1971

The use of semiconductor memories in drug dispensing

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THE USE OF SEMICONDUCTOR MEMORIES IN DRUG DISPENSING

BY

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A THESIS

Presented to the Faculty of the Graduate School of the

UNIVERSITY OF MISSOURI-ROLLA

In Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

1971

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ABSTRACT

This paper presents the problems encountered and the methods used during the design of an electronic system to be an integral part of a medical drug dispensing machine. The system has a memory composed of both random access and read only memories to enable it to operate, along with many such machines, from one data input line. The system accepts information such as patient's name, social security number, and drug location number. It also provides signal drive to an attached printer in order to reproduce this information for use on the drug label. Finally, the system electronics accepts input data in the ASCII code and provides an inherent checking ability for machine number and drug location number.

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I. INTRODUCTION

As is obvious to everyone these days, especially those who have had to pay hospital expenses, the cost of medical care has been soaring at an unbelievable rate. In fact, it has been said that if these ever-increasing costs are not halted the day will come when only the very wealthy will be able to afford hospital care without massive aid from the Federal Government. For this reason, methods are being sought to level off, and possibly reduce, the cost of hospital care. The machine described in this paper is an attempt in this direction. It is a machine capable of dispensing pre-filled syringes upon command from its operator. These syringes fit perfectly into modern hospital methods because they are for single-use applications [1], and they are disposable [2]. Thus, they are intended to be used only once on one patient and then thrown away. This particular method of distributing drugs is generally known as Unitdose or Monodose.

The ability of the machine to dispense pre-filled syringes will help the hospital in three basic areas of drug distribution: nursing time required, pharmacy control, and expense recording. The syringe dispenser will help the nurse in several ways. It will reduce the time necessary for her to distribute injectable drugs to the patients throughout the hospital because of its ability to process "batch" drug orders having each syringe package labeled with the intended patient's name and number, and because the dispensed syringe package facilititates its use. (The pre-filled syringe itself is a glass cartridge with an attached needle contained in a hard plastic package which can easily be opened and the syringe activated by forcing the needle to pierce a rubber stopper thereby entering the liquid medicine in the cartridge.) The nurse will also be able to dispense syringes by dialing-in the correct hopper number and pushing the STAT dispense switch. This method would only be used in emergencies and is referred to as STAT dispensing. The hospital pharmacist will also benefit from the use of a syringe dispensing machine. He is the person responsible for the control of hospital drugs. The dispenser will help the pharmacist since it gives him a single place in which to store pre-filled syringes while making it possible for him to maintain strict control over the dispensing of the drugs. The third area in which the dispenser can aid the hospital was listed above as being that of keeping accurate records of the expense for the drugs dispensed [7]. During the normal dispense operation the machine contains the information necessary to tabulate the drugs dispensed and to whom they were dispensed. Via a communication link this information could be printed out in the accounting office of the hospital during the dispense operation; or it could be stored on tape for transmission at a later time.

Up to this point general facts have been noted that relate to the manner in which the syringe dispenser can remedy the present problems in hospital drug distribution. Now, some details of actual operation will be presented. The dispenser has both an electronic and a mechanical system. The electronics is required to accept coded input data for a patient's name and social security number as well as syringe location number. Upon receipt of this information a command to drop the required syringe will be given to the correct hopper and a label will be printed showing the patient's name and number. (The machine contains thirty different hoppers which are individually filled by stacking the syringe packages vertically. Therefore, it is possible to dispense up to thirty different types of injectable drugs.) The mechanical system carries the dropped syringe up to the printer where the label is heat-sealed to the syringe package. At the present time the input data is punched on an IBM card for insertion into the machine. It is possible that the use of more advanced techniques, such as using the hospital computer, will replace this method of inserting data in the future.

From a circuit design standpoint the most interesting part of the electronic system consists of the semiconductor memories used to store the input data for one patient during a dispense cycle. These devices are relatively new and are perfectly suited to this application. The machine memory is made up of random access memories and read only memories. Both make use of the technique of Large Scale Integration (LSI - this refers to the extremely high density of semiconductors contained within the device package). The machine electronics also makes use of transistor-transistor logic (TTL) and Medium Scale Integration (MSI) devices, although the major concern of this paper is with the semiconductor memories and their related circuitry. Particular attention is paid to the idea of using the read only memories to address the random access memories. This is considered to be the most interesting part of the paper as well as the most unusual.

II. REQUIREMENTS OF THE SHERWOOD MEDICAL INDUSTRIES, INC. SYRINGE DISPENSER

The requirements of the syringe drug dispensing system devised by Sherwood Medical Industries, Inc. are many. The most basic are obvious and it is easy to see a need for them; but there are many more requirements which vary depending upon the individual hospital. The basic requirements consist of the following:

A. INPUT SYSTEM

A system by which it is possible to input the necessary information is required. In the first generation of electronics a card reader was used for this purpose. The input data was punched on the card in the ASCII (American Standard Code for Information Interchange) - 64 Character Subset Code (see Appendix A). The card itself was an 80 column IBM data card (see Appendix B for input data card format). The major drawback to this method consisted of punching the cards. A key punch that directly punched the data card in the ASCII code was not available. Therefore, the cards were punched manually one hole at a time.

It is obvious that the above procedure would never be acceptable as the final data input method because of the difficulty it would cause in the hospital. There are several means available to circumvent this problem. A simple solution would be to install a Hollerith to ASCII code converted in the input data line. This would allow the use of IBM key punched cards without any alterations; that is, they would be normally punched Hollerith cards.

Another input method being investigated is the tape cassette used in conjunction with a CRT terminal. Using this method the input data can be compiled and edited on the CRT then transferred to the cassette. After all the necessary information has been stored on the tape the cassette can be removed from the CRT terminal and installed on the dispenser. The electronics within the dispensing machine could then interrogate the cassette in order to learn the dispensing information. Several of these terminals have been investigated and they only differ in their editing methods and circuit techniques. CRT terminals also have the ability of transmitting and receiving data over telephone lines. This capability may prove to be useful in the future.

An input system which may be useful to hospitals as they become more computer oriented is a direct tie-in of the syringe dispenser to the central hospital computer. This system would be directly compatible with the future use of computers in hospitals [4], and would allow for a completely automated drug dispensing program within the hospital [5]. If this route is taken, and assuming that the ASCII code is used, the only major revision necessary to the syringe dispenser electronics would be the addition of a serial to parallel data converter at the input.

B. INTERNAL MEMORY

The second basic requirement of the syringe dispenser is an internal memory. This is necessary because it adds an enormous amount of versatility to the machine (this is always necessary for a prototype) and, most important, it allows many syringe dispensers to be operated from one input data line. This is accomplished by assigning to each dispenser a different machine number and storing that number in the memory. Then, before any information will be accepted and orders executed the machine number stored in the memory will be checked against that contained in the input data. If the numbers are not identical, all the input data is disregarded. Using this method, a hospital could have as many drug dispensers as required without having to duplicate the data source. The data source could be in the hospital pharmacy and thus, the pharmacist could directly control the dispensing of all syringes throughout the hospital [6].

The idea of the versatility provided by use of a memory should be expanded upon. Before production of this machine is attempted it will probably pass through many different stages and there will be many varied opinions concerning what it should and should not do. For example, it may be found necessary to check internally for more than just machine number. A double check of syringe number may also be necessary. This was, in fact, deemed important and is included in this prototype. This was a relatively easy addition since the necessary information was already stored within the random access memory. All that was required was a programming change in the read only memory; but no circuit changes or redesign was necessary.

A larger view of what this versatility can alleviate follows. At the present time many problems exist with the printer that was intended for use on the syringe dispenser. Among the peculiarities of this printer is the necessity to print on two lines before advancing, therefore, the patient's name is not printed out followed by the social security number on the next line, but is printed out on alternate print commands with the social security number. Severe reliability problems were encountered with this printer and this particular part of the program is being reviewed as to future requirements in printer redesign. The outcome of this could be a printer with completely different characteristics relative to print-out sequence rules. If this occurs all that will be required is a reprogramming of information call-out from the random access memory (RAM) to the printer. Another possibility is the addition of more information to the printer label, such as patient's room number, the drug's generic name, time of injection, total number of injections per day, and so on. As long as this information appears in the input data, the only necessary change would be a reprogramming of the read only memory (ROM). It can be seen from the above discussion that the advantages of the internal memory are many in that it allows major versatility without any circuit design changes; and it allows for quick changes to test ideas out with the ability to revert immediately to the old method if the idea does not prove out.

There is one remaining ability of the internal memory which is made use of in the syringe dispenser. This is the ability of the read only memory to perform the control operation on the electronics. That is, it is the source of direction for the sequence of logic operations and decisions performed by the electronics during a dispense cycle. This operation alone makes the internal memory vital to the performance of the syringe dispenser machine.

C. OUTPUT SYSTEM

The third requirement is an output system. The output, of course, is a correctly labeled syringe containing the correct medicine. To accomplish this there is a mechanical and an electronic requirement. The problems which must be overcome, from the mechanical view point, will not be discussed in this paper; only the electronic requirements will be studied.

At present the electronics output consists of various commands. The most obvious consists of a drop command routed to the correct syringe hopper and a printed label ejected from the printer containing the patient's name and social security number. In addition to these, there are four visual displays indicating various operations or problems. The first is a Dispense light that indicates correct operation is proceeding and a syringe can be expected shortly. The second is a Data Reject light that indicates the input data does not meet the internal checks and is refused. If this occurs the card reader ejects the data card. The third is a Failure light that indicates the called for syringe failed to drop and that no syringe will be forthcoming. If this occurs the card reader will reject the input data card. The fourth is a two digit digital readout consisting of light emitting diode displays. The purpose of this is to indicate the hopper number of the syringe requested by the input data. This is useful if a failure occurs because it indicates which hopper is empty or jammed. It should also be noted that if an input card is inserted incorrectly or if the machine is asked to dispense with no input data card, immediate rejection will take place by the card reader and no dispense cycle will be initiated.

In the future it may be necessary to have an output capable of driving devices used by the hospital to keep track of billing information. This could be as simple as a second printer or as complicated as some kind of interfacing with the hospital computer.

D. INTERFACING ELECTRONICS

The fourth requirement of the Mondose Syringe Dispenser is the interfacing electronics. These are the electronic circuits which are necessary in order to allow the Dispenser to operate in conjunction with any special input-output systems a particular hospital may have. For example, the prototype machine requires input data to be in the ASCII-64 Character Subset Code, while the hospital that it is installed for test in may not have a keypunch capable of punching the input cards in this code. The hospital may only have the ability to punch Hollerith coded input cards. In this case a Hollerith to ASCII code converter would be installed between the card reader and the main electronics. The need for this particular interface would vary from hospital to hospital.

Another example would be an interface using a serial to parallel converter at the front end of the machine electronics if it was necessary to supply the input data by means of telephone lines. The machine electronics accepts data in a parallel format, whereas it is convential to transmit data over phone lines in a serial manner for obvious reasons.

Another possibility is interfacing with the computer billing and accounting system used by the hospital. This is an area where it has been suggested that machines like the syringe dispenser could bring in extra revenue to the hospital, money that would otherwise be lost due to inadequate billing procedures.

III. PROBLEMS INVOLVED IN THE CIRCUIT DESIGN

A. CHOICE OF LOGIC FAMILY

Quite a bit of time was spent in investigating the different possibilities existing in the choice of logic type best suited to the requirements of the syringe dispenser. The speed of a particular logic family was of little concern in this case because any family would complete the required operations before the mechanical part of the machine could finish its function. That is, the time required to drop a syringe was set by the mechanics of the machine, not the electronics. The availability of complex functions in the logic family was definitely a requirement since a good amount of MSI devices were necessary in order to keep down the overall package count. The one of eight and one of ten decoders are examples of MSI devices used. It was also required that the logic used had to interface easily with the RAM's and ROM's. Low power dissipation was not a prime requirement since the syringe dispenser is a commercial product and, as such, had no power consumption specification which had to be met. However, useless waste of power would not be tolerated. Logic flexibility was of some concern because the more flexible a logic family is the more variety it has in the selection of multiple gates. For example, not only NAND functions were used in the design, but also the OR, NOR, and exclusive OR functions. Noise immunity was considered a very important feature in logic families. This is discussed in detail in the following section of the paper. It seems as though there was no single factor that was considered of primary importance. This, however, is not the case. Low cost in a logic family is the feature that was of primary importance. It was the low cost that led to the selection of 7400 series TTL logic more than any other single feature. This series, of course, is the most well known of all logic and has many second sources. The price-cutting wars among semiconductor suppliers which have taken place in recent months have all occurred around the 7400 series logic families. In fact, the 7400 series ranks well in all the categories mentioned above with the possible exception of high noise immunity. For a further discussion of this topic see the reference in the Bibliography [7].

B. NOISE IMMUNITY

There was very much time and effort spent during this project to eliminate all problems relating to electrical noise. An investigation was made into the various types of logic families available as to their relative noise immunity. There was major concern at first that TTL would not be feasible to use because of its high speed and its typical 400 mv noise immunity. It was thought that along with the high speed came the ability to respond to short duration noise spikes. Therefore, logic families such as Signetics' Utilogic and Motorola's High Threshold Logic were investigated. It was finally decided that there was no need to resort to either the Utilogic or the High Threshold Logic in the case of the syringe dispenser. The other advantages of using 7400 TTL far outweighed the disadvantage of having to scrutinize the design of the electronics to design in as much noise immunity as possible.

Once it was decided to use the TTL logic, past experience made aware the fact that maximum effort would be required to design a workable system in the noisy environment involved. This noise originated from two basic sources; noise generated by the TTL itself and noise generated by devices external to the electronics. It was decided to concentrate on the external noise sources. These consisted of two different motors, two 100 watt heaters, lights, fans, a bank of thirty solenoids, a card reader, and a printer. All of this equipment operated on AC and was subject to being switched on and off. One of the AC motors, the compressor motor, required about twenty amps surge current when starting under load, and the solenoids were especially noisy when operated.

As a start in fighting noise, it was decided to use the wire-wrap technique for inter-connecting the logic. Wire-wrap boards were used that had large copper runs for the voltage lines. This made possible the use of single point grounding. This not only helps noise immunity to external noise, but also helps tremendously to cut down on vulnerability to TTL noise. Placing of capacitance at the voltage input to each board also helped. The single point ground was not only used on each wire-wrap board, but also throughout the electronics system. The ground connection to each board, the ground connections to the power supplies, and the ground connections to external devices were all returned to a single point. Careful attention was also paid to the routing of wiring cables around the machine. All cables carrying signal levels for the electronic logic were enclosed in shielding. All AC wiring was made using twisted pairs of wires, and was routed as far as possible from low signal lines. Varistors were used across the switches of the lights and fans, and across the switching relay used to energize the card reader.

There was one other noise reduction scheme used in the syringe dispenser. It was used to energize the following AC devices: the compressor motor, the dispenser motor, the heaters, and the thirty hopper solenoids. It consisted of a zero-crossing control and switch called a Trigac. When given a turn-on command the Trigac would energize a triac with gate pulses. But, these gate pulses would only occur when the AC line voltage passed through zero. This eliminated the transients normally produced when switching on these devices. The same principal is used to turn the devices off; that is, after receiving a turn-off command the Trigac discontinues pulsing the triac on, and at the next transverse of the AC line voltage through zero the triac turns off and remains that way. The operation and uses of the Triagac are discussed in detail in the reference material [8]. It is obvious that AC line voltage exists in the zero-crossing control circuit. Therefore, it is best to use a signal ground isolation method when coupling the turn-on and turn-off commands from the logic into the Trigac-triac circuit. This was accomplished by making use of small reed relays. These reed relays were capable of being driven directly by the logic gates and were in dual-in-line packages. This ground isolation is sure to have helped immeasurably.

Paying a great amount of attention to all of these ideas during the design stage, before the machine was built, paid off more than expected. Virtually no major noise problem was encountered during debugging. Capacitors of 1000 pf were added in two places to eliminate TTL noise, and the varistors took care of noise generated by the operation of two door actuated switches. Even the cycling of the compressor did not affect the operation of the logic. Needless to say, everyone was pleased with these results.

IV. OPERATIONAL CHARACTERISTICS OF THE FINAL CIRCUIT DESIGN

A. FLOW CHART

Figure 1 is a flow chart of the events that take place during the operation of the syringe dispenser for one cycle. It shows all the possible decisions that the dispenser is capable of making. It may be of interest to point out some of the salient features of the flow chart. Three possible events can occur during the activation of the Data Enter Switch. First, the operator may have neglected to insert an input data card into the card reader. If this is the case the reader will close, but since no data card can be detected it will immediately open with no further action taking place. Second, the operator may insert the input data card in an incorrect orientation. The reader will again close and immediately open. It was necessary to include these two possibilities in the circuit design in order to eliminate a lock-up condition which would otherwise result if either case occurred. Third, assuming neither the first case nor the second develops, the card reader will close and remain closed until the operation is completed. There are three different frequencies used for the clock in the electronics. They are 1250 Hz, 625 Hz, and 20 Hz. The two higher frequencies are referred to as the fast clock.

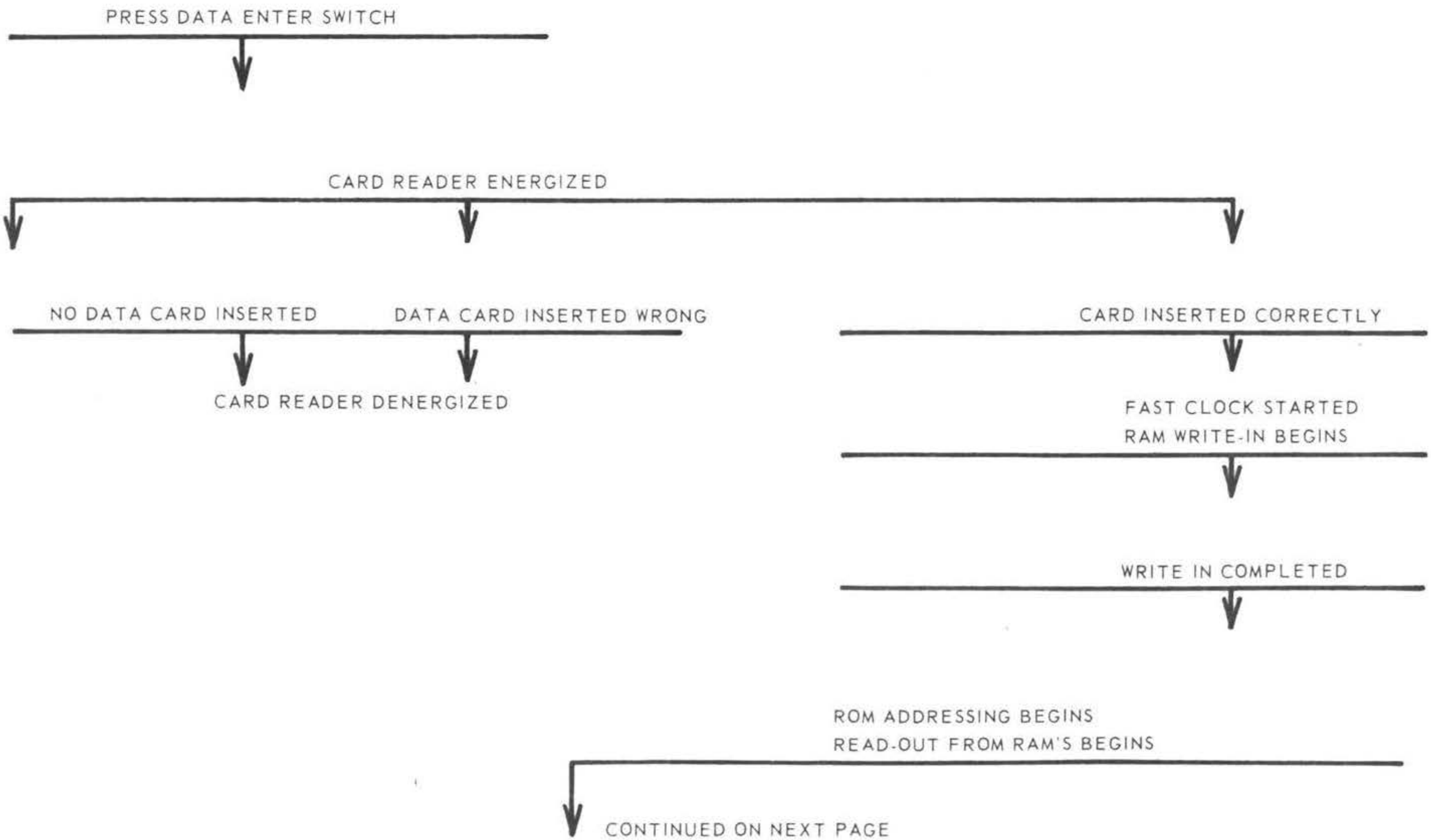

FIGURE 1. FLOW CHART FOR SYRINGE DISPENSER

FIGURE 1. CONTINUED

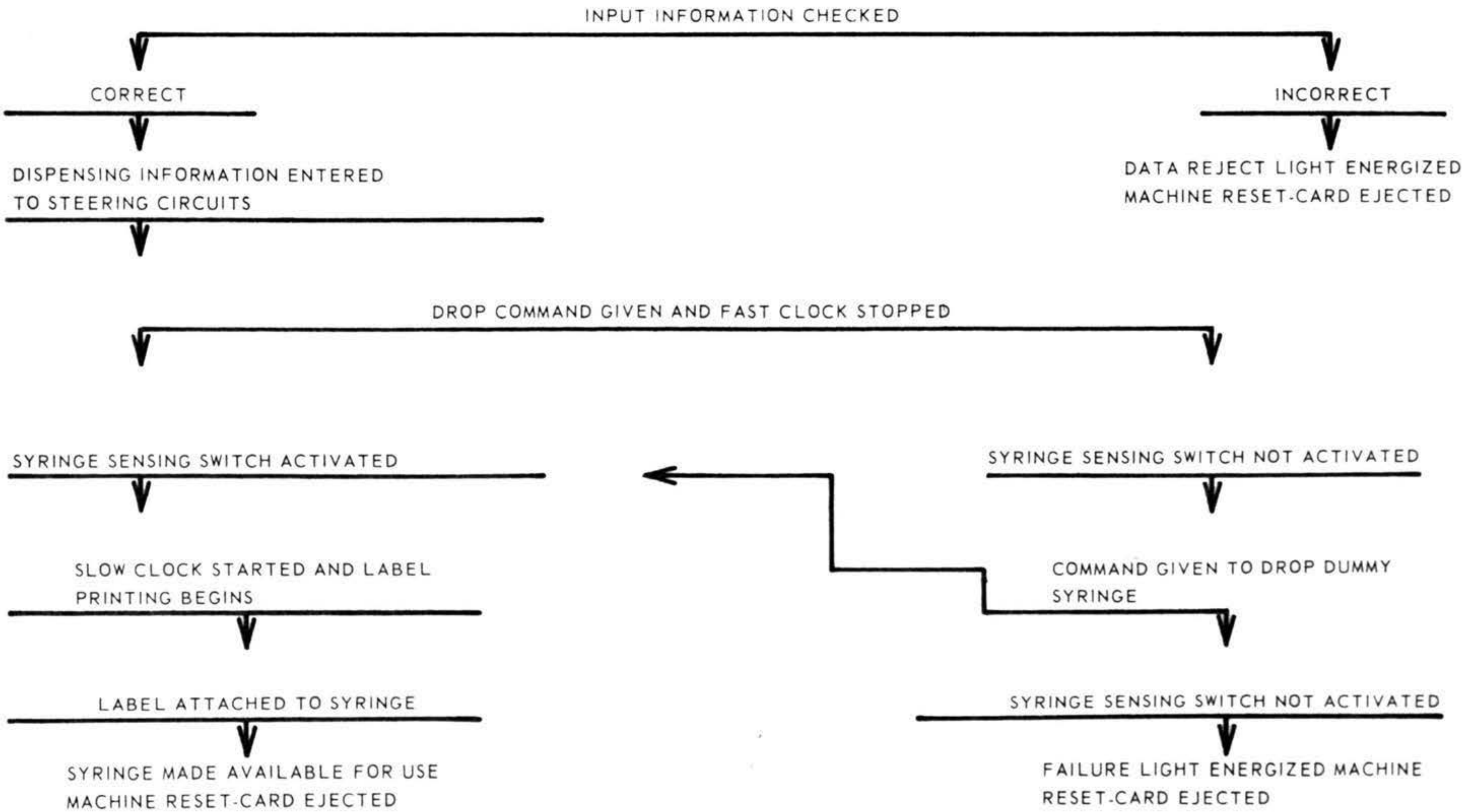

FIGURE 1. FLOW CHART FOR SYRINGE DISPENSER

The 1250 Hz is used for the write-in operations while the 625 Hz is used to run the logic during all read-out cycle operations except printing where the slow clock 20 Hz is used. This lower frequency was necessitated by the fact that the printer used was incapable of operating at speeds higher than 25 characters per second.

It can also be noted from the flow chart that a check is performed on the input information to determine its correctness. This check is used to eliminate the possibility of typing errors and to allow operation of many syringe dispenser machines from one common input data line. If this test is passed by the input information the dispensing data is entered to the steering circuitry and a syringe drop command is given. At this point the fast clock is brought to a halt, and the electronics waits for a signal from the Syringe Sensing Switch telling it that a drop actually occurred. The electronics waits for fourteen seconds, then, if no signal is sensed orders a dummy syringe to be dropped. The purpose of this is to let the nurse know that the supply of the drug requested is exhausted. If after another time period a syringe still is not sensed a failure is deemed to have occurred and, therefore, the Failure Light is activated. Once a syringe is detected by the Syringe Sensing Switch the slow clock is started and the printing of the label begins. Finally, the label is automatically attached to its corresponding syringe and the package is made available to the nurse for her use.

B. BLOCK DIAGRAMS

Figure 2 is a block diagram of the data input and output system for the syringe dispenser. Several important ideas can be derived from it. The electronics contained within the syringe dispenser can be operated from a variety of input systems. A single unit input system such as a card reader or tape cassette can be used, or a large system such as a hospital computer is also capable of interfacing with the machine electronics. The particular input system used may be an integral part of the syringe dispenser or it can be located in some remote area. The block for the input data switching and processing account for any circuitry that may be required to make the input information format identical with that acceptable to the electronics. For example, the electronics accepts information in the ASCII-64 Character Subset Code while the actual input data may be in the Hollerith format. In this case a Hollerith to ASCII code converter would be installed in the input data switching and processing block. The data transfer into and out of the read/write random access memory is in a parallel format. There are six lines for the input and six for the output. As can be seen from Figure 2 there are two different addressing circuits used

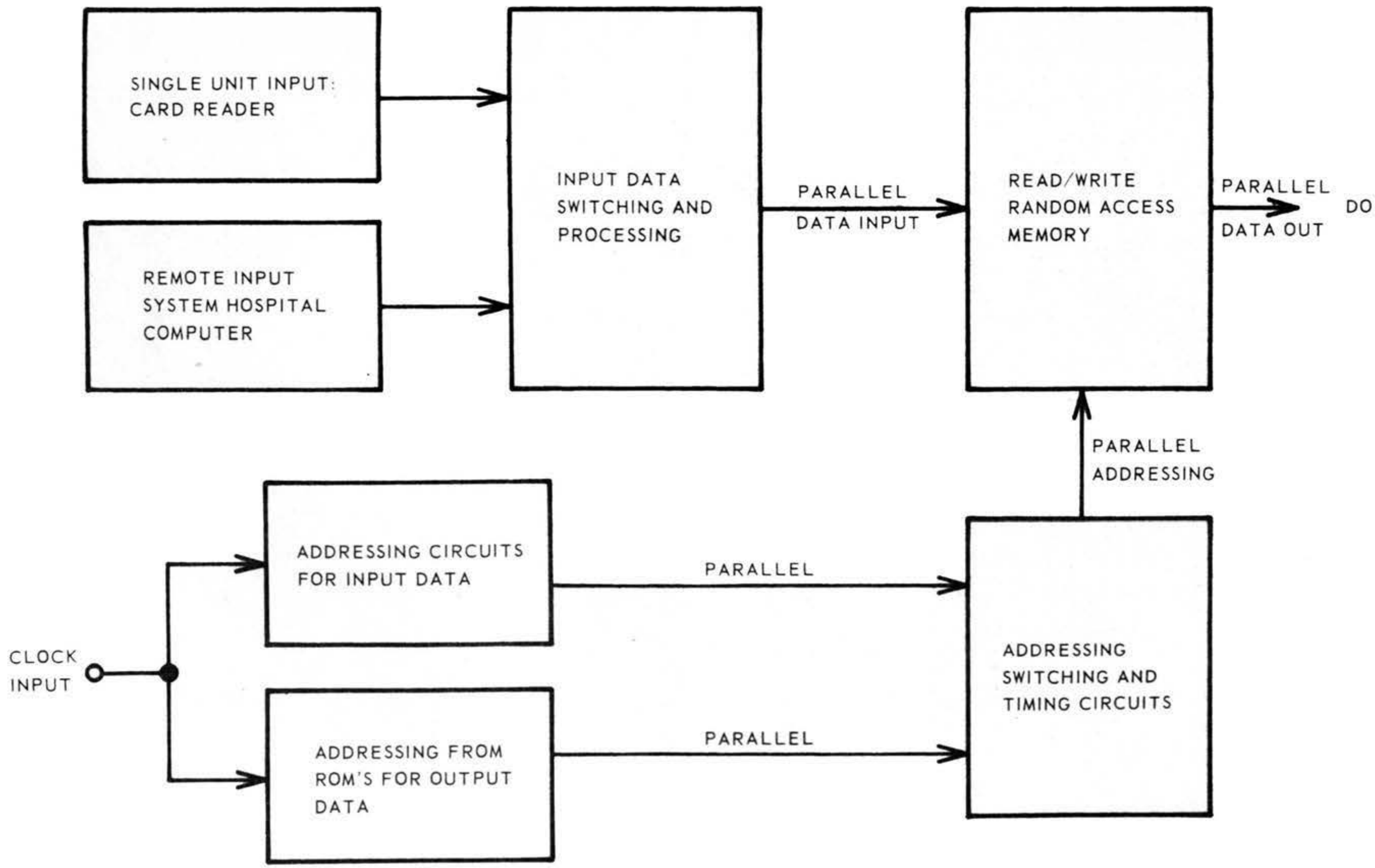

FIGURE 2. DATA INPUT/OUTPUT SYSTEM BLOCK DIAGRAM

for the RAM's. One is used to write the input data into the memory, and the other is used to read that information out of the memory. The addressing occurring during the read cycle is accomplished by the read only memory.

The block diagram of Figure 3 displays the parts contained in the checking and dispensing circuitry. The six Data Output lines come in to the Information Checking Circuit, the Dispensing Information Switching Circuit, and the Printer. The Information Checking Circuit is discussed in detail later in this paper. Its basic purpose is to eliminate typing errors and to perform checks against the machine number stored internally and that appearing in the data input. If, during this checking period, an error is detected a Data Reject command is generated by the Information Checking Circuit. This command activates the Data Reject Light, resets the Logic circuitry, and ejects the data input card. The circuits contained in the Dispensing Information Switching block determine whether the data used to drop a syringe comes from the RAM's or from binary coded decimal (BCD) information entered by the nurse on thumb-wheel switches while she is using the STAT Order System. The Dispensing-Steering Control Circuits are basically a one-of-twenty-nine decoder; that is, it accepts BCD information and selects one of twenty-nine output lines corresponding to the original BCD data. This covers the syringe hoppers up to twenty-nine. Hopper number thirty

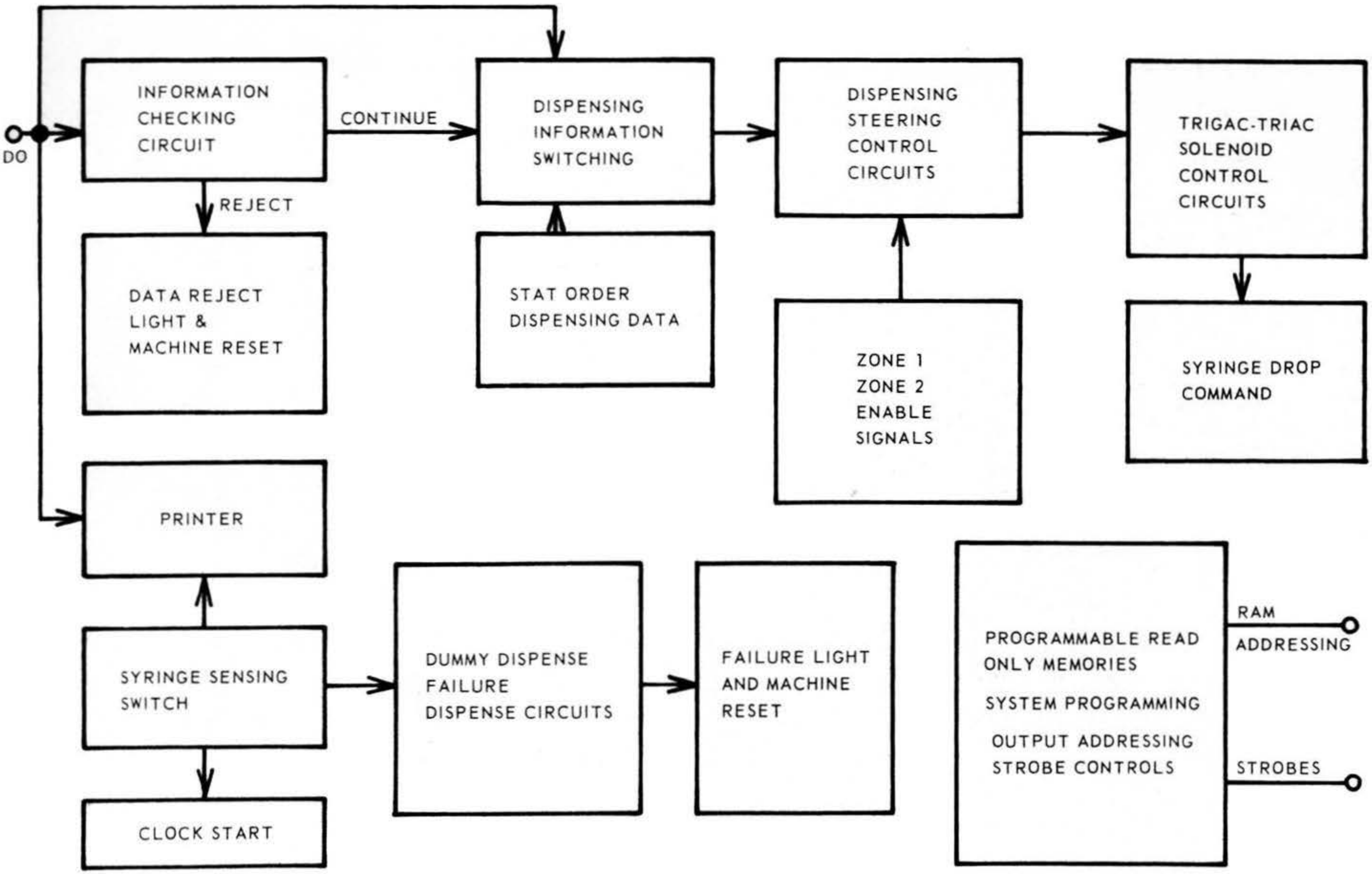

FIGURE 3. CHECKING AND DISPENSING CIRCUIT BLOCK DIAGRAM

is selected by the dummy dispensing circuits. The Zone 1 and Zone 2 Enable Signals are used to provide a final condition that must be met before a syringe is allowed to drop. These signals prevent dropping a syringe on top of a carrier lug. The block called Trigac-Triac Solenoid Control Circuits represents thirty zero-crossing circuits used to drive the hopper solenoids. The Syringe Drop Command is the signal that energizes the solenoid of the correct hopper.

After the Syringe Drop Command is given, a syringe should appear at the Syringe Sensing Switch within fourteen seconds. If this occurs the switch will be activated and will in turn start up the slow clock and begin the printing of the label. If the switch is not activated a command will be generated to drop a dummy syringe, and the electronics will again wait for activation of the Syringe Sensing Switch. This time the wait is about five seconds. In the event the switch still is not activated a Failure Light will appear, a reset pulse will be generated, and the input data card will be ejected. The only block left in Figure 3 is the one representing the read only memories. These memories are responsible for running the electronics during the RAM-read and the print cycles. They provide RAM addressing during the read cycle and the strobes required during the read and print cycles.

V. DETAILED DESCRIPTION OF THE UNUSUAL CIRCUITS USED IN THE SYRINGE DISPENSER

A. MEMORY CIRCUITRY

The memory circuitry is the center of the electronics system used in the Syringe Dispenser. It consists of random access and read only memories along with their support circuitry. The RAM's are twenty-eight pin devices manufactured by American Micro-System, Inc. of Santa Clara, California. They are 128 bit memories capable of being varied electrically to 128x1, 64x2, or a 32x4 configuration by control input lines. In the Syringe Dispenser three of these units are used and they are connected to give a 64x2 organization. Therefore, their memory capability is 64 six bit words or a total of 384 bits. The RAM's require 5VDC and minus 12VDC from their power source. The read only memories are twenty-four pin devices manufactured by Harris Semiconductor, Inc. of Melbourne, Florida. These particular devices were used because they are field programmable. This eliminated the long wait necessary when ordering a ROM which had to be programmed by mask changes at the factory. The organization of each ROM is 64x8. There are three of these units used in the Syringe Dispenser. The ROM's require only a 5 VDC power source.

It should be noted that the circuitry shown on the following schematics represents about one-fifth of that used in the Syringe Dispenser electronics system. However, the circuitry shown is the part considered to be the most unusual because it deals with using bipolar read only memories to address metal oxide semiconductor random access memories. Both the ROM's and RAM's make use of the technique of large scale integration.

The schematics discussed in the following sections of this paper use the standard military designations to represent the logic functions. In cases where some ambiguity is present the logic function is labeled next to the corresponding schematic representation. Please refer to Table I for a list of the symbols used in the schematics, to Table II for strobe definitions, and to Table IV for the 7400 series part numbers used for the desired logic functions. Each schematic will be explained separately, then a discussion of the interrelated operation will follow.

1. RAM Write-In and Timing Circuitry

The circuit used to generate the addressing for the random access memories during the write cycle is shown in Figure 4 along with associated timing networks. The basic function of this circuitry is to provide RAM addressing during the time information is being transferred from the card reader to the RAM's; and to assure proper timing of the Memory Strobe with respect to address and input information changes during write-in, and between the Memory

TABLE I

LIST OF SCHEMATIC SYMBOLS

A0-A5	Binary data used during write-in to address the random access memories (RAM) and drive the card reader decoder circuitry.
a0-a5	Binary data used during the read-out cycle to address the read only memories (ROM).
B0-B5	Binary data from the ROM used to address the RAM's during the read-out cycle.
C0-C7	Reference method used to label the eight bit outputs of each individual ROM.
DI1-DI6	ASCII coded data used as the input during the write-in cycle.
DO1-DO6	The usable binary output data from the RAM's.
PL1-PL2	The line one and line two print commands required for printing.
RA0-RA5	The direct addressing lines of the random access memories capable of carrying A0-A5 or B0-B5 information.

TABLE I (continued)

RS1-RS4	Inputs to the Data Checking Circuit capable of being switched to the first four bits of RAM or ROM outputs.
Address Enable	Provides RAM address data acceptance and latching.
Basic Clock	40 μs timing pulse or strobe used to insure that logic operations remain in sequence.
Card Presence	A high logic level received from the card reader used to initiate the write-in cycle.
Clock	A 1250 Hz drive signal used to operate the write-in circuitry.
Clock Pulse	115 μs high level logic pulse used to correctly time RAM addressing operations during the read-out cycle.
Data Enter	A switch derived low going signal used to energize the card reader and clear a Data Reject or Failure condition.
Data Reject	A high logic level used to energize the Data Reject Light and develop a XMR strobe.

TABLE I (continued)

Failure	A high logic level used to energize the Failure Light and develop a XMR strobe.
Memory Strobe	The strobe input to the random access memories. It must be enabled for every address change. A negative condition on this line samples the address inputs.
Read/write Control	Determines the mode of operation of the RAM's. A low condition on this line places the RAM's in the write mode.
ROM Address Enable	A high logic level on this line allows RAM addressing to be done by the ROM.
Write Address Enable	Allows RAM addressing to be controlled by the write-in circuit over the lines A0-A5. Also provides RAM input data acceptance and latching.
Write-In Complete	Signals the completion of the write-in cycle and switches the RAM's from a write to a read mode of operation.

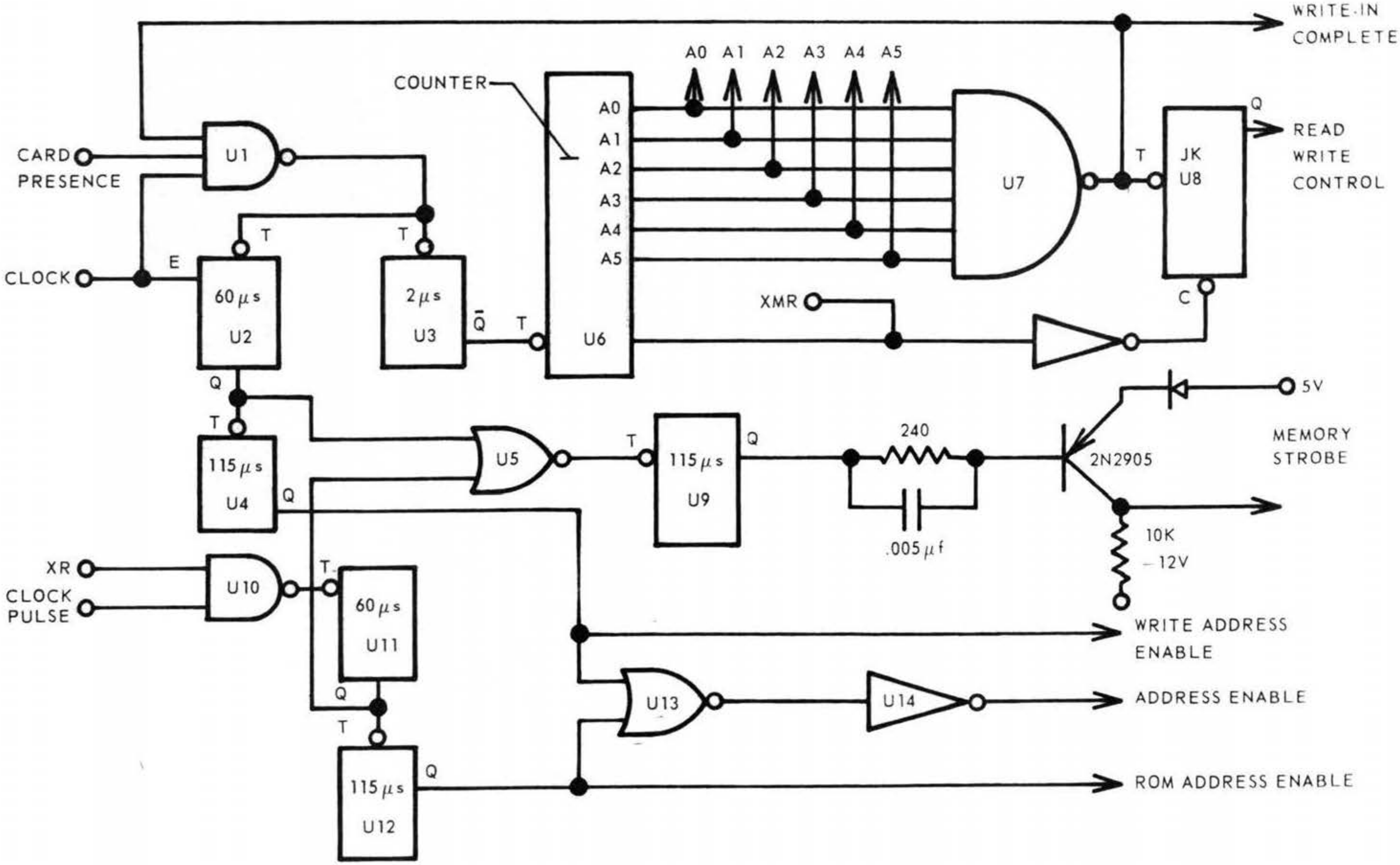

FIGURE 4. SCHEMATIC FOR RAM WRITE-IN AND TIMING CIRCUITRY

Strobe and address changes during read-out. The Card Presence signal is derived from a switch on the card reader. A high logic level here assures that an input data card has been correctly inserted into the card reader. This signal initiates the write-in cycle. The Clock is a 1250 Hz square wave continuously varying between the low and high logic levels. The lines labeled A0 through A5 are the RAM address lines used during write-in. The Write-In Complete signal is high during write-in and goes low at the end of the write-in cycle. This signal is used to lock out any further clock pulses at U1, to trigger the JK flip-flop in U8 from a write to a read mode, and to enable ROM addressing to begin. The Memory Strobe is normally about 4 VDC, but is switched to -12 VDC when changing the RAM address to write or read new data. The three enable signals will be discussed later while dealing with other schematics. It should be remembered that they are generated in this part of the circuitry. The XMR strobe is used to reset the six bit counter and U8. The transistor is used to translate the 0 to 5 volt levels of U9 into -12 to 4 volt levels suitable for strobing the RAM's. The diode is needed in the emitter of the transistor to assure that the transistor will turn off at the high level of U9's output.

2. ROM Circuits and Machine Reset Generation

The parallel addressing of the read only memories, their strobe and address outputs, and the circuit used to generate a reset pulse for the machine logic are shown in Figure 5. The ROM's are addressed in parallel over the lines marked a0 through a5. These lines originate at a six bit binary counter and are energized only after the write-in cycle is completed. ROM 3 supplies addressing to the RAM's during the read-out cycle over the lines called B0 through B5. It also supplies the XR and X1 strobes (see Table II for strobe definitions). ROM 2 is the source of more strobes and also the print commands for the label printer. PL1 is the print command for line one and PL2 the command for line two. ROM 1 is the source of the XRAM and XROM strobes used during data checking, and also the Machine Reset Signal. This reset signal is stored in address 63 of ROM 1. When the last bit of data has been fed to the printer and all other operations are completed address 63 is reached. At this point pin 20 of ROM 1 goes high and this high is transferred through the OR gates U15, U16, and U17 to become XMR, the Machine Reset Signal. This signal resets all the necessary JK's and counters in the logic circuitry and also causes the input data card to be ejected by the card reader. This process completes one cycle of the syringe dispenser and a syringe has been dropped, labeled, and made available to the nurse by this time.

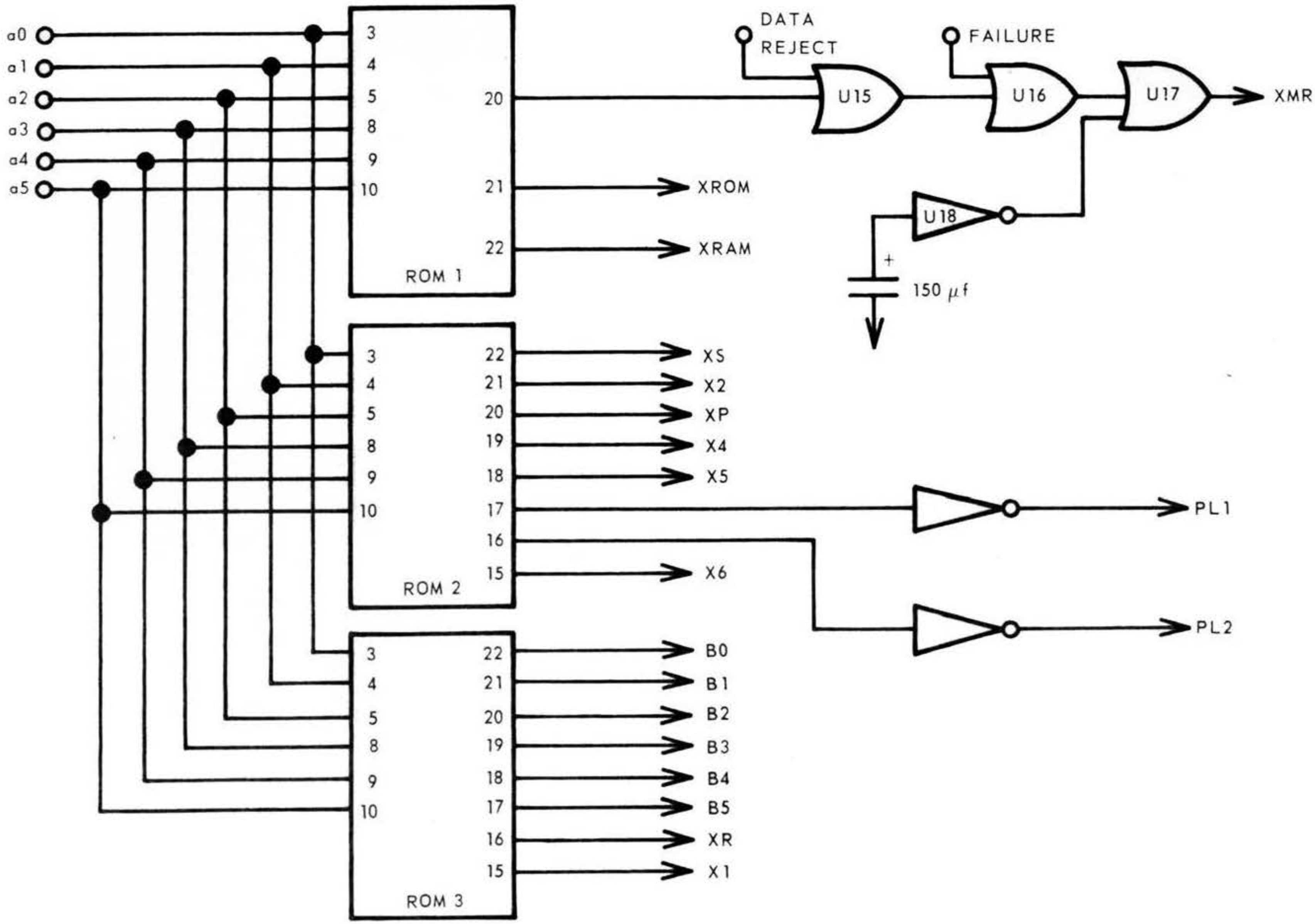

FIGURE 5. SCHEMATIC FOR ROM CIRCUITS AND MACHINE RESET GENERATION

There are two ways a dispense cycle can be interrupted and stopped before address 63 is reached. A high logic level on either the Data Reject line, U15, or the Failure line, U16, will cause premature termination of the dispense cycle. The inverter at U18 is connected to give a power-on reset to the logic. It develops a high on the XMR line for about 75 ms after the power is turned on to the machine.

3. RAM Address Switching and Input/Output Circuitry

Since the random access memories are addressed from two different circuits their addressing lines must be switched between these circuits. The circuit that accomplishes this task is shown in Figure 6. There are six NAND gate switches in this circuit. Each switch is made up of three dual-input NAND gates. During the write-in cycle the RAM's are addressed by the lines A0 through A5. Therefore, in order to switch this information into the quad latches (U19 and U20) the Write Address Enable line must be held high and the ROM Address Enable line must be held low. These signals originate in Figure 4. The opposite condition prevails, of course, during the read-out cycle and the lines B0 through B5 are switched into the quad latches (U19 and U20). During the time when either the Write Address Enable or the ROM Address Enable lines are high, a high is also present on the Address Enable line. This high allows the quad latches to pass information

TABLE II

STROBE DEFINITIONS

X1	Allows checking circuit to accept RAM output data.
X2	Allows checking circuit to accept RAM/ROM output data.
X4	Allows Syringe Location Number most significant digit to be accepted by the syringe dropping circuitry.
X5	Allows Syringe Location Number lease significant digit to be accepted by the syringe dropping circuitry.
X6	Enables the one of twenty-nine decoder used to drop the correct syringe.
XP	Switches the drive source for the logic from a fast clock to a slow clock.
XR	Enables the Memory Strobe during the read-out cycle.
XS	Stops all logic operations until a syringe drop command is issued.
XMR	Resets the machine logic.

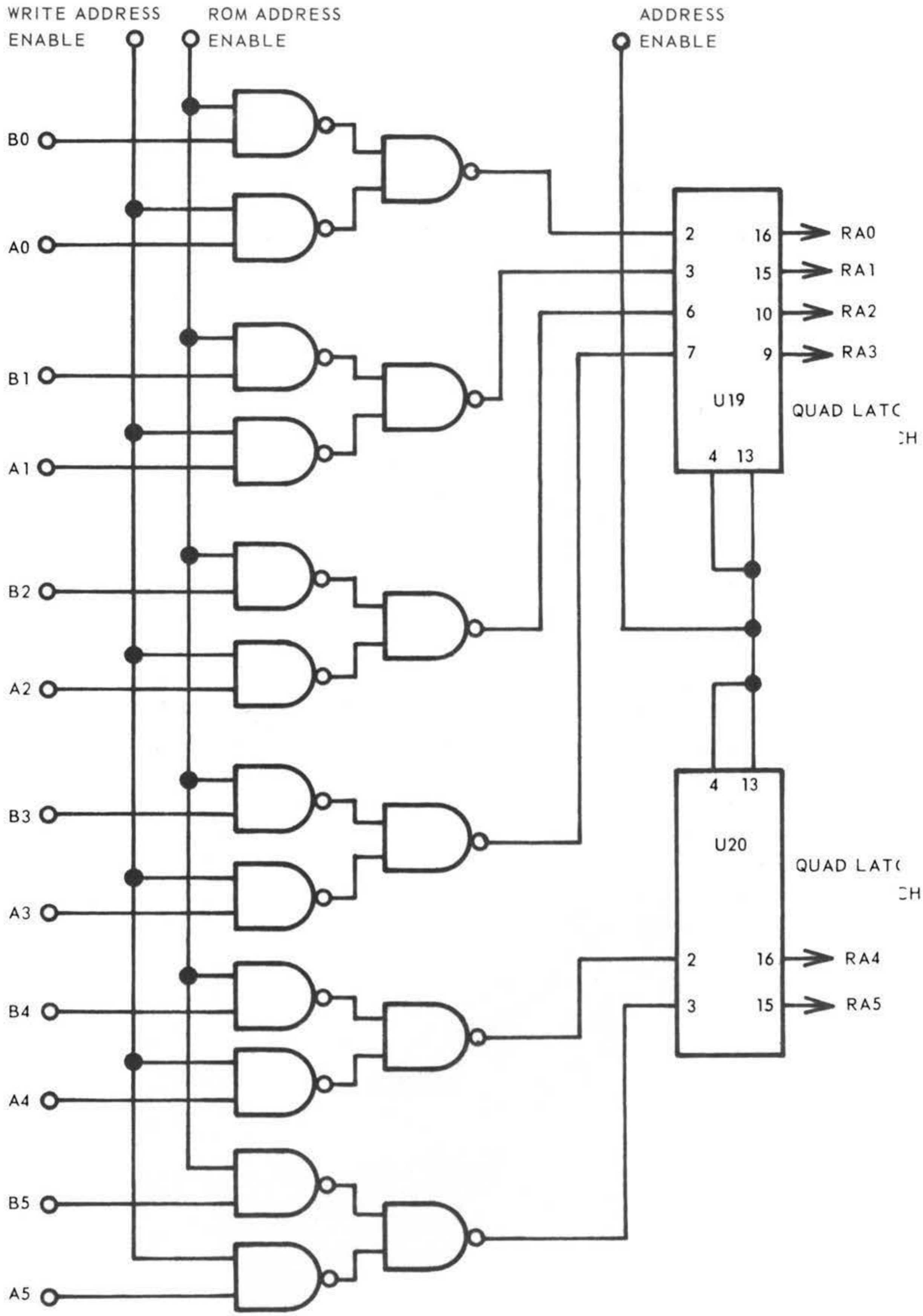

FIGURE 6. RAM ADDRESS SWITCHING CIRCUIT SCHEMATIC

present at their inputs to their outputs where it is held when the Address Enable lines goes low. This data holding is necessary because the RAM addressing can only change when the Memory Strobe is at -12 VDC.

The input/output circuitry for the random access memories is shown in Figure 7. The addressing for the RAM's comes in on lines RA0 through RA5. The input data from the card reader comes in on lines DI1 through DI6. It does not go directly to the RAM inputs but to quad latches (U21 and U22). The data is held by these latches during the time while the Write Address Enable line is low. This is required to keep the input data to the RAM's from changing while the RAM address is constant. In other words, during the write cycle it is necessary to change both the RAM address and input data simultaneously. If this condition is not observed the input data will be lost. It can be noticed that each RAM has two outputs, and these are derived from four basic output lines. Two of these outputs are "wired-or" to make one main output. The output lines coming directly out of the RAM's can not be used to drive TTL logic. Therefore, a combination OR gate and 390 ohm pull-down resistor was used at each output. The usable data output lines are then DO1 through DO6.

4. Card Reader Decoder Circuitry

During the write-in cycle it is necessary to transfer the information contained on the input data card into the

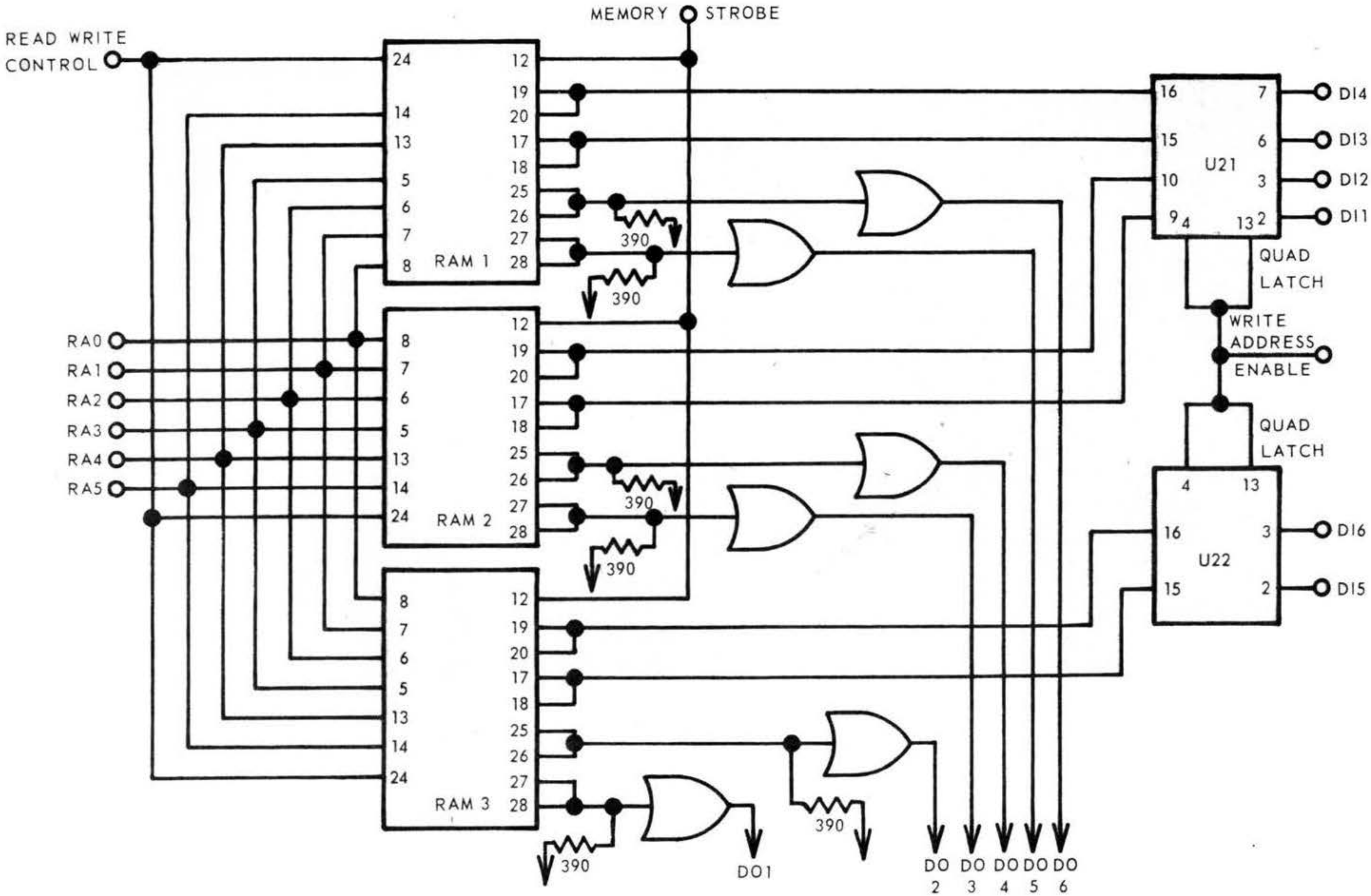

FIGURE 7. RAM INPUT/OUTPUT SCHEMATIC

random access memories. The card reader used is the type that accepts a data card and holds it. It does not contain its own clock, or any of the circuitry required to step through the columns of the data card. Therefore, it was necessary to build a circuit that was capable of accomplishing this. The circuit that was used is shown in Figure 8. In essence it is a one of sixty-four decoder; that is, it energizes one line out of sixty-four possible output lines depending upon the six bit binary input signal. The devices used are medium scale integration devices designated MC 4038 by Motorola. Each device is a one of eight decoder. Notice that the lines A0 through A5 are the six bit binary input to this circuit. These are the same lines that are used to address the RAM's during the write-in cycle. Therefore, as the RAM address is changed the decoder circuit steps to the next column of the card reader, and the data in that particular column if transferred into the random access memory.

The circuit operates as follows: A3, A4, and A5 are used to step U23 through its eight possible outputs. This device is wired to place a high on the selected output line. This high in turn enables one of the other eight possible decoders. This enabled decoder then is stepped through its eight possible outputs by the binary bits A0, A1, and A2. These eight output lines are connected directly to eight of the corresponding columns of the card reader.

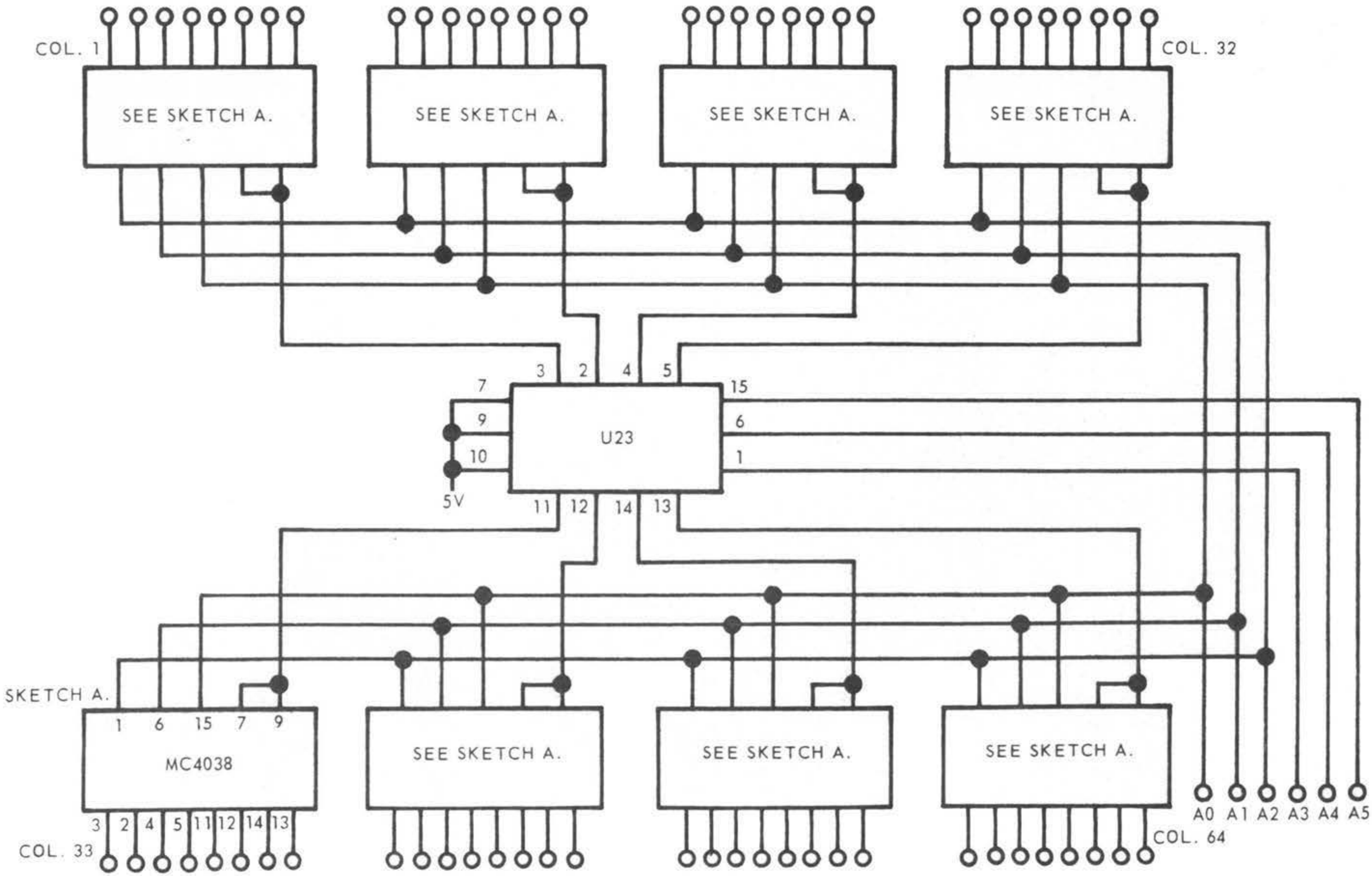

FIGURE 8. SCHEMATIC FOR CARD READER DECODER CIRCUITRY

The same process is repeated until all sixty-four of the data card columns are read. U23 is the only decoder that places a high on the selected output line; the other eight decoders place a low on it.

B. CHECKING CIRCUITRY

The checking circuitry is shown in Figure 9. U24 is a quad latch which accepts output data from the RAM's upon the application of a X1 strobe and a 40μs high level Basic Clock pulse at the input pins of U26. During the following explanation of this particular circuit please refer to Table III for a detailed listing of the ROM programming through address twelve, and to Appendix B for location of data on the input card. Assume that the input data has already been entered into the RAM's. Now, ROM address one is clocked, and the ROM's in turn address the RAM's to address one while also producing a XR strobe and a X1 strobe. This calls the information stored in RAM address one to the output pins of the quad latch, U24. The information is held here until another X1 strobe appears. Next, the ROM is clocked to address two; this action calls the information stored in RAM address sixty-one. Next, a XR and a XRAM strobe are produced. The XR strobe is the memory strobe and the XRAM strobe allows the NAND switching (This NAND switching is identical to that shown in Figure 6. In this case it is used to switch either RAM or ROM information

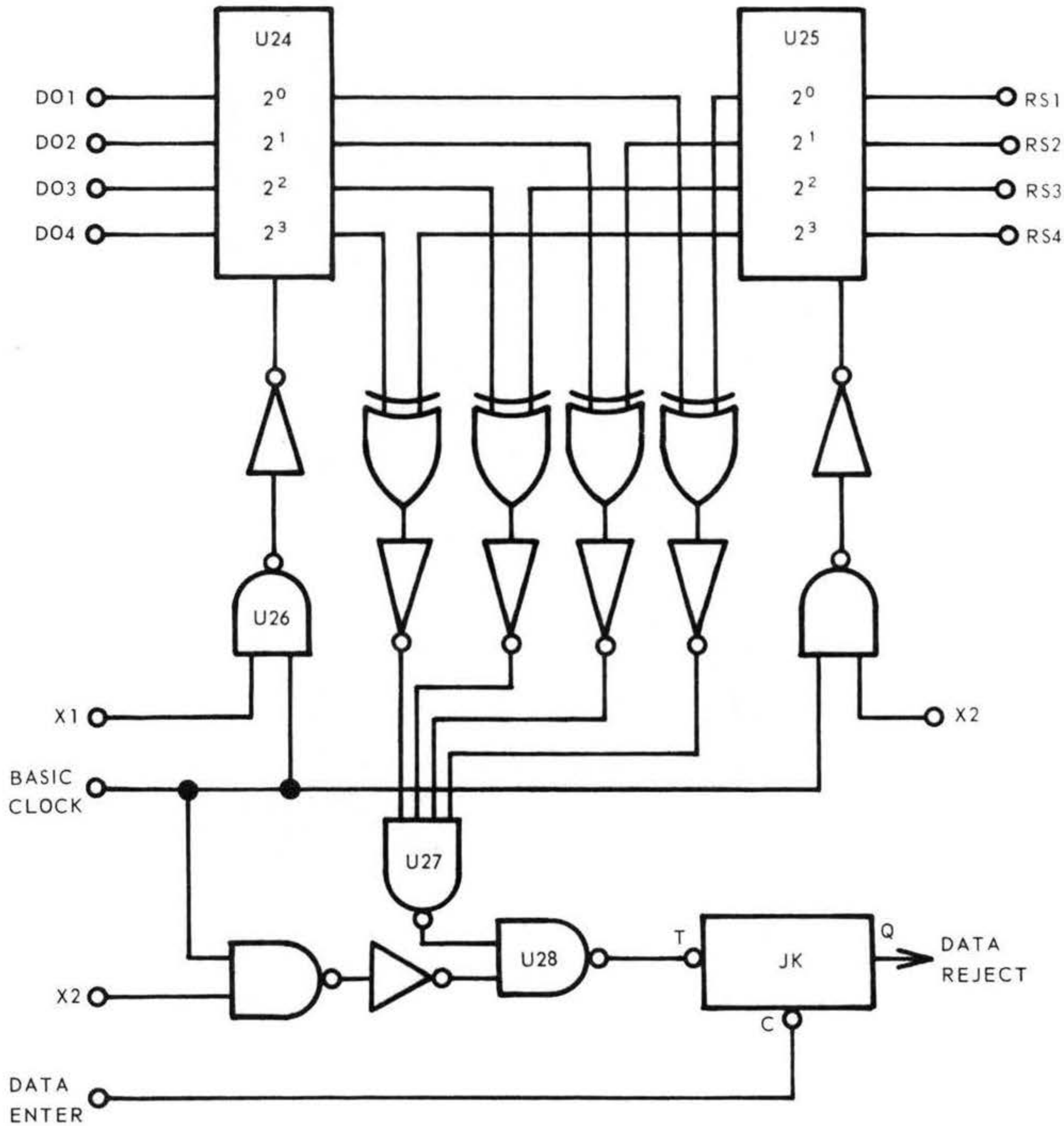

FIGURE 9. SCHEMATIC FOR DATA CHECKING CIRCUIT

into U25.) to pass the information on lines DO1, DO2, DO3 and DO4 (information stored in RAM address sixty-one) into the other quad latch, U25. At this same instant a X2 strobe is enabled, thus allowing the information to be passed to the output pins of U25 and held. This action, of course, must wait for a Basic Clock pulse before it can occur. At this time the information from column two and from column sixty-two of the input card are alternately in the input lines of the exclusive OR gates of Figure 9. These exclusive OR gates check the data bits against each other for identity. If the data matches the outputs of these gates are low. After passing through the inverters the signals are all high. This produces a low at the output of U27. This low holds the trigger line of the JK high and therefore it is not triggered. If, however any one of the outputs of the exclusive OR gates is high the output of U27 stays high and, therefore, as soon as a Basic Clock pulse appears the output of U28 goes low and the JK is triggered. This turns on the Data Reject light and provides an XMR reset pulse to all the necessary logic. So far the machine has checked the most significant digit of the Dispenser Number punched in column two of the input card against that in column sixty-two of the card. As long as no fault is found the electronics will continue in a similar manner to check the following: Dispenser Number least significant digit (LSD) punched in column three against Dispenser Number

TABLE III

ROM PROGRAMMING FOR FIRST TWELVE ADDRESSES

ROM 1

	ADDRESS						DATA							
												XMR	XROM	XRAM
NO.	A5	A4	A3	A2	A1	A0	C7	C6	C5	C4	C3	C2	C1	C0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
2	0	0	0	0	1	0	0	0	0	0	0	0	0	1
3	0	0	0	0	1	1	0	0	0	0	0	0	0	0
4	0	0	0	1	0	0	0	0	0	0	0	0	0	1
5	0	0	0	1	0	1	0	0	0	0	0	0	1	1
6	0	0	0	1	1	0	0	0	0	0	0	0	0	0
7	0	0	0	1	1	1	0	0	0	0	0	0	1	0
8	0	0	1	0	0	0	0	0	0	0	0	0	0	0
9	0	0	1	0	0	1	0	0	0	0	0	0	0	1
10	0	0	1	0	1	0	0	0	0	0	0	0	0	0
11	0	0	1	0	1	1	0	0	0	0	0	0	0	1
12	0	0	1	1	0	0	0	0	0	0	0	0	0	0

TABLE III - continued

ROM 2

	ADDRESS						DATA							
							X6	$\overline{PL2}$	$\overline{PL1}$	X5	X4	XP	X2	XS
NO.	A5	A4	A3	A2	A1	A0	C7	C6	C5	C4	C3	C2	C1	CO
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
2	0	0	0	0	1	0	0	0	0	0	0	0	1	0
3	0	0	0	0	1	1	0	0	0	0	0	0	0	0
4	0	0	0	1	0	0	0	0	0	0	0	0	1	0
5	0	0	0	1	0	1	0	0	0	0	0	0	1	0
6	0	0	0	1	1	0	0	0	0	0	0	0	0	0
7	0	0	0	1	1	1	0	0	0	0	0	0	1	0
8	0	0	1	0	0	0	0	0	0	0	1	0	0	0
9	0	0	1	0	0	1	0	0	0	0	0	0	1	0
10	0	0	1	0	1	0	0	0	0	1	0	0	0	0
11	0	0	1	0	1	1	0	0	0	0	0	0	1	0
12	0	0	1	1	0	0	1	0	0	0	0	0	0	1

TABLE III - continued

ROM 3

							X1	XR	B5	B4	B3	B2	B1	B0
NO.	A5	A4	A3	A2	A1	A0	C7	C6	C5	C4	C3	C2	C1	C0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	1	1	1	0	0	0	0	0	1
2	0	0	0	0	1	0	0	1	1	1	1	1	0	1
3	0	0	0	0	1	1	1	1	0	0	0	0	1	0
4	0	0	0	1	0	0	0	1	1	1	1	1	1	0
5	0	0	0	1	0	1	0	0	0	0	0	0	0	0
6	0	0	0	1	1	0	1	1	0	0	0	0	0	1
7	0	0	0	1	1	1	0	0	0	0	0	0	0	1
8	0	0	1	0	0	0	1	1	0	0	0	1	0	0
9	0	0	1	0	0	1	0	1	1	0	1	1	1	1
10	0	0	1	0	1	0	1	1	0	0	0	1	0	1
11	0	0	1	0	1	1	0	1	1	1	0	0	0	0
12	0	0	1	1	0	0	0	0	0	0	0	0	0	0

LSD punched in column sixty-three; the Dispenser Number LSD punched in column three of the input card with that permanently recorded in address five of the third ROM; the Dispenser Number most significant digit (MSD) punched in column two of the card with that permanently recorded in address seven of the third ROM; the MSD of the Syringe Location Number punched in column five of the input card with that punched in column forty-eight of the card; and the LSD of the Syringe Location Number punched in column six of the card with that punched in column forth-nine of the input data card. This completes the checking done in the Checking Circuitry; and the ROM input addressing has reached address twelve. At this position a X6 and a X5 strobe have been enabled. This application will be discussed further later in the paper. There are two basic reasons for including the Checking function in the machine electronics. The first is to eliminate any typing errors by making it necessary for the keypuncher to punch the Dispenser number and the Syringe Location Number at two different and distant locations on the input data card. These two numbers are very important since they determine which medicine a patient will receive. The additional check performed on the Dispenser number (that of comparing the number punched on the input card with that permanently recorded in the third ROM) is necessary to determine if the incoming data is meant for that particular Syringe

TABLE IV

PART NUMBERS OF LOGIC DEVICES USED IN SCHEMATICS

LOGIC FUNCTION	DEVICE NUMBER
DUAL NAND GATE	7400
FOUR INPUT NAND GATE	7420
EIGHT INPUT NAND GATE	7430
OR GATE	MC 3003
NOR GATE	7402
EXCLUSIVE-OR GATE	7486
INVERTER	7404
QUAD LATCH	7475
JK FLIP-FLOP	7473
COUNTER	7493 & 7473
MONOSTABLE	9601
ONE OF EIGHT DECODER	MC 4038
RANDOM ACCESS MEMORY	S1509
READ ONLY MEMORY	PROM-0512

Dispenser. In a large hospital there may be many Syringe Dispensers tied to the same input data line making it necessary to designate each one by a different number.

C. OVERALL OPERATION

During this part of the paper the inter-related operation of the circuitry shown in Figure 4 through 8 will be explained, so that the function of the complete circuit may be understood. Before the input data card is inserted the machine electronics can be in any one of three conditions; Data Reject, Failure, or normal. Upon insertion of the data card by pressing the Data Enter Switch a Data Reject or Failure mode is cleared out, thus returning the system to the normal "start" condition. One second after the input card is accepted by the card reader a Card Presence signal is received at U1 in the form of a high logic level. The write-in complete signal is originally high and the 1250 Hz clock is operating. This condition at the input of U1 causes the NAND gate to transfer the clock to the two monostable multivibrators, U2 and U3. These monostables are connected to trigger on the low going edge of the clock. The six bit binary counter is used to count the low going transitions of the 2μs one-shot, and to transform this information into acceptable addresses for the RAM's and the card reader decoder circuit. This address information appears on line A0 through A5. It is important to switch the Memory Strobe to -12 VDC before any changes are made in RAM addressing or input data. It is also necessary to switch the RAM address and input data simultaneously. And, of course, having the correct input data appear with its corresponding address is also a requirement. All of this is accomplished as follows. When the counter is triggered to a given address the same clock pulse triggers U2 sending the output high triggering U9. The output of U9 goes high turning off the 2N2905 transistor. This action applies the Memory Strobe of -12 VDC and lasting 115μs to pin 12 of each RAM. When U2 goes low after 60μs it triggers U4 which puts out a 115μs high level pulse. This pulse does two things. It connects lines A0 through A5 to the input of the quad latches U19 and U20 and simultaneously energizes these quad latches transferring the addressing data from their inputs to their outputs while the pulse is high and holding it at their outputs after the pulse goes back low. While the addressing data is being transferred and latched the input data from the card reader is simultaneously being transferred to the RAM inputs and latched via U21 and U22. Note that ever since the counter was clocked to the given address the Card Reader Decoder Circuit selected a corresponding card column and the input information was present at the inputs of U21 and U22. It is also interesting to note that for any given address the corresponding card column is one greater in value. Therefore, the information from column six will be found in RAM address five.

At this point the circuit has strobed the RAM's, then addressed them and connected the correct input data to their inputs. During the write-in cycle this procedure occurs 64 times. When address 63 is reached lines A0 through A5 are high. This causes the Write-in complete line to go low locking out any more clock pulses at U1. This concludes the write-in cycle. The first 64 columns of information on the input data card are now stored in the random access memories. At the moment when the Write-in Complete signal goes low it triggers the JK in U8. This switches the Read/Write Control line from a low to a high changing the RAM's from a write to a read mode.

Up to this point in circuit operation the read only memories have not been used and have been set on address zero. When the Write-in Complete lines goes low a six bit binary counter (not shown) begins to address the ROM's over lines A0 through A5. The ROM's now take over RAM addressing over the lines B0, B1, B2, B3, B4, and B5. The strict conditions noted above regarding the timing of the Memory Strobe and RAM address change must be followed during the read-out cycle just as they were followed during the write-in cycle. The circuit responsible for maintaining this timing is U10, U11 and U12. When it is necessary to call data out of the RAM's a XR strobe is put out by ROM 3 in the form of a high logic level. This high appears at one of the inputs of U10. As soon as a high level Clock Pulse signal arrives at the other input of U10 its output goes low triggering the monostable U11. The circuit function from this point on is similar to that during the write-in cycle. The only difference being that the ROM Address Enable line is actuated instead of the Write Address Enable line. This, of course, is the determining factor in the NAND switching operation, Figure 6, in order to address the RAM's over the lines B0 through B5 instead of A0 through A5. See Table III for data concerning the ROM generated XR strobe and B0-B5 information during the first thirteen ROM addresses.

VI. CONCLUSION

This paper has attempted to show a comtemporary method of bringing modern electronic technology to bear on the needs of medicine. The use of electronics in the medical field has been a much talked about subject during recent years, but actually it seems as though little has been accomplished and that which has is concentrated in the field of patient monitoring. The Syringe Dispenser represents a use of electronics in a field removed from patient monitoring, but still in medical electronics. There are many areas similar to this where electronic technology can be applied to solve the present problems being encountered by hospitals.

The system electronics for the syringe dispenser was built during November and December 1970, and was installed in the syringe dispenser in January 1971. The total system was operating correctly by the end of January with no major problems.

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VITA

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Mr. DeLargy is a member of Eta Kappa Nu, and the IEEE Circuit Theory Group.

APPENDIX A

ASCII-64 CHARACTER SUBSET CODING

Bit Value

2^5	2^4	2^3	2^2	2^1	2^0	Char.
0	0	0	0	0	0	@
0	0	0	0	0	1	A
0	0	0	0	1	0	B
0	0	0	0	1	1	C
0	0	0	1	0	0	D
0	0	0	1	0	1	E
0	0	0	1	1	0	F
0	0	0	1	1	1	G
0	0	1	0	0	0	H
0	0	1	0	0	1	I
0	0	1	0	1	0	J
0	0	1	0	1	1	K
0	0	1	1	0	0	L
0	0	1	1	0	1	M
0	0	1	1	1	0	N
0	0	1	1	1	1	O
0	1	0	0	0	0	P
0	1	0	0	0	1	Q
0	1	0	0	1	0	R
0	1	0	0	1	1	S
0	1	0	1	0	0	T
0	1	0	1	0	1	U
0	1	0	1	1	0	V
0	1	0	1	1	1	W
0	1	1	0	0	0	X
0	1	1	0	0	1	Y
0	1	1	0	1	0	Z
0	1	1	0	1	1	[
0	1	1	1	0	0	∿
0	1	1	1	0	1	]
0	1	1	1	1	0	Λ
0	1	1	1	1	1	_

Bit Value

2^5	2^4	2^3	2^2	2^1	2^0	Char.
1	0	0	0	0	0	b̸
1	0	0	0	0	1	!
1	0	0	0	1	0	"
1	0	0	0	1	1	#
1	0	0	1	0	0	$
1	0	0	1	0	1	%
1	0	0	1	1	0	&
1	0	0	1	1	0	'
1	0	1	0	0	0	(
1	0	1	0	0	1	)
1	0	1	0	1	0	*
1	0	1	0	1	1	+
1	0	1	1	0	0	,
1	0	1	1	0	1	-
1	0	1	1	1	0	.
1	0	1	1	1	1	/
1	1	0	0	0	0	Ø
1	1	0	0	0	1	1
1	1	0	0	1	0	2
1	1	0	0	1	1	3
1	1	0	1	0	0	4
1	1	0	1	0	1	5
1	1	0	1	1	0	6
1	1	0	1	1	1	7
1	1	1	0	0	0	8
1	1	1	0	0	1	9
1	1	1	0	1	0	:
1	1	1	0	1	1	;
1	1	1	1	0	0	<
1	1	1	1	0	1	=
1	1	1	1	1	0	>
1	1	1	1	1	1	?

APPENDIX B

INPUT DATA CARD FORMAT

CARD COLUMNS	INFORMATION
2	Dispenser Number Most Significant Digit (MSD)
3	Dispenser Number Least Significant Digit (LSD)
5	Syringe Location MSD
6	Syringe Location LSD
8-21	Patient's Last Name
22	Space
23-30	Patient's First Name
32-34	First Three Digits of Social Security Number
35	Hyphen
37-38	Two Middle Digits of Social Security Number
39	Hyphen
40-43	Last Four Digits of Social Security Number
48	Syringe Location MSD
49	Syringe Location LSD
62	Dispenser Number MSD
63	Dispenser Number LSD