

ELECTRICAL ENGINEERING DEPARTMENT  
MASTER'S THESIS PROPOSAL

TITLE: MULTI-COORDINATE SELECTION SYSTEMS FOR MAGNETIC-CORE STORAGE

STATEMENT OF THE PROBLEM

The purpose of this thesis is to consider the practicability of a magnetic-core memory system using more than three coordinates of selection and requiring selection ratios of less than 2 to 1.

HISTORY OF THE PROBLEM

When J. W. Forrester proposed the three-coordinate magnetic-core memory in the spring of 1950,<sup>1</sup> existing digital storage systems were utilizing either electrostatic storage tubes or devices requiring time and one space coordinate. The former resulted in bulky construction; the latter, in long access time.

It was the development of ferromagnetic materials with nearly rectangular hysteresis loops which made Forrester's proposal feasible. The basic element of a magnetic-core memory is a toroid of such a material with two remanent-flux states of opposite polarity used to arbitrarily represent the two digits (ZERO and ONE) of the binary system.

To understand the operation of a core memory, several facts about the hysteresis loop (Fig. 1) should be noted. If a core in the ONE state is excited with  $I_m$  and the excitation is then removed, the core will "switch" to the ZERO state. Likewise, a core in the ZERO state can be switched to the ONE state by an excitation of  $-I_m$ . Excitations of  $\pm \frac{I_m}{2}$  can at most change the flux state only slightly; except in a discussion of "noise" voltages the flux state can be considered unchanged.

Fig. 2 shows one digit of a three-coordinate array (i.e., there

is only one Z coordinate). As the core memory is used in Whirlwind I, the intersection of an excited X and Y plane selects a register, the word length of which is determined by the number of Z planes. The "read" operation consists of exciting the selected X and the selected Y plane with  $\frac{I_m}{2}$  and observing the voltage induced in the "sense" winding of each digit (Z) plane. (The sense winding is one which goes through all the cores of a digit.) With this coincident-current type of readout, the following points should be noted:

1. Only one core in each Z plane is selected (excited with  $I_m$ ); all others are either nonselected (no excitation) or half selected (excited with  $\frac{I_m}{2}$ ). If the selection ratio is defined as the value of the excitation applied to the desired cores divided by the maximum excitation applied to any undesired cores, then the selection ratio is 2 to 1.
2. If a selected core is in the ONE state, a large voltage is induced in the sense winding, whereas a selected core in the ZERO state will induce only a small voltage; therefore, amplitude discrimination can be used to distinguish a ONE from a ZERO.
3. The read operation destroys the information if the core is in the ONE state and must therefore be followed by a "write" operation if the core is to be restored to its original state.
4. Half-selected cores induce unwanted voltages on the sense winding.<sup>3</sup>

The write which follows every read consists of exciting the selected X and the selected Y planes with  $\frac{-I_m}{2}$  and in those digits where ZERO's are required exciting the Z plane with  $\frac{I_m}{2}$ . Therefore, the write

requires three coordinates, whereas the read requires two coordinates.

Two units employing the system described are now operating very reliably in Whirlwind I. Each unit consists of 1024 registers of 16-digit words and requires 144 vacuum-tube drivers to perform the selection.

#### PROPOSED SCHEME

The reliability of an electronic computer is to a large degree a function of the number of vacuum tubes. In a three-coordinate memory of the size described, the number of drivers is not excessive; however, with very large memories (see below), schemes to reduce the number of drivers are worth consideration. A means of doing this is to use N - coordinate systems ( $N > 3$ ) with reduced selection ratios.<sup>2</sup>

Fig. 3 shows one digit plane of a possible system in which the read utilizes four coordinates and the write five. To read out of a register, the selected X coordinate, Y coordinate, and Z coordinate are excited with  $\frac{I_m}{3}$  (this alone would fully select several registers, each of which lies on a different U coordinate), and all but one of the U coordinates is excited with  $\frac{-I_m}{3}$  (of the registers fully selected by the X and Y and Z coordinates, only one remains selected).

For the write operation a fifth coordinate (V) is necessary to write ZERO in a digit. To write, the excitation on the X, Y, Z, and U coordinates is reversed, and in those digits where a ZERO is required the V coordinate is excited with  $\frac{I_m}{3}$ .

As an illustration of the reduction in drivers, consider a square digit plane of 256 cores on a side (65,536 registers). A tabulation for n digits is shown for both systems described.

Three-Coordinate System	Five-Coordinate System
Read:	Read:
No. of X Drivers.....256	No. of X Drivers.....16
No. of Y Drivers.....256	No. of Y Drivers.....16
No. of Z Drivers..... 0	No. of Z Drivers.....16
Write:	No. of U Drivers.....16
No. of X Drivers.....256	No. of V Drivers..... 0
No. of Y Drivers.....256	Write:
No. of Z Drivers..... <u>n</u>	No. of X Drivers.....16
TOTAL .... 1024+n	No. of Y Drivers.....16
	No. of Z Drivers.....16
	No. of U Drivers.....16
	No. of V Drivers..... <u>n</u>
	TOTAL ..... 128+n

TABLE I

One drawback to increasing the number of coordinates is that the selection ratio decreases; consequently a core with a more rectangular hysteresis loop is needed (Maximum Selection Ratio =  $\frac{N + 1}{N - 1}$  where N is the number of coordinates).<sup>2</sup> A more important drawback is the buildup of unwanted voltages from the partially excited cores. To illustrate this fact, the following derivation is made for the five-coordinate system described above.

Consider a square array  $n^2 \times n^2$ . Selection by the X and Y coordinates divides the array into three types of square arrays  $n \times n$ , (i.e., a single array is excited with  $\frac{2I_m}{3}$ , 2 (n-1) arrays with  $\frac{I_m}{3}$ , and

$(n-1)^2$  arrays with 0 - Fig. 4). The final selection by the Z and U coordinates divides each  $n \times n$  array into three types of cores, one with an additional  $\frac{I_m}{3}$  excitation,  $2(n-1)$  with no additional excitation, and  $(n-1)^2$  with an additional  $\frac{-I_m}{3}$ . If it is assumed that the sense winding is wound as in the Whirlwind system<sup>3</sup>, the following expression for the induced voltage applies:

$$V = 1 \left[ V_s - 2 V_{\frac{2}{3}} + (n-2) \delta_{\frac{2}{3}} + V_{\frac{1}{3}} + \frac{n(n-2)}{2} \delta_{\frac{1}{3}} \right] \\ + 2(n-1) \left[ V_{\frac{2}{3}} - 2V_{\frac{1}{3}} + (n-2) \delta_{\frac{1}{3}} \right] \\ + (n-1)^2 \left[ V_{\frac{1}{3}} + V_{-\frac{1}{3}} + \frac{n(n-2)}{2} \delta_{-\frac{1}{3}} \right]$$

where

- $V_s$  = the voltage output of the selected core;
- $V_k$  = the voltage output of a core excited with  $kI_m$ ;
- $\delta_k$  = the difference between the average voltage output of the  $kI_m$  - excited cores whose polarities on the sense winding are the same as that of the selected core and the average voltage output of the  $kI_m$  - excited cores whose polarities on the sense winding are opposite to that of the selected core.

Simplifying

$$V = V_s + 2(n-2) V_{\frac{2}{3}} - (4n-5) V_{\frac{1}{3}} + n \delta_{\frac{2}{3}} + \frac{n^4 - 4n^3 + 12n^2 - 20n + 12}{2} \delta_{\frac{1}{3}}$$

A similar expression can be obtained for the three-coordinate system.<sup>4</sup>

$$V = V_s - 2V_{\frac{1}{2}} + (n^2 - 2) \delta_{\frac{1}{2}}$$

Using experimental data from single cores (General Ceramics type body MF1326-B, F-394 die size) and the two expressions given above,

the three-coordinate system can be compared with the five-coordinate system. For a 64 x 64 digit plane, the convergence ratio (ratio of largest possible ZERO readout to the smallest possible ONE readout) for the three-coordinate system is 2% whereas it increases to 14% for the five-coordinate system. However, it should be noted that the type of core used (the memory core now used in the three-coordinate system) is not necessarily a desirable type for the five-coordinate system. Any investigation to determine the practicability of such a system must include a study of the existing cores to determine which will operate most successfully at lower selection ratios.

#### PROPOSED PROCEDURE

The investigation will proceed as follows:

1. Investigation of cores

Single cores will be tested to determine which materials will allow a selection ratio smaller than the 2 to 1 ratio used now. Factors to be considered are excitation current, switching time, rectangularity of the hysteresis loop, and the relative sizes of the ONE, ZERO, and partially selected outputs.

2. Investigation of selection schemes

The general theory of selection will be reviewed and extended where possible, with special consideration given to a specific N-coordinate scheme to be decided upon after completion of Part 1 and consideration of the theoretical and practical problems involved. This will require an investigation of the number and complexity of the drivers necessary, the sensing problems, and the construction requirements.

EQUIPMENT NEEDS

The magnetic cores and the equipment necessary for testing the cores are available at the MIT Digital Computer Laboratory.

ESTIMATED DIVISION OF TIME

- 1. Preparation of proposal..... 40 hours
  - 2. Further study of literature..... 40 hours
  - 3. Experimental work and analysis.....150 hours
  - 4. Correlation of results and formulation  
of deductions and conclusions.....100 hours
  - 5. Preparation of thesis report..... 70 hours
- TOTAL                    400 hours

Signed: Richard S. Di Nolfo  
Richard S. DiNolfo

RSD/rb

Date: January 19, 1954

Supervision Agreement

The problem described herein seems adequate for a Master's thesis. The undersigned agrees to supervise the research and evaluate the thesis.

Signed: William K. Linvill  
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Dudley A. Buck  
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- James R. Freeman
- Joseph H. McCusker

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1. Forrester, J. W., "Digital Information Storage in Three Dimension Using Magnetic Cores," R-187 (May 16, 1950), MIT Servomechanisms Laboratory.
2. Everett, R. R., "Selection Systems for Magnetic Core Storage," Engineering Note E-413 (August 7, 1951), MIT Servomechanisms Laboratory.
3. Guditz, E. A., "Delta<sub>n</sub> in Ceramic Array #1," Engineering Note E-488 (October 14, 1952), MIT Digital Computer Laboratory.
4. Freeman, J. R., "Pulse Response of Ferrite Memory Cores," Memorandum M-2568 (December 15, 1953), MIT Digital Computer Laboratory.

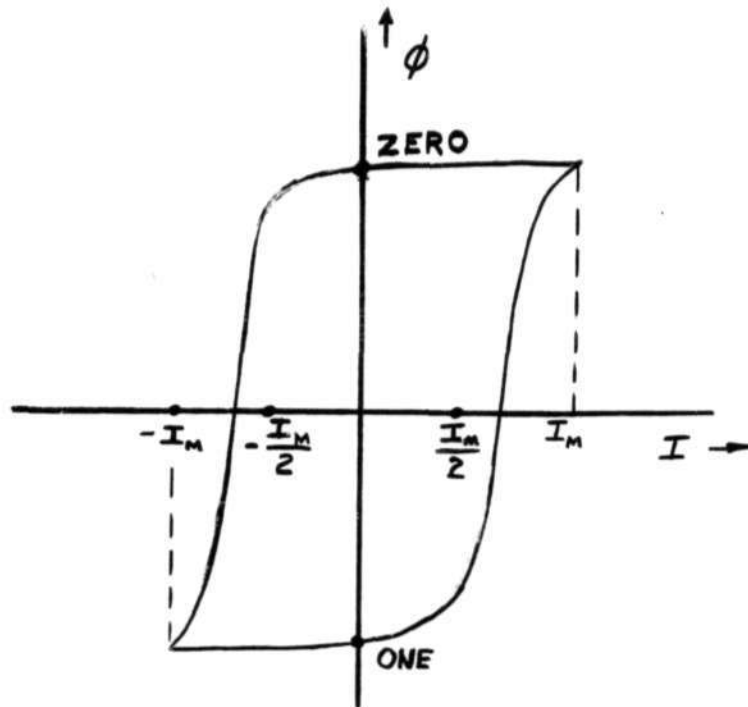


FIG. 1

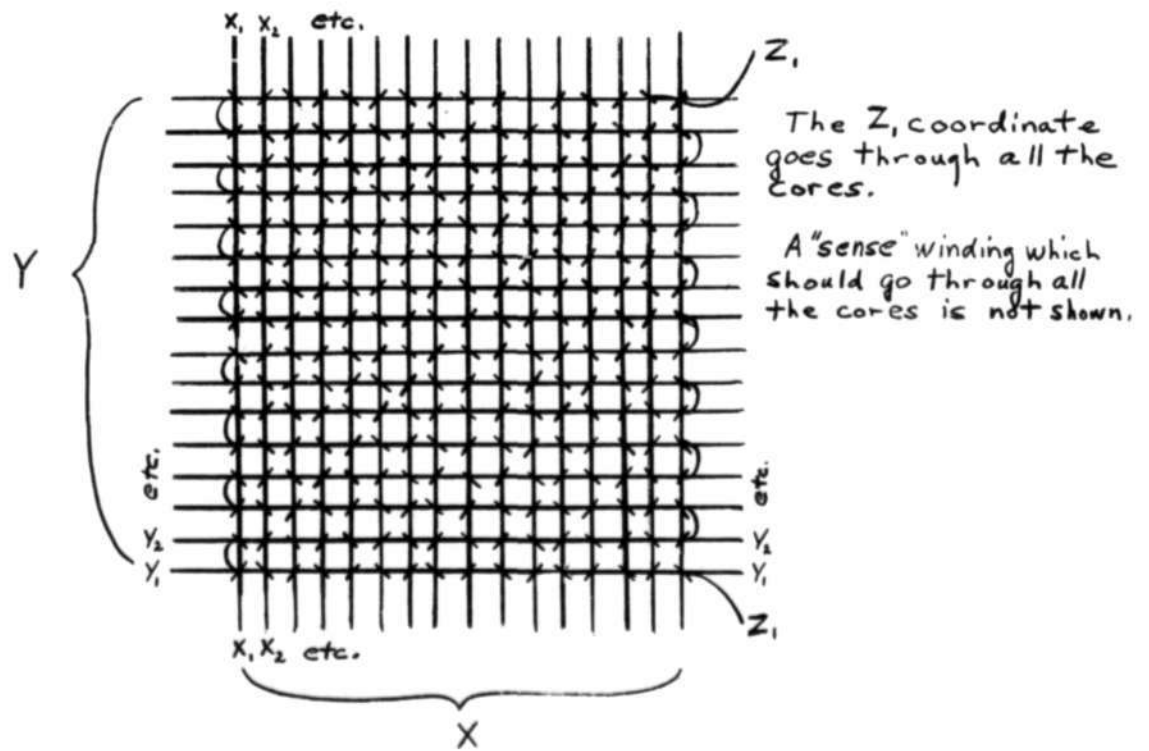


FIG. 2

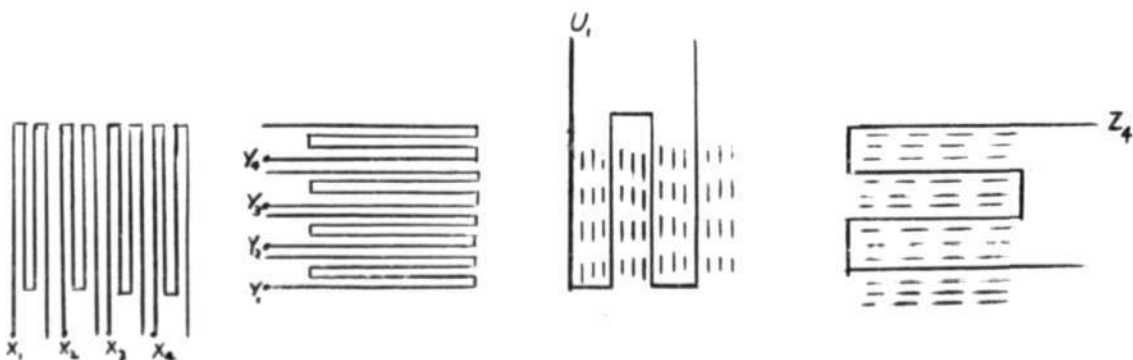
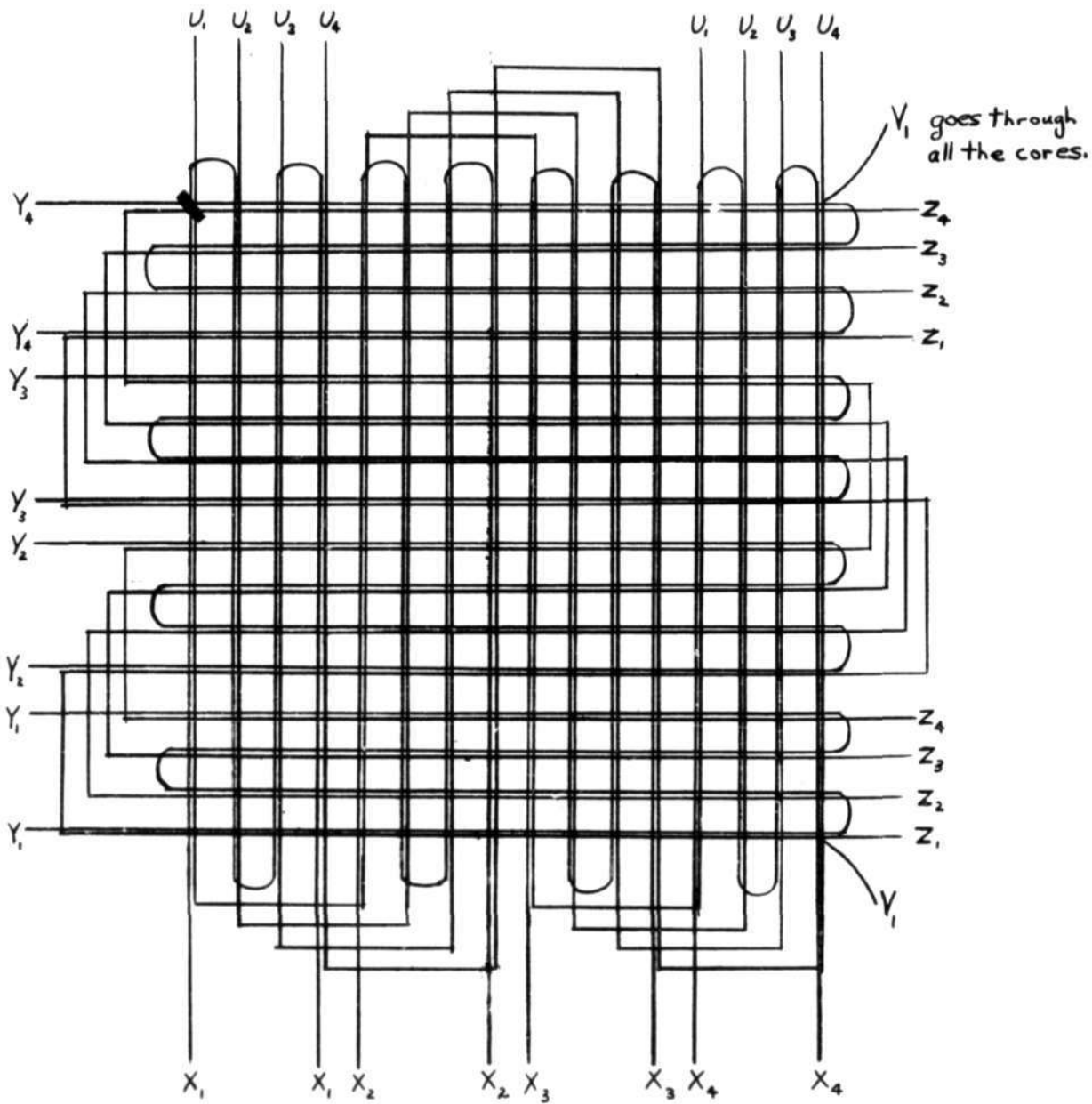


FIG. 3

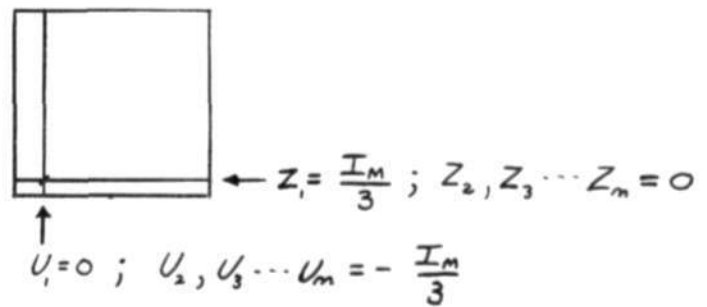
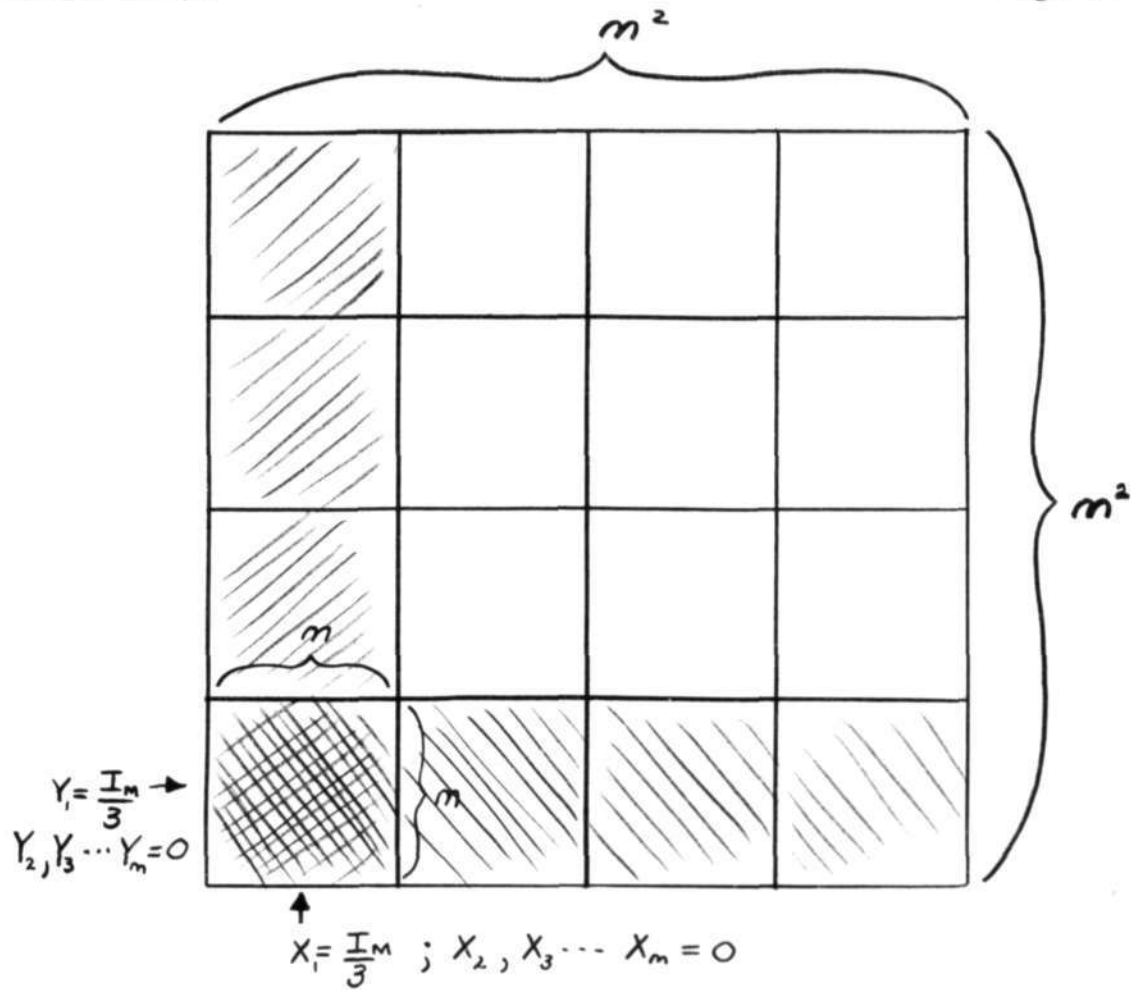


FIG. 4