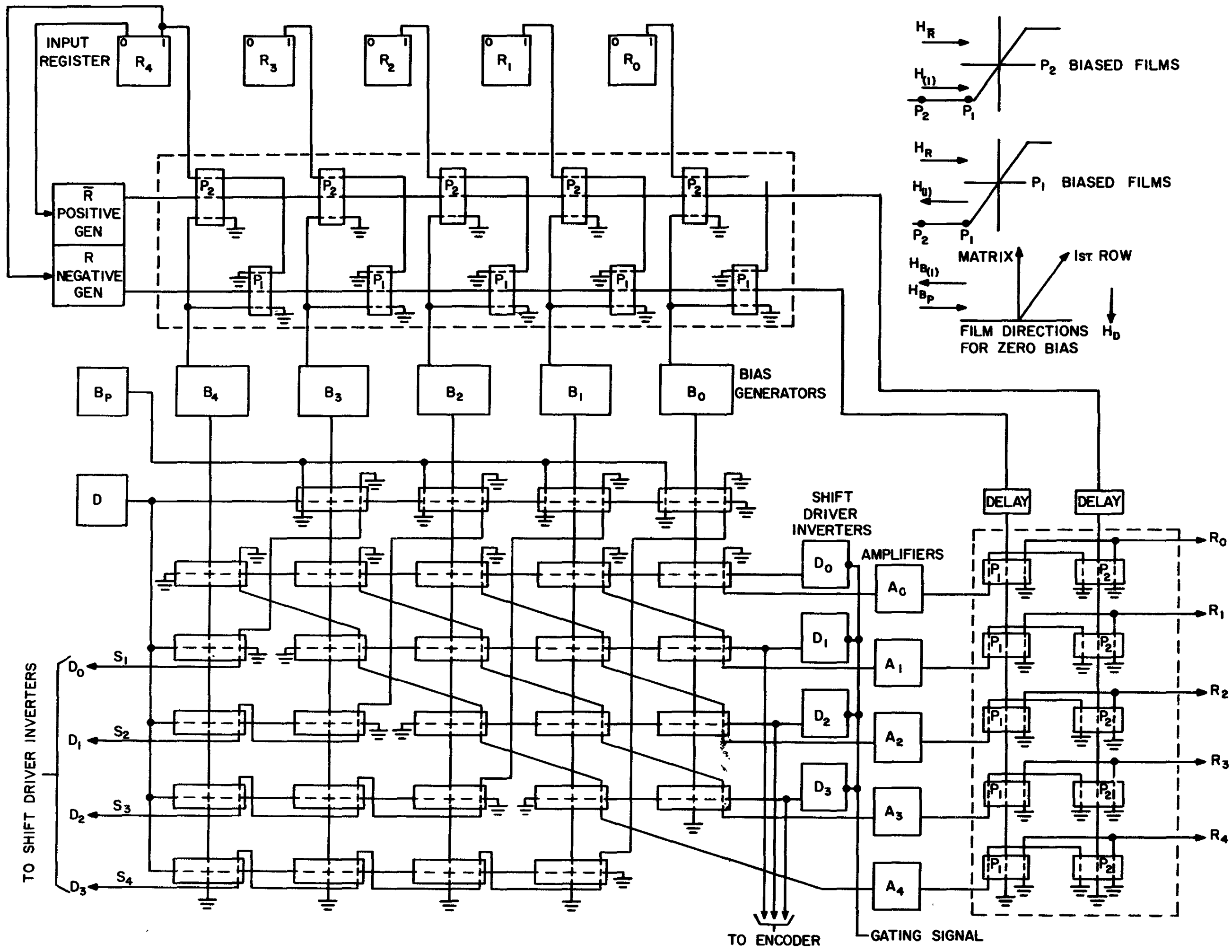


Fig. 10—Scale-factor network.

directly to the bias generators and output circuits.

The encoding network shown in Fig. 9 serves in conjunction with the scale-factoring network of Fig. 10. The outputs of shift driver inverters D_1–D_3, which drive the shift array, are also used as the inputs to the encoding network. In this manner the amount of the shift performed is recorded in the shift count register at the same time that the shifted number is entered into the output register.

Circuit Timing

A detailed timing sequence for the scale-factor operation is presented in Table I. Included in the table are approximate expressions that might be used to determine execution times on the basis of word length and other circuit parameters. The parameters used are defined as follows:

M = word size in bits
T = transistor rise time
f = film, drive, bias, and sense line transmission time
R = rise time of film element in saturable transformer mode

From Table I the approximate expression for the execution time of the scale-factor operation is

$$\text{max. time} = 4T + (4M + 5)f + 2R$$

Assuming a transistor rise time $T = 5$ mμsec, film-element transmission time $f = 0.12$ mμsec, film-element rise time $R = 1$ mμsec, and a word size $M = 36$ bits, the maximum shift time for the scale-factor operation would be 39.9 mμsec.

Circuit Components

The components required for the scale-factor operation, exclusive of the component requirements for the design of the input register and the encoder, are as follows:

TABLE I

SCALE-FACTOR TIMING SEQUENCE

Initiate Scale Factor Operation		Locate Most Significant Bit	Store Shifted Word	Encoding
Test sign	(Negligible)			
+	−			
Initiate $\bar{R}$ Generator (T)	Initiate R Generator (T)			
Transmission time	(Mf)	Initiate input transfer		
		Conditional complementer Drive transmission time (2f) Film element rise time (R)		
		Initiate bias generators (T)		
		Bias transmission time (Mf + f)	Initiate scale-factor driver (T)	
			Drive- and sense-transmission time (Mf)	
			Initiate inverter driver (T)	
			Drive- and sense-transmission time (Mf)	Encoder bias transmission time (maximum) (Mf)
			Amplifier (T)	Initiate read driver (T)
			Conditional complementer Drive transmission time (2f) Film-element rise time (R)	Drive and sense transmission

1. Film elements

$$\begin{aligned} \text{Input} &= 2M \\ \text{Output} &= 2M \\ \text{Matrix} &= M^2 + M - 2 \\ \hline \text{Total} &= M^2 + 5M - 2 \end{aligned}$$

2. Transistors

$$\begin{aligned} \text{Bias Generators} &= M + 1 \\ \text{Inverter Drivers} &= M - 1 \\ \bar{R} \,\&\, R \text{ Generators} &= 2 \\ \text{Amplifiers} &= M \\ \hline \text{Total} &= 3M + 2 \end{aligned}$$

Table II presents the film-element and transistor requirements for encoders of various sizes. For comparison purposes, the number of diodes that would be required for conventional encoders of equivalent size are shown. The input and output components are omitted for both types of encoders.

Since film elements, unlike diode elements, permit the use of more than one input per element, the film-element encoder uses very few film-elements in comparison with the number of diodes in a diode encoder. Furthermore, the only semiconductor devices required are one transistor for each output bit. The number of diodes required for the larger diode encoders would be greater because of the diode OR circuit input limitation. For these encoders the diodes would probably be arranged in a "tree" or "pyramid" configuration, which would result in an increased time requirement for the diode encoder. Without the "pyramid" arrangement, the times for the two encoders are approximately equal.

TABLE II

ENCODER COMPONENT REQUIREMENTS

Output Word Size (In Bits)	Film-Element Encoders		Diode Encoders
	Film Elements Required	Sensing Transistors Required	Diodes Required
2	2	2	4
3	3	3	12
4	8	4	32
5	20	5	80
6	48	6	192

OTHER APPLICATIONS

The illustration given in this paper utilizes a five-bit word in the one's complement number representation. The method applied, however, is not restricted to this representation, this word size or the particular application which has been described. With minor modifications the device can be adapted to any complement, sign and magnitude, or binary-coded number representation. Devices to perform such operations as locating the least significant information digit and shifting the word accordingly, or locating a predetermined information digit within a certain field or portion of a word can also be readily designed.

Although this paper is concerned primarily with the application of film-element logic and the design of a specific logical device, the techniques described have a much wider range of applicability. The authors have investigated and designed a variety of logical devices such as decoders, counters, accumulators, and special-purpose devices.

ACKNOWLEDGMENT

For consultation on the physical properties of magnetic film elements, the authors are indebted to members of the Physics Department of Remington Rand Univac (St. Paul), especially Dr. A. V. Pohm[2] and Dr. R. M. Sanders.

DISCUSSION

H. Aiken: I wonder if you would discuss a couple of points for me. One, your primary approach to the logics was with the aid of the matrix, so I am wondering what you have done to minimize the number of elements, making further use of Boolean for this purpose. And the second comment you can answer yes or no, have you any attempt so far to build whole circuits with this technique in one fell swoop to set up a standard?

Mr. Franck: As to the first question, no attempt was made to phrase the logic in such Boolean form as to use minimization techniques. In general, as can be noted for the device discussed, which uses the film elements quite efficiently, these techniques would probably offer little if any results in the way of reducing the number of components.

In respect to the second question, a design for a shifting matrix is actually working. For obvious reasons, I cannot say too much about it. In your sense of one fell swoop, one can say it essentially was so done, *i.e.*, a single evaporation placed films on a substrate, then printed-wiring techniques were used for the wiring arrangement.

P. D. Goodman (Clevite Transistor): What switching speed can be obtained with these devices? What current and voltage are required for switching? How large is each element?

Mr. Franck: I might point out I am not trained as an electrical engineer but as a mathematician and obtained this type of information from appropriate sources. I can give estimates. For full switching, the speed is 250 millimicroseconds, whereas for rotational switching, it is 3 to 30 millimicroseconds. Input voltages of 10 volts and currents of 200 milliamperes have been used in the design of the shift array. Typical sizes for the element range from 1 millimeter for circular elements to 1½ by 5 millimeters for rectangular elements. Output voltages of 4 millivolts per turn have been measured for the shift array.

G. A. Sellers (Bell Labs.): Please describe the physical characteristics of a "thin film": size, etc., and how they are fabricated?

Mr. Franck: I am not sure whether you mean actual dimensions. I think I have described this as essentially one millimeter. The thickness is 1 to 200 angstroms. Typical dimensions of films range from 1 to 4 millimeters. A few of 8 millimeter size have been used in experiments. The films have been deposited on thin cover-skip glass. Both 6-mil and 9-mil glass have been used. The methods of fabrication are described in an article in the *Physical Review* by C. D. Olson and A. V. Pohm.

R. Turner (Philco): What sort of switching speed is realized?

Mr. Franck: The speed for rotational switching is as fast as 3 millimicroseconds. For full switching, a quarter microsecond is typical.

J. Jacoby (BTL): How are the leads, drive and sensing leads, physically associated with films?

Mr. Franck: Printed wire techniques are used.

L. Mintzer (Honeywell-DATAmatic): Since these are passive elements, the number of sense amplifiers is not negligible. Approximately how many active elements in sense amplifiers?

Mr. Franck: In the shift array which has been designed, three transistors have been used on the output of a given sense line for amplification.

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