AN ENCODER FOR A GRADE II BRAILLE TYPEWRITER

by

ROBERT J. DIRKMAN
B.S., Tufts University
(1958)

SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

at

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
May 21, 1960

Signature of Author Robert J. Dirkman
Department of Electrical Engineering, May 21, 1960

Certified by______________________________
Thesis Supervisor

Accepted by______________________________
Chairman, Departmental Committee on Graduate Students

AN ENCODER FOR A GRADE II BRAILLE TYPEWRITER

by

ROBERT JOHN DIRKMAN

Submitted to the Department of Electrical Engineering on May 24, 1960 in partial fulfillment of the requirements for the degree of Master of Science.

ABSTRACT

The Braille system of embossed dots is the conventional method of presenting published material to the blind. The present method for translating inkprint text into Grade II Braille requires a highly trained operator. The purpose of the thesis is to develop a typewriter-operated encoder which will facilitate this translation.

In the first chapter the Braille system is summarized, and the important factors which complicate the problem of designing a typewriter-to-Grade II Braille encoder are pointed out. Based on these considerations, the thesis objective is given.

To more completely define the problem, a summary of existing devices is presented. These devices include manually operated machines such as braillers, stereotypers, and modified standard typewriter systems; and automatic systems which are in effect either digital computer programs or special purpose digital systems. The uses, advantages, and disadvantages of these devices are discussed.

The functional requirements of the proposed system are then considered. An attempt is made to select a system which is a compromise between simple devices which demand highly skilled operators and very complex systems.

Based on these functional requirements, the basic design of the encoder system is developed. Emphasis is placed on the principles of operation of the various subsystems which comprise the encoder rather than their detailed design.

A chapter is devoted to the problem of selecting a suitable code and designing a simple matrix to generate it.

The final chapter suggests areas for future investigation. This includes the evaluation of the proposed system and the adaption of the basic design to other purposes.

Thesis Supervisors: Samuel J. Mason and Ronald J. Massa
Titles: Professor of Electrical Engineering and Instructor

ACKNOWLEDGMENT

The author is grateful to Prof. Sam Mason and Ronald J. Massa for consenting to supervise this thesis, and for their very helpful advise during its development.

The author is also indebted to D. N. Baumann, Instructor in the Department of Mechanical Engineering, whose invaluable suggestions and criticisms have been greatly appreciated; to Mr. John K. Dupress, Director of Technological Research of the American Foundation for the Blind, for much encouragement and inspiration; to Mr. Edward Waterhouse, Director of the Perkins School for the Blind, and the members of his staff for their enthusiastic discussions; and to the members of the Sensory Aids Research Group of the Research Laboratory for Electronics for their many excellent comments.

To my wife also goes much credit for her patience, constant encouragement, and tireless effort in typing this thesis.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I. THE PROBLEM DEFINED

The Braille system of raised dots is the conventional method of presenting published material to the blind. The purpose of this thesis is to develop a typewriter-operated encoder which will facilitate translation of published material to Grade II Braille. Since conventional methods of performing this translation require highly trained transcribers, such an encoder would be useful if the required operator's skill can be reduced.

The purpose of this chapter is to summarize the Braille system and to point out the factors which complicate the problem of designing such a device. Based on these considerations, the object of the thesis is discussed.

1.1 A summary of the Braille system

The Braille system, since its introduction in 1829, has been subject to careful study by various committees in an effort to produce a system which presents the greatest benefit to the blind. The evolution of Braille has been a very tedious process and countless revisions of the system have occured throughout its development. The accepted set of rules for Braille used for general literature at the present time is called Standard English Braille.(1)*

---

* Numbers refer to bibliography in Appendix D.

Standard English Braille is based on the "cell" which contains six embossed dots arranged in two columns as shown in Fig. 1.1.* There are 63 possible combinations of these six dots which are used to represent letters of the alphabet, numerals, punctuation marks, signs, common groups of letters, and whole words.

Several levels or "grades" of Standard English Braille are used:(1)

(1) Grade I Braille is uncontracted; a one-to-one correspondence exists between the letters of a standard inkprint text and its Braille counterpart.

(2) Grade II Braille is moderately contracted; a total of 185 contractions are employed. These contractions include words and common groups of letters which may be used as part-words.

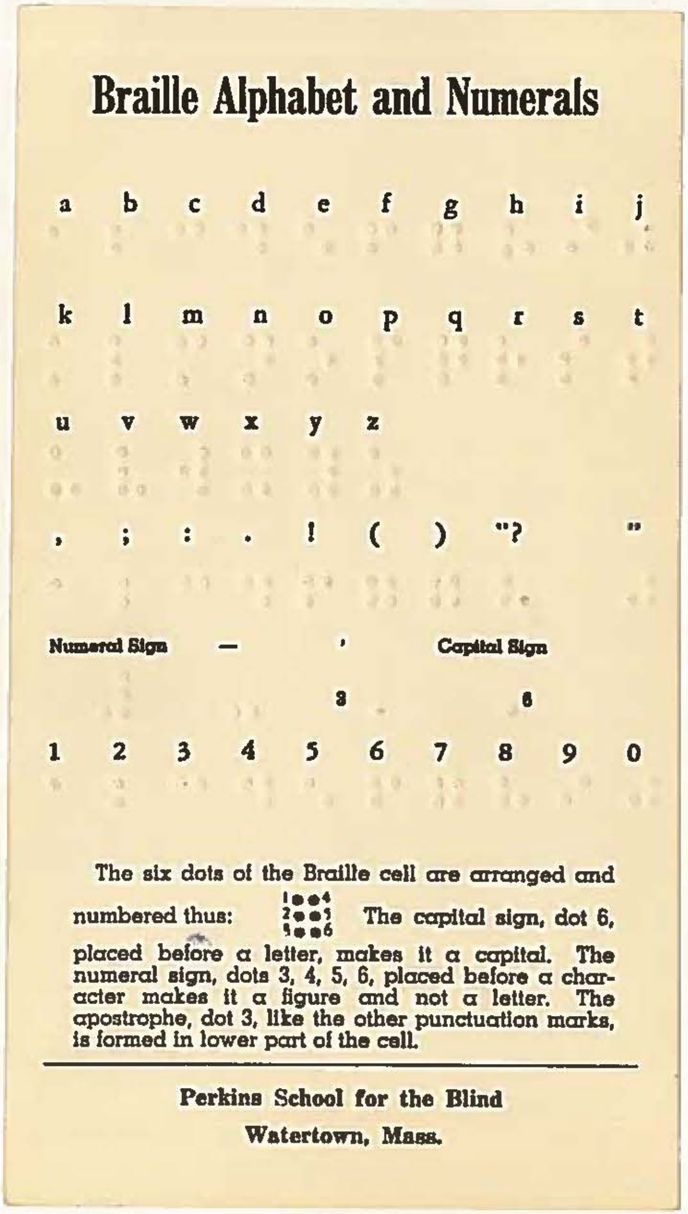
(3) Grade III Braille is a highly contracted form and has limited usage in applications where a shorthand notation is convenient.

Although strictly not a form of Standard English Braille, Grade One-and-a-Half Braille is used to a large extent for general publications.

The contracted forms of Braille result in space economy. For example Grade II Braille requires an average of 3½ cells per word as compared to 5 cells for Grade I Braille.

---

* Braille sample used by permission of the Perkins School for the Blind.



Braille Alphabet and Numerals

a b c d e f g h i j

k l m n o p q r s t

u v w x y z

, ; : . ! ( ) “? ”

Numeral Sign — ’ **Capital Sign**

3 6

1 2 3 4 5 6 7 8 9 0

The six dots of the Braille cell are arranged and numbered thus: 1 ● ● 4 / 2 ● ● 5 / 3 ● ● 6 The capital sign, dot 6, placed before a letter, makes it a capital. The numeral sign, dots 3, 4, 5, 6, placed before a character makes it a figure and not a letter. The apostrophe, dot 3, like the other punctuation marks, is formed in lower part of the cell.

Perkins School for the Blind
Watertown, Mass.

Fig. 1.1 A Sample of Embossed Braille

1.2 A description of Grade II Braille

The transcription of text to Grade II Braille is complicated by the contractions and the numerous rules regarding their use. For example, it is possible to transcribe the word "gathered" three ways: gather/ed,* gathered, and gathered. Only one of these, gathered, is however in accordance with the rules.(1)

The contractions may be classified as follows:(1)

(1) Abbreviated words have no special Braille signs to express them, but they are always abbreviated and are represented by certain letters only. For example the word "afterward" is always denoted by the Braille signs for the letters "afw" in Grade II Braille. The abbreviated words require from 2 to 5 cells for their representation.

(2) Word signs are one or two-celled contractions which may be used as whole words. In general the Braille symbol for the first letter of the word is often used as, for example, "j" for "just".

(3) Initial contractions are two-celled contractions which may appear either as words or as part-words.

(4) Final contractions are two-celled contractions which may not be used as whole words or as the beginnings of words. Examples are "ation" and "ence".

(5) Other one-celled contractions may be used as whole words or part-words.

---

* Groups of letters which are underlined are contracted.

Of the 185 contractions, 73 are abbreviated words. The contractions and the other symbols used in Grade II Braille are included in Appendix A. Note that with the exception of the abbreviated words, the contractions require either one or two cells.

The rules regarding the usage of the contractions of Grade II Braille are complicated and the exceptions to the rules are many. The examples listed are typical:(1)

(1) Some contractions may not overlap well-defined syllables. For example the one-celled contraction "of" may be used in "s<u>of</u>t" but not in "profound".

(2) Certain contractions are preferred to others whenever two possibilities occur. As an example the contraction "ea" is properly used instead of "ar" in the word "<u>ea</u>rth".

(3) Some contractions may not be used if the pronounciation of the group is affected. The contraction "under", for example, may not be used in the word "launder".

1.3 <u>Thesis objective</u>

The objective of this thesis is to develop an encoding system which will facilitate the translation of text into Grade II Braille. This grade is chosen specifically since it is the conventional form for published material. Because the Braille authorities are reluctant in general to modify the rules of Braille, the device must be capable of producing Grade II Braille exactly. Possible encoding techniques should receive careful consideration so that the proposed system is simple and inexpensive.

II. A DESCRIPTION OF EXISTING DEVICES FOR PRODUCING BRAILLE

The various devices for producing Braille cover a wide range of complexity. For example the simplest device, the slate, is merely a guide plate which is clamped to the paper, and the embossing is done by forming the proper dots manually with a small tool. At the other extreme, the IBM 704 computer has recently been programmed to automatically translate inkprint to Grade II Braille.(2)

To more completely define the problem of designing a Grade II Braille encoder, a summary of some of the existing devices, their uses, advantages, and disadvantages, is presented in this chapter. These devices are divided catagorically into those which are manually operated and those which are automatic.

2.1 Manually operated devices

2.1.1 Braillers and stereotypers

The most common device, excluding the slate, for embossing a single copy of Braille text is the brailler. This machine has six keys, one corresponding to each dot of the Braille cell, and a space bar. By depressing the proper combinations of the six keys simultaneously, an embossing head forms a complete Braille cell directly on the paper. The two most commonly used braillers in this country are the Perkins Brailler,(3) made at the Perkins School for the Blind, and the Hall Braillewriter,(4) manufactured by the American Printing

House for the Blind. The brailler, which is designed specifically for use by the blind, is a great improvement over the slate. The mechanical speed of the device is quite high; The Perkins Brailler, for example, can produce up to seven cells per second.* Any grade of Braille can be produced on the device depending on the needs of the operator.

The stereotyper(5) is related to the brailler in that it also has six keys. The stereotyper is used to emboss zinc plates for printing Braille and, hence, is operated by the sighted.

Both of these devices have several disadvantages. First the operator must be an expert in the rules of Braille and must know the Braille code for the alphabet, contractions, and abbreviated words. Secondly the operator is required to depress up to six keys simultaneously rather than only one key as with a standard typewriter. Because of these two requirements, it typically requires nearly two years to train a stereotyper operator.**

2.1.2 Modified standard typewriters

One disadvantage of the brailler can be eliminated by devising a system in which only one key need be depressed to

---

* From a discussion with Mr. David Abraham, Chief Engineer, Howe Press, Perkins School for the Blind.

** From a discussion with Mr. Waterhouse, Director of the Perkins School for the Blind.

form the complete Braille cell. A standard typewriter has been used in several systems for producing Braille.

John Wheeler of IBM has developed a system for producing any grade of Braille by employing a standard IBM electric typewriter and a diode matrix.(6) Since a typewriter has only 44 keys and the Braille system employs 63 possible characters, a special switching arrangement was necessary. This was accomplished by inverting two columns of the Braille cell when the shift key was depressed. Although this arrangement eliminates one disadvantage of the brailler, the operator must still be expert in the Braille code.

A typewriter system which will emboss Grade I Braille is presently being developed by the Department of Mechanical Engineering of MIT under the supervision of Dwight Baumann. This system can be operated by an ordinary typist with little additional training and will be useful in businesses which employ the blind. In addition to the Braille copy, a standard typewritten copy will be simultaneously produced.

2.2 Automatic devices

Automatic devices for producing Braille are necessarily much more complex than the manually operated machines. The methods described represent either special purpose digital systems or computer programs.

A switching circuit arrangement to translate teletypesetter punched tape to Grade I Braille is being developed by Friberger of the Veterans Administration.* Teletypesetter tape is punched by a linotype machine simultaneously as it sets type to be used for printing. Since these tapes are ordinarily discarded after use, they can be used to make available a considerable amount of literature which otherwise would be impossible. One disadvantage is the fact that the resulting output is not Grade II Braille.

Several attempts to automatically produce Grade II Braille have involved computer programs. IBM has programmed the 704 computer to translate teletypesetter tape to Grade II Braille.(6) The output, also on magnetic tape, is used to emboss zinc plates on a specially designed embossing machine. Abraham Nemeth of the University of Michigan is developing a similar program for the IBM 650 computer.**

A special purpose computer, which has been developed by David Milne, a 17 year old high school student from San Diego, California, produces a contracted form of Braille.(7) This device has been named the Beta Braille Electronic Translator Automatic.

---

* From a discussion with Dr. Eugene Murphy, Director of the Department of Prosthetics, Veterans Administration.

** From a discussion with Mr. John Dupress, Director of Technological Research, American Foundation for the Blind.

III. FUNCTIONAL REQUIREMENTS OF THE PROPOSED SYSTEM

From the preceding chapter, it is evident that the existing devices for producing Grade II Braille fall generally into two distinct categories:

(1) relatively simple devices which require a skilled operator highly trained in the Braille system, and

(2) highly complex systems such as general purpose computers which eliminate the need for a specially trained operator.

This grouping is possible because in the second category the memory of the operator is replaced entirely by the system resulting in a large increase in its complexity.

The proposed system is intended to be a compromise between these two categories. The complexity of the system increases as the skill demanded of the operator decreases. It is the purpose of this chapter to define the requirements of the system and the requirements of the operator so that the resulting system is reasonably inexpensive and a minimum of training is required of the operator.

For convenience the system will be considered in three parts: the input, the encoder, and the output.

3.1 Possible approaches to the problem

In the operation of the brailler and the other simple devices which produce Grade II Braille, the operator must make several decisions before forming a cell. The following questions must first be answered:

(1) Is the word an abbreviated word?

(2) Does the letter normally form part of a contraction?

(3) Are there any rules which forbid the use of the contraction in this particular word?

(4) What is the Braille symbol for the abbreviated word, contraction, or letter?

The required complexity of the automatic systems for producing Grade II Braille is primarily a consequence of the first three questions. For instance, to answer the third question, it is necessary that the system contain in storage some form of a list of words which are exceptions to the rules of Standard English Braille. Otherwise it would be impossible, using ordinary digital system techniques, to forbid, for example, the use of the contraction <u>under</u> in the word <u>launder</u> because the sound of the contraction has changed.

To devise a relatively inexpensive system which does not require the usual skill of a trained operator, two approaches are possible in view of the preceding discussion. One approach would be to modify the rules of Braille so that the translation would be more amenable to ordinary digital techniques. The other would be to eliminate the need for the operator to know the Braille symbols, but only to recognize when contractions and abbreviated words should properly be used.

There is much to be said for both approaches. The first would be very desirable if a considerable reduction in required equipment would result and if the modifications of the rules would be acceptable to both the Braille authorities and the blind. Such an approach would require careful consideration of the rules of Braille and the increased difficulty in reading Braille as a consequence of changing these rules. The second would be desirable if a reliable and economical system could be developed which would result in substantially less operator skill than existing devices demand. The proposed system is based on this second approach.

3.2 Input equipment requirements

An obvious choice for the basic input device is the standard typewriter. Considerable advantage can be taken of the fact that typing is a very common skill if the operation of the input equipment is designed to deviate as little as possible from standard typing procedure. Further advantage is gained from this choice since a typewritten copy of the material would be available for proofreading.

It is necessary, of course, to supplement the standard typewriter so that it can provide the proper form of information to the encoder. This would require some arrangement of switches associated with each typewriter key. Care should be taken in designing the encoder to insure that a typewriter can be conveniently modified to accomplish this purpose.

In addition some auxiliary means is required to indicate that a group of letters forms a contraction. This could be accomplished by employing an additional switch, such as a foot pedal, which is depressed, for example, as a group of letters which comprise a contraction is typed. By using this additional switch, or contraction key, the operator is in effect signifying that the letters which are being typed are to be considered collectively as a single input determining the proper Braille symbol. As an example the word "complete", which requires six Braille cells, would be formed by using the contraction key for the contraction "com" and then typing the letters "plete" without using the contraction key.

In determining the required speed of the encoder and the output equipment, the maximum typing speed must be chosen. Sixty words per minute seems to be a reasonable choice for this maximum since this value is the typical speed achieved by an average typist. The use of the contraction key will tend to slow the operator down somewhat.

3.3 Encoder requirements

The encoder is a digital system whose purpose is to provide the proper Braille symbol or symbols to the output device in accordance with the input signals. In general the encoder should be reliable, inexpensive, simple, and should be easily reproducible.

The nature of the Braille output of the encoder poses two problems which require consideration. The first is in regard to the method in which each Braille cell is read out of the encoder and the second involves the maximum number of cells which are produced for each separate input.

Each Braille cell is essentially a six digit binary number. It is possible for the encoder to provide this number in two different ways: sequentially so that one digit follows the next in time; or simultaneously by using six separate parallel channels, one for each digit. Because of the simplicity which the second method lends to the readout operating of the encoder, as discussed in the next section, this scheme is chosen. The encoder then requires six separate channels.

In the Braille system each letter of the alphabet is represented by one cell. A contraction, however, may require either one or two cells, and an abbreviated word, from two to five cells. If a contraction or abbreviated word is considered to be a single input, as is essentially the case when the contraction key is used, then the encoder must be designed to produce more than one Braille cell for a single input. Several factors must be considered in choosing the maximum number of cells which can be generated by each input.

The complexity of the encoder will be reduced if the operation is the same regardless of the number of cells corresponding to a single input. For example, if the encoder is designed to produce a maximum of five cells, it would simplify the encoder design to consider every output to consist of five cells; some of these would include cells containing no dots. If this scheme is used, however, the encoder and the output equipment must be capable of producing five Braille cells in the time required for each input. Either the encoder and the associated output equipment must be operated at excessive speed (25 cells per second for a typing speed of 60 words per minute) or the rate of the information input must be decreased.

Since the maximum number of cells required for any contraction is only two and since the abbreviated words, which require from two to five cells for a single input, can be formed by typing logical groups of single letters such as "abv" for "above", the choice of two cells as a maximum output for a single input seems to be a reasonable selection. The contraction key would then be used only when a contraction is typed; an abbreviated word would be formed by typing the letters comprising the abbreviation without employing the contraction key. The encoder must then be capable of producing an average of 10 cells per second to be consistent with an input speed of 60 words per minute.

The memory of the encoder must contain the alphabet, numerals, contractions, excluding the abbreviated words, punctuation marks, and the miscellaneous signs peculiar to Braille. This includes a total of 163 entries which are listed in Appendix B.

3.4 Output equipment requirements

The output device may be either an embossing mechanism which forms the dots in the Braille cell directly or some form of recording equipment. Although it may seem convenient to produce the Braille in a form directly usable by the blind, several advantages result from the use of punched tape.

First the tape can be used to operate a variety of secondary devices to produce the embossed Braille. These include plate-embossing machines similar to the stereotyper for automatically producing zinc plates suitable for printing Braille,(2) automatic braillers which can make one or several embossed copies of the recording,* or Braille reading machines which reproduce temporarily the Braille code recorded on punched tape.(6) Each of the above devices have been developed, and presently an effort is being made to improve them.

It would be desirable if errors can be easily corrected. Since a typed copy of the material is available for proofreading, a punched tape would be advantageous since corrections can be easily made before the tape is used as an input to the auxiliary devices described above.

---

* From a discussion with Mr. Waterhouse.

IV. THE ENCODER SYSTEM

In this chapter the basic design of the encoder system is presented. The essential processes involved in a permanent-storage memory encoding system are described, and the proposed system operation is considered with reference to this description. In particular careful consideration is given to the process of coincidence detection.

Emphasis has been placed on the principles of operation of the various subsystems which comprise the encoder rather than on their detailed design. This chapter by no means represents a completed design of the encoder but rather a functional description on which such a design can be based. Various techniques have been carefully considered so that the overall system is simple and inexpensive.

4.1 The essentials of a permanent-storage memory encoder

There are two different types of systems which lend themselves to encoding: switching circuit systems and permanent-storage memory systems. In a switching circuit system, the encoded output is generated by the input code. The input manipulates suitable switching elements, such as relays or diodes, in a network to produce the output. In a permanent-storage memory system, the encoded output is selected from a table of possible outputs by the input. In such a system the members of the table are examined until the desired output is found.

The essential components of a permanent-storage memory encoder are shown in Fig. 4.1.(8) The purpose of the system is

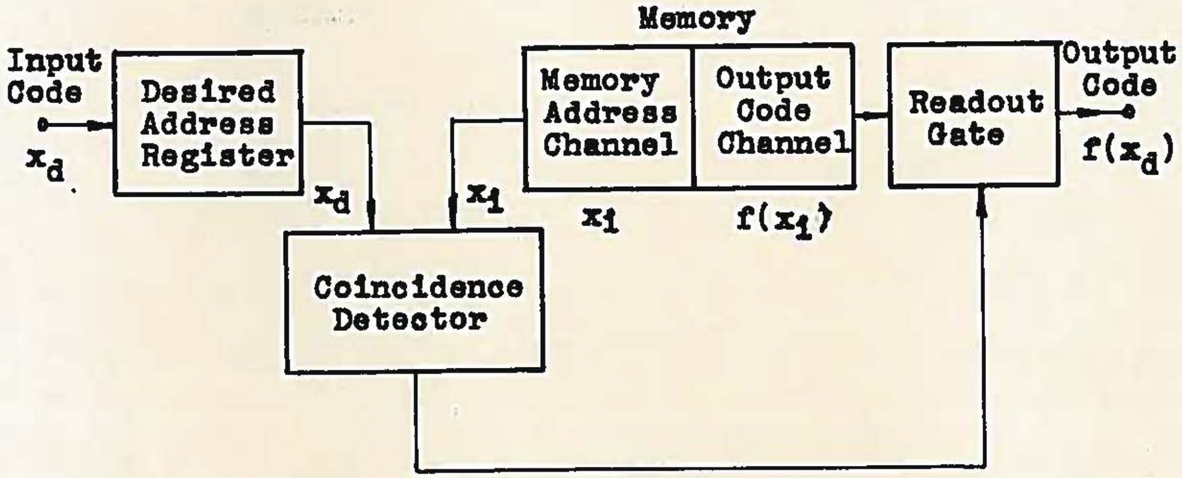


Fig. 4.1 Essentials of a Memory System

to select the output code, $f(x_d)$, corresponding to desired input code, x_d. This input code is temporarily stored in the desired address register and sequentially compared to the addresses, x_i, in the memory, each address corresponding to an output code $f(x_i)$. When x_d and x_i are identical, the coincidence detector operates the readout gate and allows the desired output code, $f(x_d)$, to be read out of the memory.

4.2 Choice of a memory system

In chapter III the encoder requirements were discussed. These are briefly summarized.

(1) In general the encoder must be reliable, inexpensive, and simple.

(2) The encoder requires six separate channels for the output corresponding to each dot in the Braille cell.

(3) The encoder must be capable of producing two Braille cells for each single input. A single input implies either a single typewriter key is depressed, or several are depressed while the contraction key is used.

(4) The memory must contain 163 address words.

(5) The encoder speed must be consistent with an input speed of 60 words per minute.

A variety of memory systems are possible for use in the encoder. A photographic memory system was chosen because a design is possible which satisfies all of the above requirements.

An encoder based on a photographic memory arrangement can be made quite inexpensively. Ordinary photographic techniques can be used for reproducing the memory. A unique optical system can be designed without requiring lenses, and a variety of photodetectors are available for converting light signals into electrical signals.(9)

4.3 Principle of encoder operation

4.3.1 A brief description of the encoder

A sketch of the arrangement of the basic components of the memory is shown in Fig. 4.2. The memory element is a constant-speed rotating photographic disc containing information in the form of transparent and opaque areas stored in concentric tracks. These tracks form two channels, one containing the addresses and the other the output code.

The basic operation is summarized:

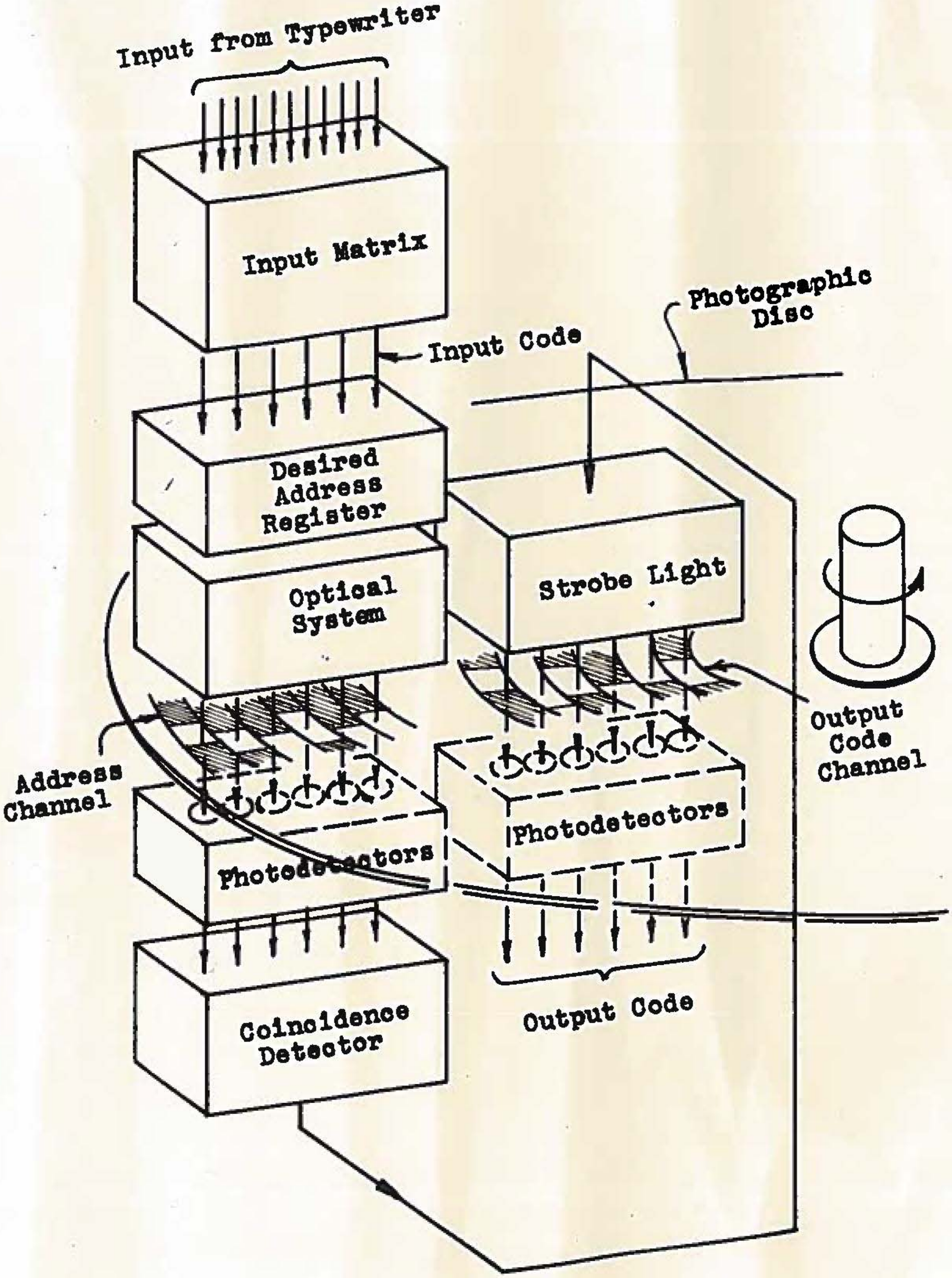


Fig. 4.2 The Basic Arrangement of the Photographic Memory

(1) Switches associated with the keys of the typewriter are used to generate with the input matrix an appropriate input code.

(2) This code is temporarily stored in the desired address register in the form of light sources.

(3) An optical system is necessary to focus the light sources through the tracks onto photodetectors.

(4) The coincidence detector determines when an address on the disc coincides with the address stored in the desired address register.

(5) When coincidence occurs a strobe light is flashed, reading out the desired output code stored on the disc through appropriate photodetectors.

4.3.2 Coincidence detection

A coincidence detector compares two binary numbers and produces a signal if, and only if, they are identical. The principle of operation of such a device can be seen by considering the logical operations which must be performed in detecting this equality.

Coincidence between two binary variables, x and y, is given by the logical expression:(8)

$$C = xy + x'y' \qquad (4.1)$$

where the prime denotes the complement of the variable. The validity of this relation can be established by considering Table 4.1. From this it can be seen that $C = 1$ only if either both $x = 1$ and $y = 1$, or both $x = 0$ and $y = 0$.

x	y	x'	y'	xy	x'y'	C
0	0	1	1	0	1	1
0	1	1	0	0	0	0
1	0	0	1	0	0	0
1	1	0	0	1	0	1

Table 4.1 Coincidence Between Two Binary Numbers

Consider two binary numbers of N digits each which are to be tested for coincidence. If these two numbers are identical then every digit of one number must be identical to the corresponding digit of the other number. Then to detect total coincidence between the two number, Eq. (4.1) must be applied to each of the N pairs of corresponding digits of the two number, x_i and y_i, and the "AND" operating must be applied to the resulting N variables, C_i. This combined operation is expressed in logical notation by the following two equations:

$$C_i = x_i y_i + x'_i y'_i \qquad (4.2a)$$

$$C_t = C_1 C_2 \cdots C_i \cdots C_N \qquad (4.2b)$$

For the two numbers to be identical then C_t must be 1, otherwise they are not equal.

The specific method by which coincidence is detected between the binary number stored in the desired address register and the corresponding number in the address channel of the photographic disc is considered in the following paragraphs.

A method is proposed and, by making the proper identifications, is shown to satisfy the operations defined by Eqs. (4.2a) and (4.2b).

Storing a number in the desired address register corresponds to turning on appropriate light sources. Suppose that two light sources are used for each digit in the register such that one is the complement of the other. For convenience call these light sources source #1 and source #2. Then when source #1 is on, source #2 will be off, and vice versa. Suppose also that corresponding to each light source there are two tracks, track #1 and track #2, on the photographic disc. These two tracks are also complements; when track #1 is transparent track #2 is opaque, and vice versa.

Further consider the following notation:

Let x denote the state of light source #1;

if $x = 1$ then source #1 is on,

if $x = 0$ then source #1 is off.

Then x' will denote the corresponding state of light source #2.

Let y denote either an opaque or a transparent area on the photographic disc;

if $y = 1$ then the area on track #1 is transparent,

if $y = 0$ then the area on track #1 is opaque.

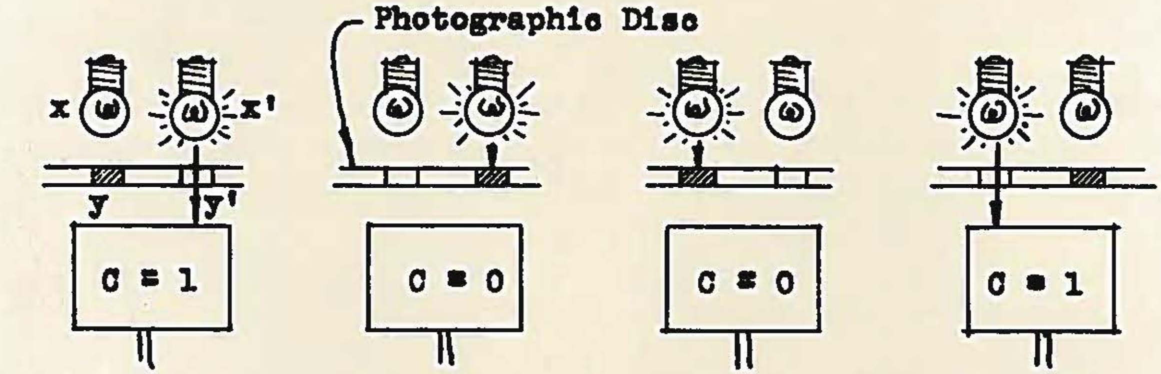
Then y' will denote the corresponding state of track #2.

Also let C denote either the presence or absence of light incident on the photodetector;

if C = 1 then light is present,

if C = 0 then light is absent.

There are four possible configurations involving the light sources and the photographic disc. These are shown in Fig. 4.3. Table 4.2 corresponds to these four configurations using the notation displayed above. A comparison of Tables 4.1 and 4.2 demonstrates that by using two light sources and two tracks on the disc for each digit in the manner described above, the first step in detecting coincidence is indeed accomplished.



(a) $x = 0$, $y = 0$ (b) $x = 0$, $y = 1$ (c) $x = 1$, $y = 0$ (d) $x = 1$, $y = 1$

Fig. 4.3 Possible Configurations of the Address System

x	y	x'	y'	C
0	0	1	1	1
0	1	1	0	0
1	0	0	1	0
1	1	0	0	1

Table 4.2 Address System Relations

If two corresponding digits in the register and on the disc are identical, then the related photodevice will be excited. For total coincidence between the two numbers, it is necessary for all N photodetectors to be simultaneously excited. This second step can be accomplished by using a multiple "AND" gate.

4.4 Components of the basic encoder

4.4.1 The desired address register

The desired address must be temporarily stored while it is being compared with the binary numbers in the address channel of the photographic disc. In Section 4.3.2 it was shown that the coincidence detection could be performed very simply if in addition to each digit, its complement is stored.

This can be accomplished by using a bistable multivibrator with two ordinary six volt incandescent lamps in the collector circuits. Unsymmetrical triggering is used since the flip-flop must be set only once though several input signals may occur. The multivibrator must be reset after the output code has been read.

4.4.2 The optical system

The required precision of the optical system is dictated by the storage density of the information on the photographic disc. A system of lenses can be designed to properly focus the light on the channels, but such a system tends to be expensive, especially if a large number of channels is necessary. A simpler less elaborate method is desirable.

A unique "light-pipe" optical system, based on the reflection of light, can be incorporated into the encoder design. The light-pipe is simply a tapered transparent plastic tube with polished surfaces so designed that all light entering the large end is reflected down the tube and emitted from the small end. The design is based on the principle that light, in passing from one transparent medium into another with a smaller index of refraction, will be totally reflected back by the surface if the incident angle is greater than some critical angle. A paraboloid can be constructed of clear plastic on this basis so that it effectively focuses light on a small area. A sketch of the optical system for a single digit in the address channel is shown in Fig. 4.4, and the details of the design are considered in Appendix C.

The advantages of this arrangement over a lens system are apparent:

(1) The light-pipe can be molded in quantity of a clear acrylic plastic such as plexiglas at low cost.

(2) Mounting requirements are less critical than a lens system would impose. Initial alignment of the light-pipes can be made quite simple if the mount is properly designed.

(3) The shape of the light-pipe allows two adjacent tracks on the disc to be closely spaced resulting in a more compact arrangement of information.

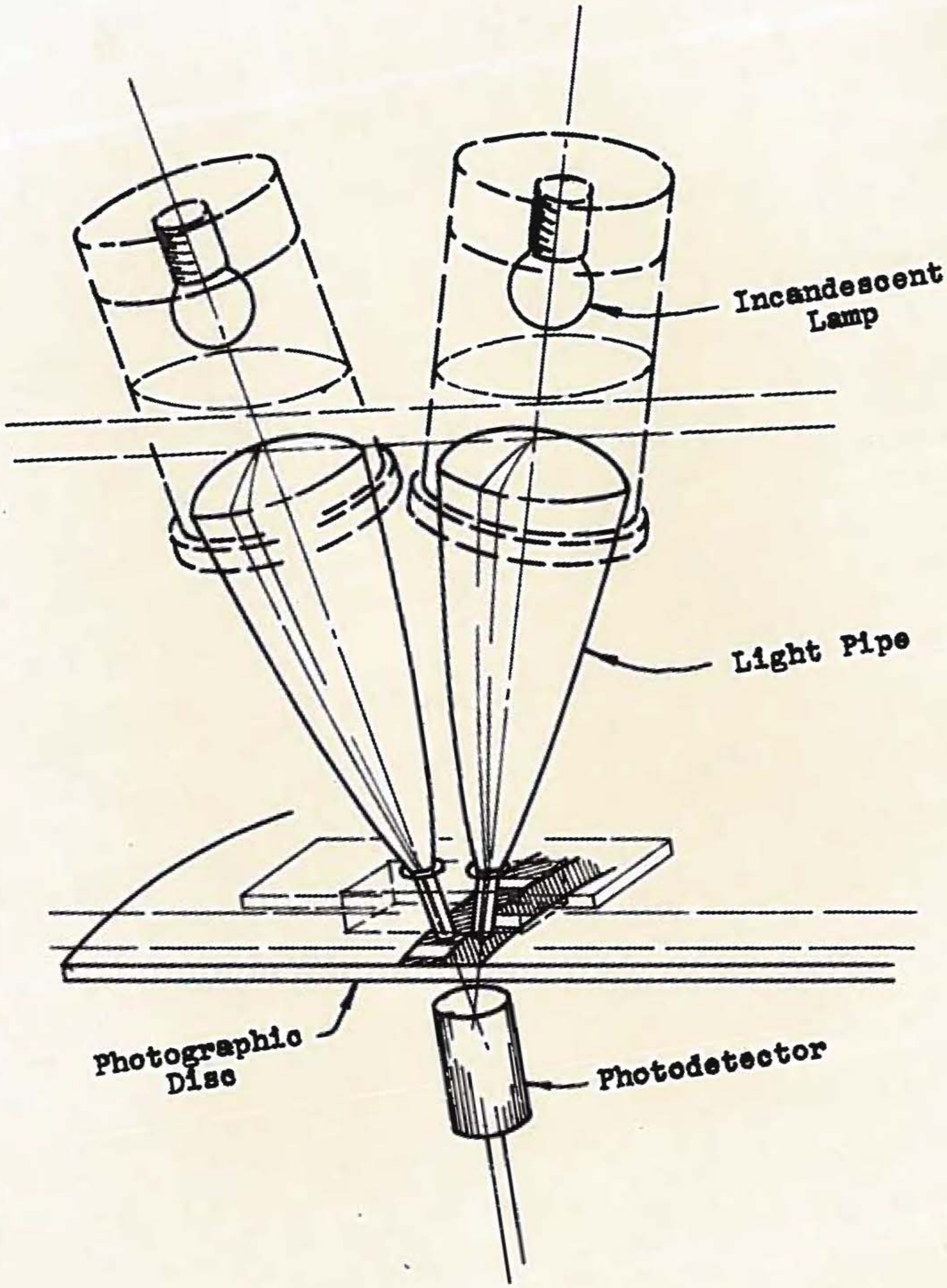


Fig. 4.4 "Light-Pipe" Optical System

4.4.3 The photographic disc

In this section the arrangement of information on the photographic disc is considered. This information is stored on concentric tracks in the form of transparent and opaque areas. The address channel contains the input code which identifies the two-celled Braille symbols stored in the output channels.

The two Braille cells are produced sequentially. Two methods are possible:

(1) The first cell may be read out during one revolution of the disc and the second on the following revolution, the same address position being used for both of the cells.

(2) Both cells may be read out during one revolution from the same channel, two address positions being necessary.

The second method requires twice as many address code numbers along the circumference as the first. Since the storage density in the tracks of the address channel is a critical factor, the first method is preferable. The disc then contains one address channel and two separate Braille output channels.

Each digit in the address code requires two adjacent complementary tracks as shown in Fig. 4.5. Because of the nature of the method of coincidence detection, it is useful to arrange the address code numbers on the disc so that as few corresponding digits as possible change in each successive number. It is then advantageous to use a nonreturn-to-zero type of storage when the consecutive digits of the address

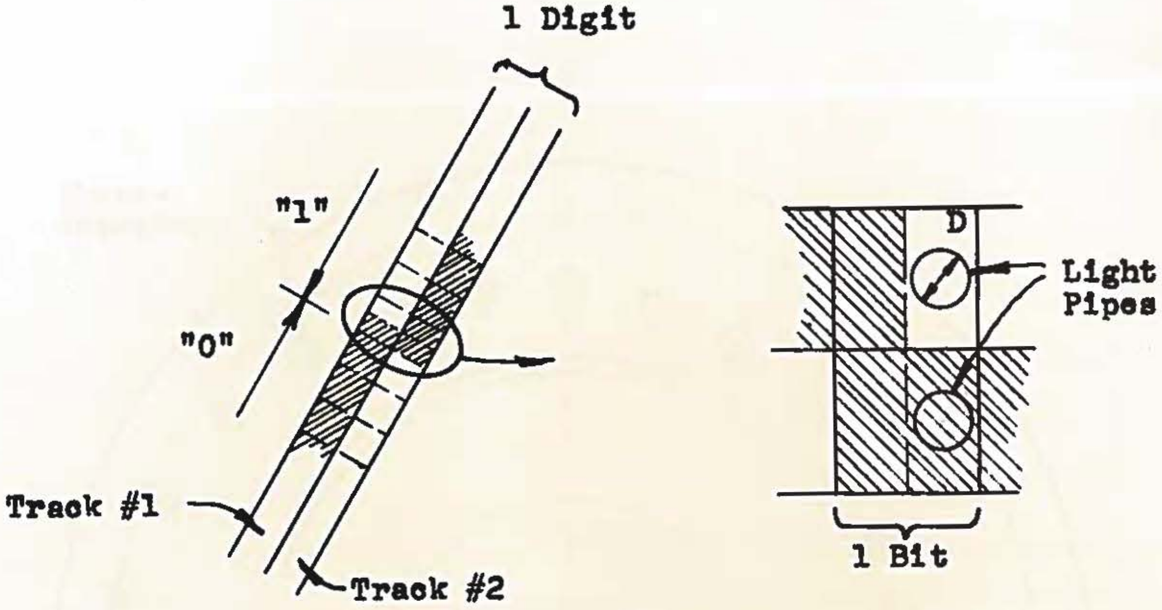


Fig. 4.5 Address Channel Tracks for a Single Digit

numbers do not change. This implies that one track is completely transparent and the other opaque as shown. When a digit does change however, both light-pipes must be blocked off so that both are not exposed to a photodetector simultaneously. This is done as indicated by the enlarged sketch of a single bit on the track. Notice that the diameter of the small end of the light-pipe is less than half the width of a bit.

Fig. 4.6 is a drawing of a possible layout of the disc. Several pertinent features of the design should be noted:

(1) The address channel is outermost on the disc since the tracks are more critical than on the Braille output channels.

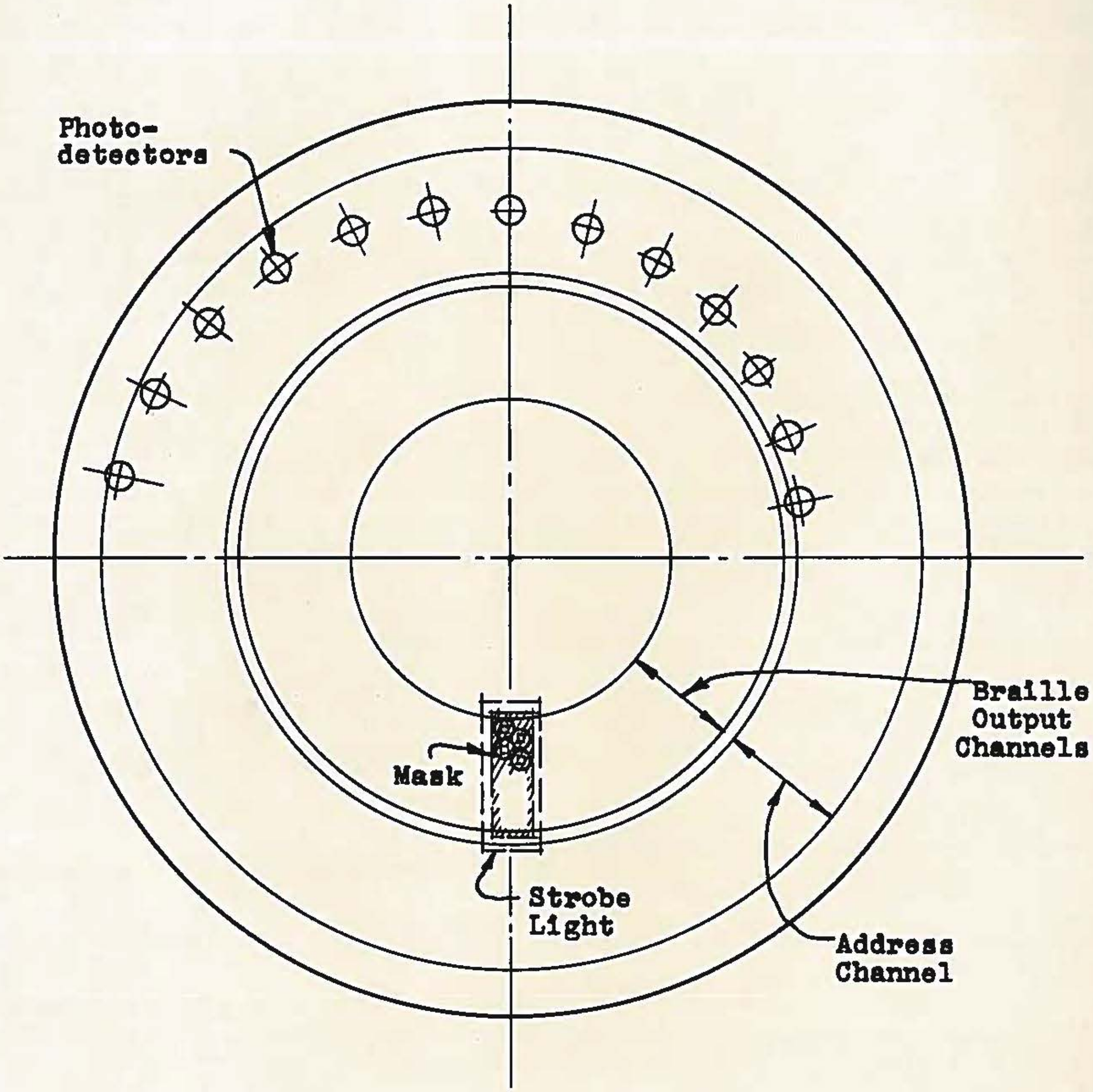


Fig. 4.6 Possible Photographic Disc Layout

(2) Digits associated with the same address number are not radially aligned since space must be provided for the light-pipes.

(3) Both Braille output channels are read out with only one strobe light through six different photodetectors. This requires staggering the photodetectors and providing a masking arrangement as indicated.

4.5 The timing system

The timing of the system is a very important aspect of the encoder design. The following sequence is necessary for each character or contraction that is encoded:

(1) The appropriate light sources in the desired address register are set according to the input code.

(2) The coincidence detector becomes operative when the rotating disc reaches a reference position.

(3) During the first revolution of the disc, the first Braille cell is read out through a set of six photodetectors.

(4) During the next revolution, the second cell is read out through a different set of photodetectors.

(5) When the disc has made exactly two revolutions, the coincidence detector becomes inoperative, and the desired address register is reset to receive the next input code.

A timing system for accomplishing these steps is shown in Fig. 4.7.

(1) A reference light is turned on simultaneously as the light

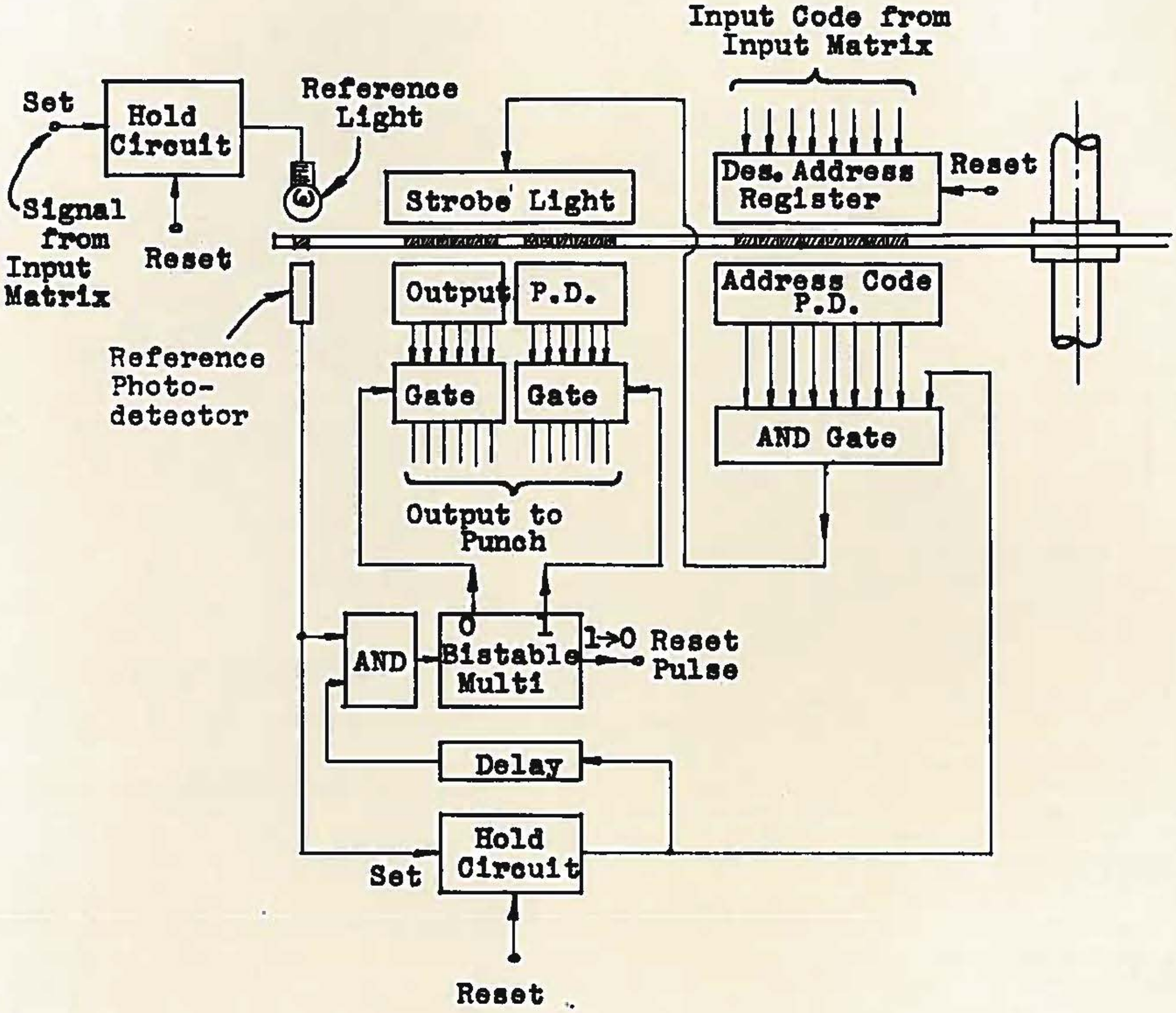


Fig. 4.7 Encoder Timing System

sources are set in the desired address register.

(2) When the reference position on the disc, which is indicated by a transparent spot on the circumference, is aligned with the reference light, a timing pulse occurs which operates the coincidence detector "AND" gate through the "HOLD" circuit.

(3) The first Braille cell is read out during the following revolution of the disc.

(4) A second timing pulse then flips a bistable multivibrator from state "0" to state "1" gating the second set of photodetectors through which the second cell is read out. Notice that the first timing pulse has no effect on the multivibrator since both signals to the "AND" gate are not present.

(5) A third timing pulse flips the multivibrator back into state "0" and generates a reset pulse which resets the desired address register, turns off the reference light, and makes the total coincidence detector inoperative. The system is ready to receive another character and begin a new cycle.

4.6 Logic associated with the contraction key

When the contraction key is depressed, the encoder operation must be modified. The system must be inoperative until the total input code identifying the contraction is generated and stored in the desired address register. When the contraction key is released, the proper Braille output is determined in exactly the same manner as for a single character input.

A convenient arrangement for performing this modification is shown in Fig. 4.8. Normally the contraction key is in the position indicated. When a typewriter key is depressed, a signal from the input matrix is allowed to pass through "AND" gate #1 and initiate the timing system as described previously.

When the contraction key is depressed however, "AND" gate #1 will not allow the signal to pass. Instead it sets a multivibrator in the desired address register through "AND" gate #2. The purpose of this is considered in Chapter V. "AND" gate #2 is used to increase the reliability of the system; if the contraction key is depressed accidently, the desired address register is unaffected.

Since the encoder does not operate if the contraction key is depressed, the last letter of a contraction must be typed with the contraction key in its normal position. For example to form the contraction "ation", the contraction key is held depressed while the letters "atio" are typed, then released before striking the letter "n".

4.7 Logic associated with the shift key

In the Braille system, a capital is formed by adding a separate symbol, the capital sign, in front of a letter. It is desirable to include this symbol in the usual way by depressing the shift key and striking the desired letter key.

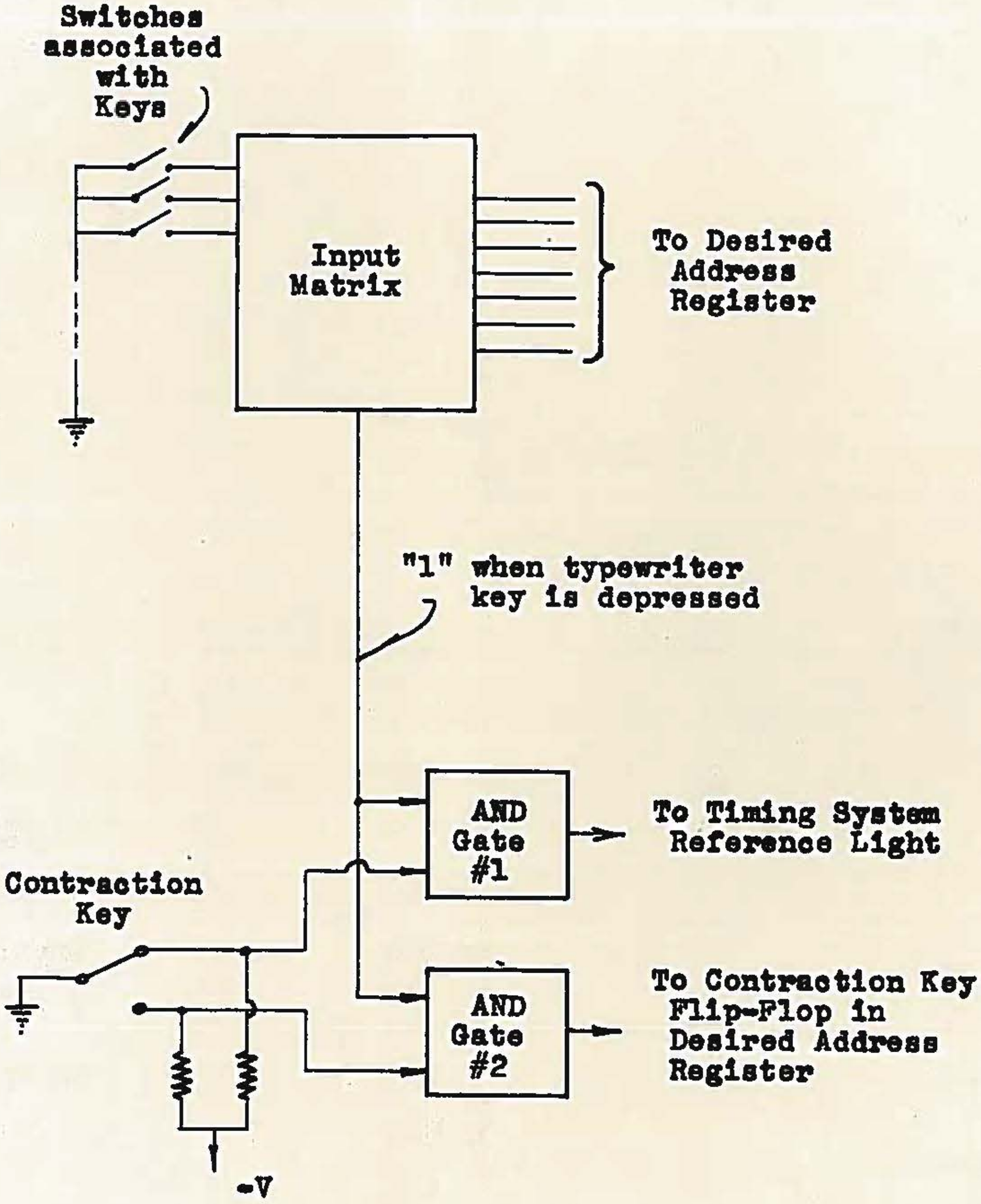


Fig. 4.8 Logic Associated with the Contraction Key

Obviously it is not adequate to generate the capital sign every time the shift key is used since this would be incorrect for upper-case non-letter characters. For this reason, the capital sign is generated without the use of the photographic disc.

The scheme shown in Fig. 4.9 is a convenient method for forming the capital sign:

(1) The "AND" gate produces a signal only if (a) a key is depressed, (b) the key is a letter key, and (c) the shift key is depressed. The arrangement for obtaining the signals when (a) and (b) occur is described in Chapter V when the input matrix is considered.

(2) A signal from the "AND" gate flips the multivibrator to state "1" which gates the timing pulse to a driver which activates hole #6 of the punch, the capital sign, and resets the multivibrator back to state "0".

(3) A revolution later, the timing pulse is gated to the timing system and the proper Braille symbols are read out as usual.

The advantage of this arrangement is that the punch is not required to produce more than one cell for each complete revolution of the photographic disc.

4.8 The overall system

A diagram of the complete encoder system is shown in Fig. 4.10. The details of the various subsystems have been previously considered, and the input design is discussed in Chapter V.

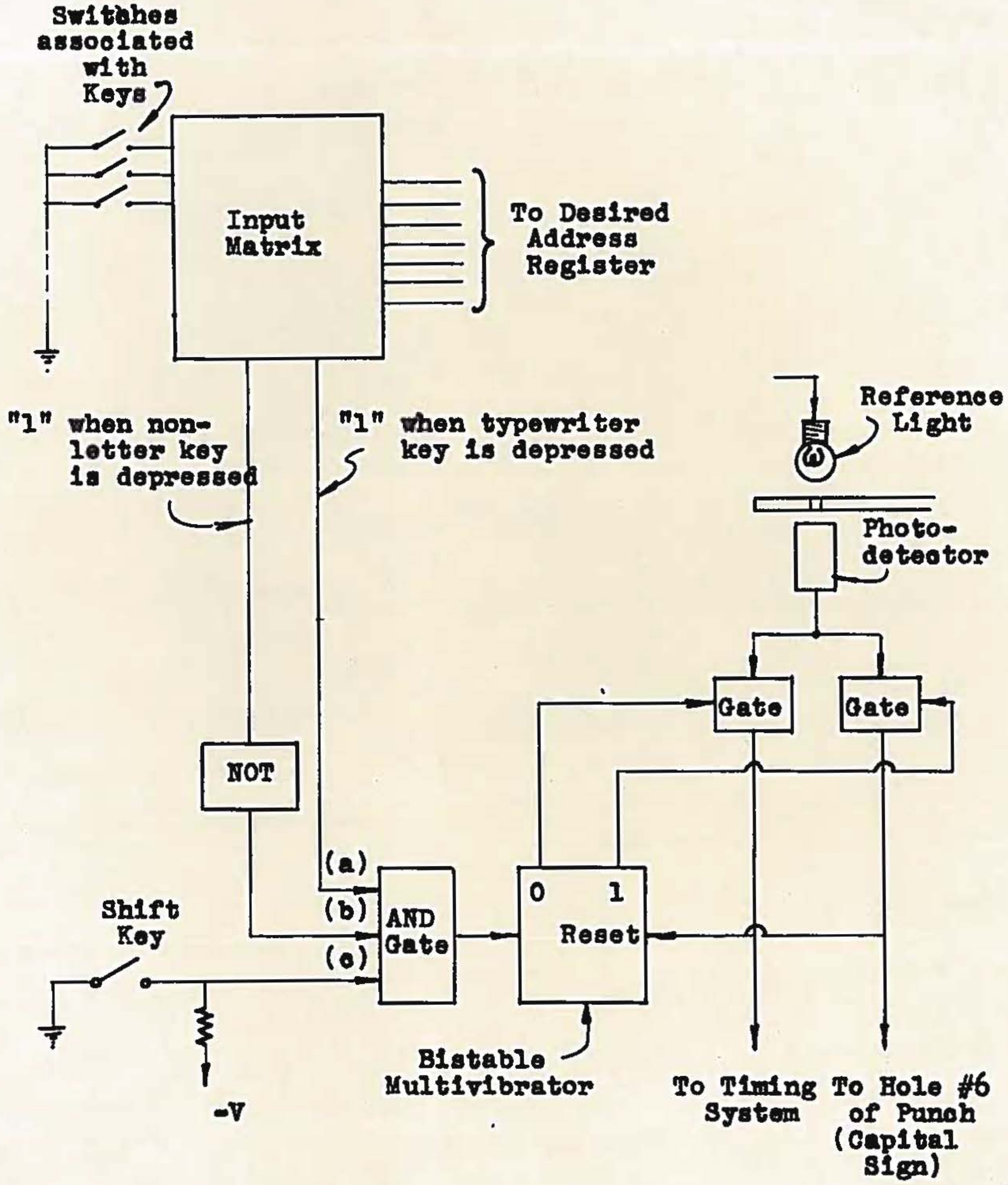
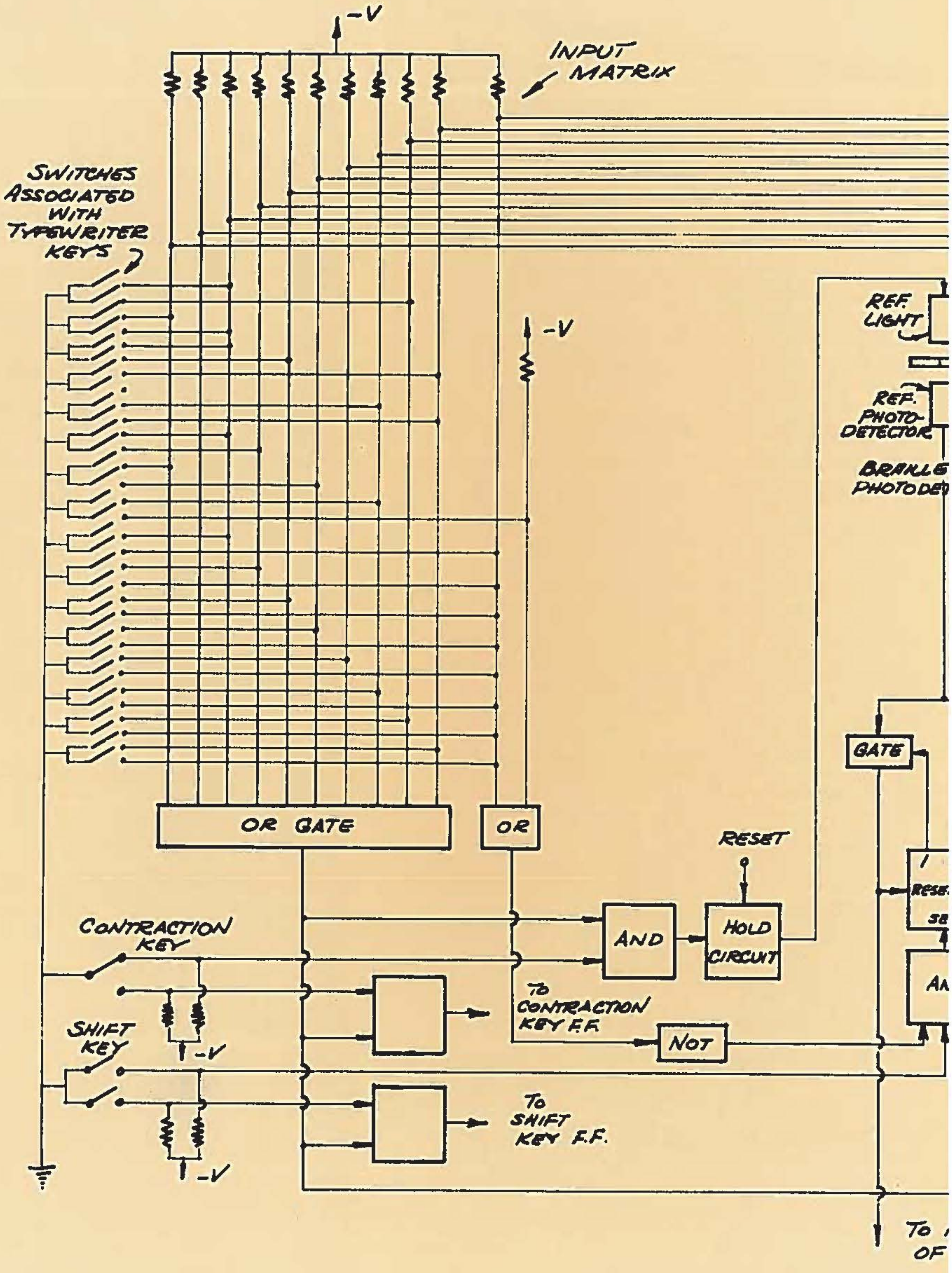


Fig. 4.9 Logic Associated with the Shift Key


-V
INPUT MATRIX
SWITCHES ASSOCIATED WITH TYPEWRITER KEYS
REF. LIGHT
REF. PHOTO-DETECTOR
BRAILLE PHOTODE
-V
GATE
OR GATE
OR
RESET
AND
HOLD CIRCUIT
1
RESE
SE
AN
CONTRACTION KEY
-V
TO CONTRACTION KEY F.F.
NOT
SHIFT KEY
TO SHIFT KEY F.F.
-V
TO
OF

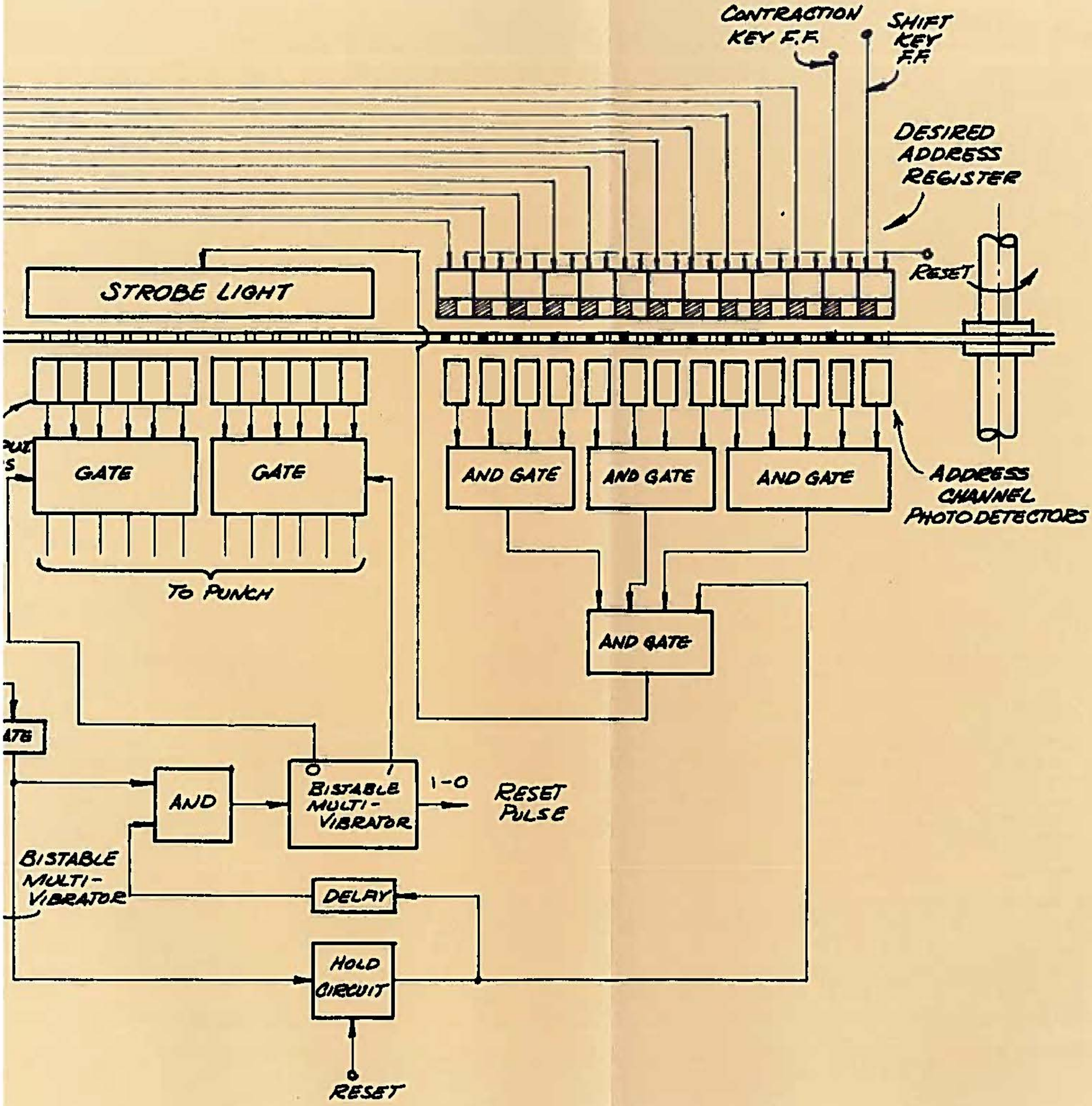


Fig. 4.10 Complete Encoder System

V. THE INPUT CODE

The input code which is stored in the desired address register must be generated as the typewriter keys are depressed. This preliminary encoding is accomplished by the input matrix which is operated by switches associated with the typewriter keys.

The input code and the matrix for generating it are designed in this chapter.

5.1 The typewriter keyboard

The standard typewriter keyboard is inadequate for producing all of the Braille symbols. For instance the Braille system contains special symbols which have no inkprint equivalents. Fortunately the typewriter likewise contains characters which are not employed in Grade II Braille, and a modification of the keyboard is possible.

Two factors require consideration in modifying the typewriter keyboard: (1) The Braille system employs special signs to aid in interpreting a sequence of characters. These include the number sign, the letter sign, the italic sign, the accent sign, and the poetry-line sign. (2) Certain keys on the typewriter are used to produce several different characters. Difficulty arises when these are represented by different symbols in Braille. Included in this category are: (a) The right and left quotation marks, (b) The right and left single quotation marks and the apostrophe, (c) The letter "l" and the numeral "1", and (d) The period and the decimal point sign.

Based on these considerations, a possible keyboard arrangement is given in Fig. 5.1.

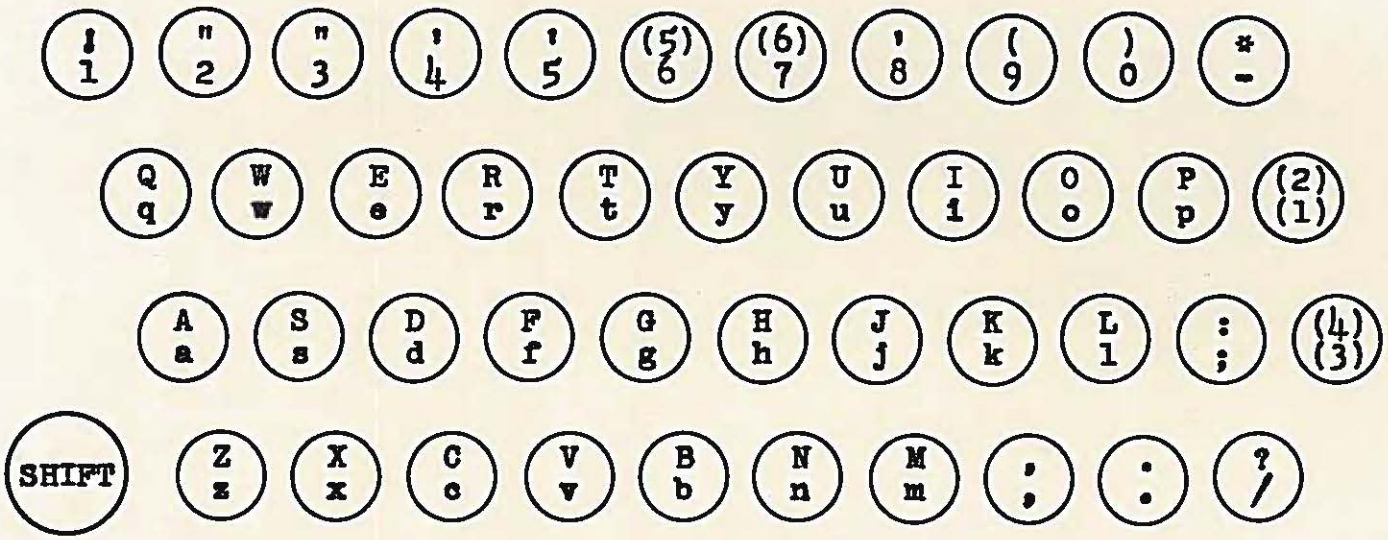
5.2 <u>Basis for the code design</u>

5.2.1 <u>Method of encoding the contractions</u>

When a typewriter key is depressed, an appropriate binary code must be generated and stored in the desired address register. This code is compared to similar codes in the address channel of the photographic disc, and the corresponding Braille symbol is selected. If a contraction is to be encoded however, the binary codes generated by each letter in the contraction must be combined to form a new code which uniquely identifies the contraction. This code is then used to select the corresponding Braille symbol.

A great simplification of the input code results if the binary code identifying a contraction can be formed from the component binary codes <u>combinatorially</u> rather than <u>sequentially</u>. Combinatorial implies that only the letters comprising the contraction need be considered in forming the code rather than the order in which these letters occur. For example, consider the words "taste" and "state"; the order in which the letters occur is important, and a sequential arrangement would be required to distinguish them.

The contractions, which are included in Appendix A, contain only two such pairs which would require sequential coding.



<u>KEY</u>

(1) Number sign
(2) Letter sign
(3) Decimal-point sign
(4) Italic sign
(5) Accent sign
(6) Poetry-line sign

Fig. 5.1 Possible Keyboard Arrangement

These are "into" and "tion"; "every" and "very". Since the Braille symbol for "into" can be formed from the symbols for the contractions "in" and "to", and the Braille symbol for "very" in simply "v", these two contractions will not be considered so that a simpler input code can be used.

The complexity of the encoding system is reduced since a combinatorial arrangement can be employed. Considerable advantage can be gained, for instance, if all of the code numbers corresponding to the keys and the contractions contain the same number of digits. Such a requirement allows two code numbers to be combined digit by digit.

The method for combining the code numbers is based on this principle. Consider for convenience the contraction "the" represented by the N-digit code number $C = c_1c_2..c_i..c_N$. This number is to be formed by combining the N-digit code numbers corresponding to the letters t, h, and e: $T = t_1t_2.t_i.t_N$, $H = h_1h_2..h_i..h_N$, $E = e_1e_2..e_i..e_N$, so that:

$$C = C(T,H,E) \qquad (5.1)$$

By forming this combination digit by digit, Eq. (5.1) can be expressed in terms of the N functional relations:

$$c_i = c_i(t_i, h_i, e_i) \qquad (1 \leq i \leq N) \qquad (5.2)$$

The most convenient logical operation to perform on the digits of the code numbers is the "OR" operation:

$$c_i = t_i + h_i + e_i \qquad (5.3)$$

The i-th digit of the code number for a contraction will then be "1" if any of the i-th digits in the component code numbers are "1"; otherwise it will be "0". For example if:

$$\begin{array}{rl} & T = 01000 \\ & H = 00011 \\ & E = 01010 \\ \cline{2-2} \text{then:} & C = 01011 \end{array}$$

5.2.2 The minimum number of digits in the code numbers

The type of switches associated with the typewriter keys influences the complexity of the input matrix. It is possible to design a diode matrix which will generate the required code when single-pole switches are used. A much simpler matrix can be designed when double-pole switches are employed if the code is carefully chosen. This simplification will be apparent when the input matrix design is considered.

If double-pole switches are used on the typewriter, the input matrix can be constructed without diodes. It is merely necessary to select code numbers associated with the keys with only one or two digits which are "1", and the remaining digits "0" such as, for example, 0101000.

A question arises concerning the number of digits which are necessary in the required code numbers so that the above condition can be fulfilled. A typewriter has 44 keys including the shift key which require a code number containing one or two "1's".

A surprising relation exists between the binomial coefficients and the binary numbers. Consider the Pascal triangle of binary coefficients shown in Table 5.1. The coefficients in any one row can be associated with all of the binary numbers containing as many digits as the second coefficient in that row in the following manner. Consider for example the row containing the coefficients 1331 and the set of 3-digit binary numbers: 000,001, 010, 011, 100, 101, 110, 111. In this set there ~~is~~ 1 binary number containing no "1's", 3 binary numbers containing one "1", 3 binary numbers containing two "1's", and 1 binary number containing all three "1's". This identification is easily confirmed for any row in the triangle and the corresponding set of binary numbers.

1										
1	1									
1	2	1								
1	3	3	1							
1	4	6	4	1						
1	5	10	10	5	1					
1	6	15	20	15	6	1				
1	7	21	35	35	21	7	1			
1	8	28	56	70	56	28	8	1		
1	9	36	84	126	126	84	36	9	1	
1	10	45	120	210	252	210	120	45	10	1

Table 5.1 Pascal's Triangle of Binary Coefficients

Since 44 binary numbers are necessary which contain only one or two "1's", it can be seen from Table 5.1 that the code numbers require a minimum of 9 digits each since the set of

9-digit binary numbers contains 45 such numbers.

5.3 Code design

The process of devising an appropriate code by trial and error is a difficult chore. Rather than assume a possible code and test it to see that no ambiguities result when the contraction addresses are formed according to Eq. (5.3), a more straightforward method can be used.

A set of letters is selected which divides the contractions into two approximately equal groups: those which contain the letters, and those which do not. Another set is chosen and the two above groups are separately divided as before into four groups. This process is continued until all of the contractions are separated. In selecting the set of letters to be used in dividing the groups, care is taken not to use each letter more than twice and not to use the same pair of letters in two different sets. When this separation is accomplished, a possible code can be written. This process is repeated until a code requiring as few digits as possible is obtained.

By using the above method, a possible code has been determined. Although a 9-digit code would be adequate as demonstrated above, the best effort produced the 10-digit code given in Table 5-2.

In addition to these 10 digits, three additional digits are required to produce an unambiguous input code for all of the Braille characters which are considered. The

A	0000010010	J	0001000001	S	0001000100
B	1010000000	K	0010001000	T	0100000000
C	0010100000	L	0100010000	U	1000000010
D	0000000001	M	0100100000	V	0000000011
E	0000000101	N	0000010001	W	0001001000
F	0011000000	O	1000000000	X	0000011000
G	1000010000	P	0001000010	Y	0001100000
H	0010000001	Q	[illegible]01000010	Z	0000010100
I	0000100001	R	0000[illegible]001		

Table 5.2 A Possible Code

first is necessary so that the letters can be discriminated from the non-letters in using the capital sign, this will be clear from the design of the input matrix. The second indicates that the contraction key has been depressed. This is necessary to distinguish the contraction <u>bb</u>, <u>cc</u>, <u>dd</u>, <u>ff</u>, and <u>gg</u> from the respective letters b,c,d,f, and g. The third is associated with the shift key and is required to distinguish between characters in the upper and lower shift positions.

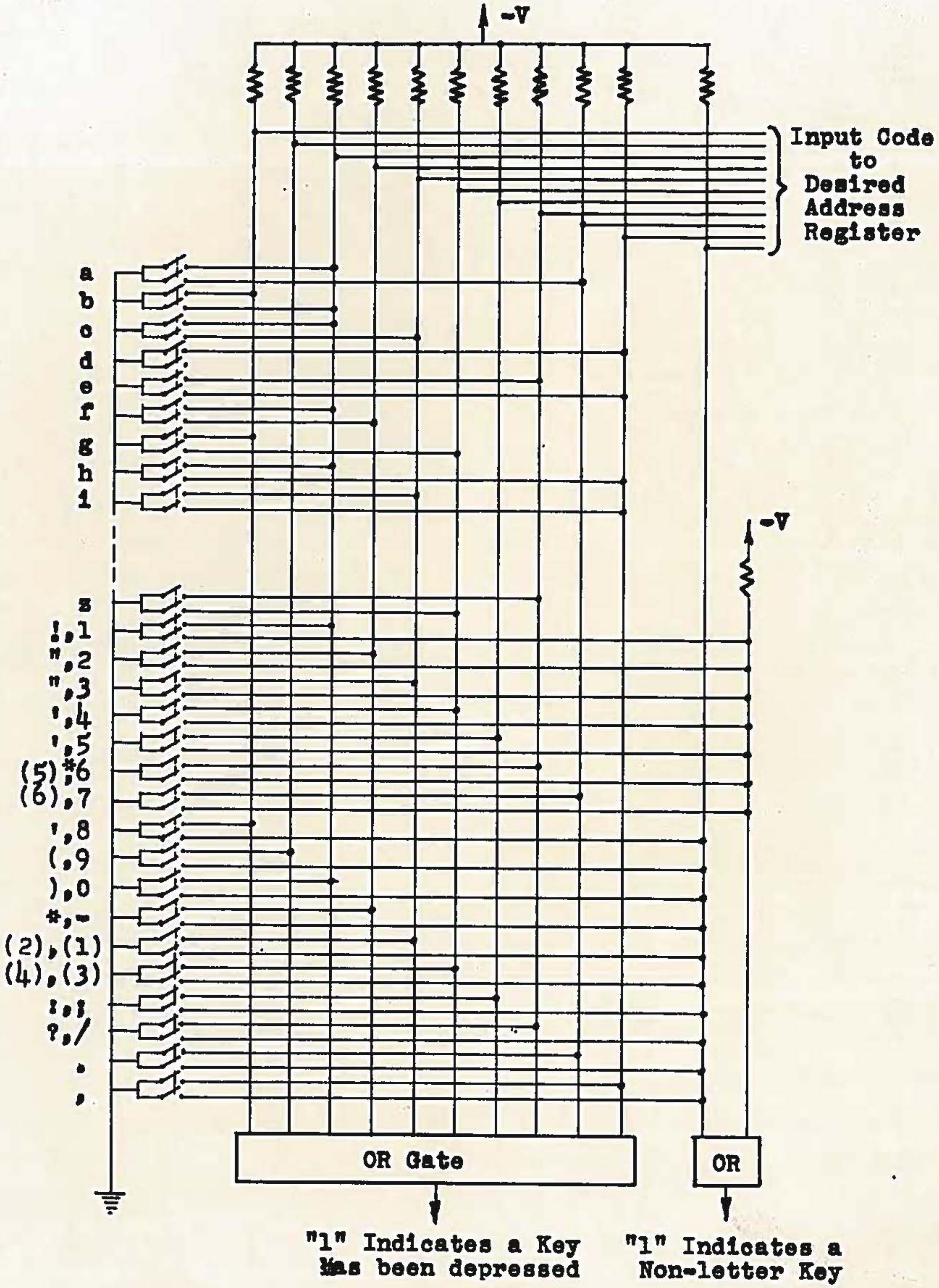
Appendix B contains the 13-digit input code numbers for the 163 Braille characters based on Table 5.2. Notice that both of the complementary tracks for the 13th digit of the code numbers on the photographic disc are transparent for the letters of the alphabet, the period, and the comma. This is done since it is not necessary to distinguish between the upper and lower shift positions for these characters; the code numbers are identical whether or not the shift key is used. Notice also that three of the punctuation marks, the dash, the left and the right bracket, require the use of the contraction key. The dash is formed by typing two hyphens, and the left and right brackets by typing two left and right parenthesis respectively in the same manner as a contraction would be formed.

5.4 The input matrix

The choice of code numbers containing only one or two "1's" results in a very simple input matrix. If double-pole switches are used in conjunction with the typewriter keys the matrix can be constructed as shown in Fig. 5.2 without the use of diodes.

In this circuit the more positive voltage is considered to be "1". When a key is depressed, the one or two channels corresponding to the "1's" of the code numbers are grounded, and the multivibrators in the desired address register are set accordingly. If several keys corresponding to a contraction are depressed sequentially, then the code numbers associated with that contraction is stored in the register.

The need for the 11th digit in the code numbers can be seen from the figure. The 11th channel and the additional channel which has no association with the desired address register receive a connection from each of the double-pole switches which are associated with the non-letter typewriter keys. Hence the output of the "OR" gate which is common to these two channels can be used to discriminate between letters and non-letters. The "OR" gate which contains the first ten channels as inputs indicates merely that a key has been depressed. This arrangement is required for the logical system associated with the shift key as discussed in Section 4.7.



*Refer to Key in Figure 5.1

Fig. 5.2 Input Matrix Design

VI. SUGGESTED AREAS FOR FUTURE INVESTIGATION

The proposed encoder system is intended to reduce the amount of training required for transcribing inkprint text into Grade II Braille. Specifically, the encoder eliminates the need for knowing the Braille symbols by substituting a standard typewriter keyboard for the present six key brailler or stereotyper. By typing the letters of a contraction, for example, the operator is in effect selecting the corresponding Braille symbol from the memory. The usefulness of the encoder clearly depends on the reduction of skill resulting from this modification.

An evaluation of the system from the operator's point of view should be made to ascertain its usefulness. It should be pointed out that a working knowledge of the rules of Braille is still necessary; the operator must know which groups of letters are properly contracted. Since the Standard English Braille rules were developed specifically for the Braille reader, considerable effort was made to produce a communication system for the blind which is free from ambiguities. Consequently the rules are complicated and contain many exceptions. The present difficulties in training transcribers is due partly to these involved rules and partly to the actual Braille code. An evaluation of the usefulness of the proposed encoder should be based on a study of the relative influence of these on the operator's performance.

The simplicity of the encoder design suggests that it may be useful for purposes other than the production of Grade II Braille. For example, the design may be adapted to the translation of teletypesetter tape to Grade I Braille, Present efforts in this area have been based on switching circuits. The difficulties which arise are a consequence of the complexity of the required system, particularly in regard to the problem of the capital sign. The flexibility of the proposed encoder indicates that such an approach may result in a reasonably simple system.

The ideal solution to the problem of producing Grade II Braille would be the development of an inexpensive scheme to <u>automatically</u> translate teletypesetter tape. Present systems for accomplishing this, which have been discussed in Chapter II, employ general purpose digital computers. It is interesting to note that it is slightly more expensive to produce a Braille copy of a novel from a suitable program using the IBM 704 than by employing a human transcriber.* Again the possibility exists for using the proposed encoder design as the basis for a system considerably less complex than a general purpose computer.

---

* From a discussion with Mr. Waterhouse.

APPENDIX A.

THE SYMBOLS USED IN GRADE II BRAILLE (1)

1. The alphabet and numerals

⠁	a,1
⠃	b,2
⠉	c,3
⠙	d,4
⠑	e,5
⠋	f,6
⠛	g,7
⠓	h,8
⠊	i,9
⠚	j,0
⠅	k
⠇	l
⠍	m
⠝	n
⠕	o
⠏	p
⠟	q
⠗	r
⠎	s
⠞	t
⠥	u
⠧	v
⠺	w
⠭	x
⠽	y
⠵	z

2. The contractions

⠠⠽	ally
⠨⠑	ance
⠯	and
⠜	ar
⠵	as
⠠⠝	ation
⠆	bb
⠆	be
⠼	ble
⠃	but
⠴	by
⠉	can

⠸⠉	cannot
⠒	cc
⠡	ch
⠐⠡	character
⠡	child
⠤	com
⠒	con
⠐⠙	day
⠲	dd
⠲	dis
⠙	do
⠂	ea
⠫	ed
⠢	en
⠰⠑	ence
⠢	enough
⠻	er
⠐⠑	ever
⠑	every
⠐⠋	father
⠖	ff
⠿	for
⠋	from
⠰⠇	ful
⠶	gg
⠣	gh
⠛	go
⠸⠓	had
⠓	have
⠐⠓	here
⠦	his
⠔	in
⠬	ing
⠔⠖	into
⠭	it
⠰⠽	ity
⠚	just
⠐⠅	know
⠅	knowledge
⠨⠎	less
⠇	like
⠐⠇	lord
⠸⠍	many
⠰⠞	ment
⠍	more
⠐⠍	mother
⠐⠝	name
⠰⠎	ness
⠝	not
⠷	of
⠐⠕	one

⠰⠛	ong
⠳	ou
⠐⠳	ought
⠨⠙	ound
⠨⠞	ount
⠳	out
⠪	ow
⠐⠏	part
⠏	people
⠟	quite
⠗	rather
⠐⠗	right
⠩	sh
⠩	shall
⠨⠝	sion
⠎	so
⠐⠎	some
⠸⠎	spirit
⠌	st
⠌	still
⠹	th
⠞	that
⠮	the
⠸⠮	their
⠐⠮	there
⠘⠮	these
⠹	this
⠘⠹	those
⠐⠹	through
⠐⠞	time
⠠⠝	tion
⠖	to
⠐⠥	under
⠘⠥	upon
⠥	us
⠧	very
⠴	was
⠶	were
⠱	wh
⠐⠱	where
⠱	which
⠘⠱	whose
⠺	will
⠾	with
⠘⠺	word
⠐⠺	work
⠸⠺	world
⠽	you
⠐⠽	young

3. Punctuation marks and signs

⠲ . (period)

⠂ , (comma)

⠦ ? (question mark)

⠖ ! (exclamation point)

⠆ ; (semi-colon)

⠒ : (colon)

⠦ " (left quote)

⠴ " (right quote)

⠠⠦ ' (single left quote)

⠴⠄ ' (single right quote)

⠄ ' (apostrophe)

⠤ - (hyphen)

⠤⠤ — (dash)

⠔⠔ * (asterick)

⠶ ((left parenthesis)

⠶) (right parenthesis)

⠠⠶ (left bracket)

⠶⠄ (right bracket)

⠠ capital sign

⠌ / (fraction-line sign)

⠼ number sign

⠰ letter sign

⠨ . (decimal-point sign)

⠨ italic sign

⠈ accent sign

⠜ poetry-line sign

⠄⠄⠄ ellipsis

4. The abbreviated words

ab	about
abv	above
ac	according
acr	across
af	after
afw	afterward
ag	again
agst*	against
alm	almost
alr	already
al	also
alth	although
alt	altogether
alw	always
bec	because
bef	before
beh	behind
bel	below
ben	beneath
bes	beside
bet	between
bey	beyond
bl	blind
brl	Braille
chn	children
concv	conceive
concvg	conceiving
cd	could
dcv	deceive
dcvg	deceiving
dcl	declare
dclg	declaring
ei	either
gd	good
grt	great
herf	herself
hm	him
hmf	himself
imm	immediate
xs	its
xf	itself
lr	letter
ll	little
mch	much
mst	must
myf	myself
nec	necessary
nei	neither
o'c	o'clock
onef	oneself
ourvs	ourselves
pd	paid
percv	perceive
percvg	perceiving
perh	perhaps
qk	quick
rcv	receive
rcvg	receiving
rjc	rejoice
rjcg	rejoicing
sd	said
shd	should
sch	such
themsv	themselves
thyf	thyself
to-d	to-day
tgr	together
to-m	to-morrow
to-n	to-night
wd	would
yr	your
yrf	yourself
yrvs	yourselves

---

* Groups of letters which are underlined are contracted in forming the abbreviation.

APPENDIX B.

A LIST OF POSSIBLE INPUT CODE NUMBERS

1. <u>The alphabet and numerals</u>

000001001000*	a,A	100000001000*	u,U
101000000000*	b,B	000000001100*	v,V
001010000000*	c,C	000100100000*	w,W
000000000100*	d,D	000001100000*	x,X
000000010100*	e,E	000110000000*	y,Y
001100000000*	f,F	000001010000*	z,Z
100001000000*	g,G		
001000000100*	h,H	-----	
000010000100*	i,I		
000100000100*	j,J		
001000100000*	k,K	0010000000000	1
010001000000*	l,L	0001000000000	2
010010000000*	m,M	0000100000000	3
000001000100*	n,N	0000010000000	4
100000000000*	o,O	0000001000000	5
000100001000*	p,P	0000000100000	6
010100000000*	q,Q	0000000010000	7
000000100100*	r,R	1000000000100	8
000100010000*	s,S	0100000000100	9
010000000000*	t,T	0010000000100	0

---

* Indicates that both of the complementory tracks of the 13th digit on the photographic disc are transparent.

2. The contractions

010111001001*	ally	000000111101*	ever
001011011101*	ance	000110111101*	every
000001001101*	and	011101111101*	father
000001101101*	ar	101100100101*	for
000101011001*	as	111110100101*	from
110011001101*	ation	111101001001*	ful
101000010101*	be	101001000101*	gh
111001010101*	ble	100001000001*	go
111000001001*	but	001001001101*	had
101110000001*	by	001001011101*	have
001011001101*	can	001000110101*	here
111011001101*	cannot	001110010101*	his
001010000101*	ch	000011000101*	in
011011111101*	character	100011000101*	ing
011011000101*	child	010010000101*	it
111010000001*	com	010110000101*	ity
101011000101*	con	110100011101*	just
000111001101*	day	101101100101*	know
000110010101*	dis	111101110101*	knowledge
100000000101*	do	010101010101*	less
000001011101*	ea	011011110101*	like
000000010101*	ed	110001100101*	lord
000001010101*	en	010111001101*	many
001011010101*	ence	010011010101*	ment
101001011101*	enough	110010110101*	more
000000110101*	er	111010110101*	mother

010011011101*	name
000101010101*	ness
110001000101*	not
101100000001*	of
100001010101*	one
100001000101*	ong
100000001001*	ou
111001001101*	ought
100001001101*	ound
110001001101*	ount
110000001001*	out
100100100001*	ow
010101101101*	part
110101011101*	people
110110011101*	quite
011001111101*	rather
111011100101*	right
001100010101*	sh
011101011101*	shall
100111010101*	sion
100100010001*	so
110110010101*	some
010110111101*	spirit
010100010001*	st
010111010101*	still
011000000101*	th
011001001101*	that
011000010101*	the
011010110101*	their
011000110101*	there
011100010101*	these
011110010101*	this
111100010101*	those
111001101101*	through
010010010101*	time
110011000101*	tion
110000000001*	to
100001111101*	under
100101001101*	upon
100100011001*	us
000101111001*	was
000100110101*	were
001100100101*	wh
001100110101*	where
001110100101*	which
101100110101*	whose
010111100101*	will
011110100101*	with
100100100101*	word
101100100101*	work
110101100101*	world
100110001001*	you
100111001101*	young

3. Punctuation marks and signs

000000001010*	.	(period)
000000000110*	,	(comma)
0000000100101	?	(question mark)
0010000000001	!	(exclamation point)
0000001000100	;	(semi-colon)
0000001000101	:	(colon)
0001000000001	"	(left quote)
0000100000001	"	(right quote)
0000010000001	'	(single left quote)
0000001000001	'	(single right quote)
1000000000101	'	(apostrophe)
0001000000100	-	(hyphen)
0001000000110	—	(dash) **
0001000000101	*	(asterick)
0100000000101	(	(left parenthesis)
0010000000101	)	(right parenthesis)
0100000000111	[	(left bracket) **
0010000000111	]	(right bracket) **

** Indicates punctuation marks which require the use of the contraction key as explained in Chapter V.

0000000100100	/ (fraction-line sign)
0000100000100	number sign
0000100000101	letter sign
0000010000100	. (decimal-point sign)
0000010000101	italic sign
0000000100001	accent sign
0000000010001	poetry-line sign

APPENDIX C.

LIGHT-PIPE DESIGN

C.1 Basis of the design

The light-pipe is designed so that light rays entering the tube always strike the polished surface at an angle less than the critical angle and are completely reflected back into the pipe. The end of the pipe at which the light enters is rounded to serve as a lens so that the light rays inside the tube are parallel to the axis before they strike the surface.

The light-pipe has two sections: a paraboloid and a conical section as shown in Fig. C.1. A paraboloid is used since it has the property that all incident rays parallel to its axis are reflected through the focus. Consider ray (1) which strikes the intersection of the two segments. The reflected ray passes through the focus, F, and just enters the exit tube at angle θ_c which is the maximum angle of incidence. It can be seen that any other ray such as (2) or (3) will enter the exit tube at an angle not greater than θ_c after having made only one reflection from the surface of the pipe.

C.2 Derivation of equations

Consider a parabola whose focus is at the origin of a coordinate system as shown in the figure. This curve has the equation:

$$y^2 = 4a(x+a) \tag{C.1}$$

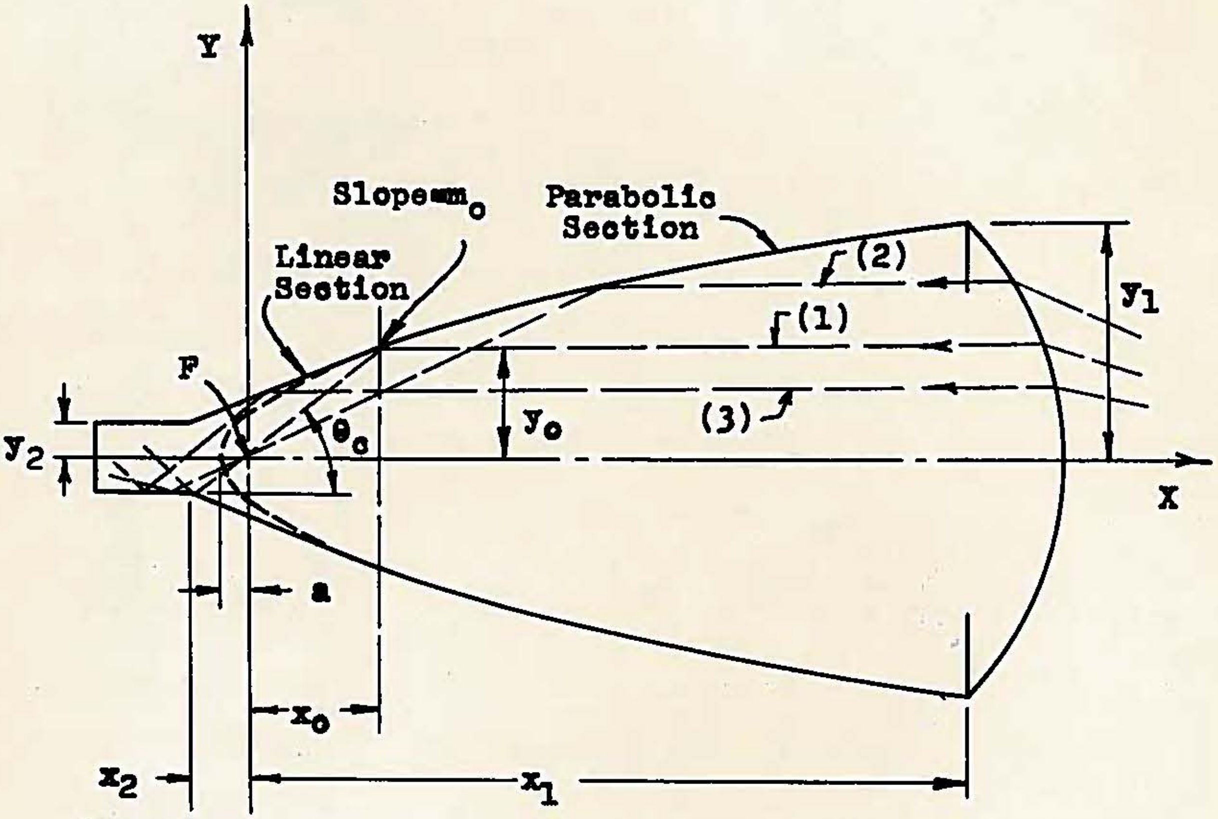


Fig. C.1 Light-Pipe Design

where a is the distance from the vertex to the focus as shown. The slope of this curve is:

$$\frac{dy}{dx} = m = \frac{2a}{y} \tag{C.2}$$

If an incident ray, parallel to the axis, is reflected from a surface of the pipe which has a slope $m_o = \tan \phi_o$, the angle that the reflected ray makes with the axis is $2\phi_o$. Then using the expression for the tangent of a double angle:

$$\tan 2\phi_o = m_c = \frac{2m_o}{1-m_o^2} \tag{C.3}$$

where m_c is the slope of the reflected ray. Solving Eq. (C.3) for m_o in terms of m_c, there results:

$$m_o = \frac{-1+\sqrt{1+m_c^2}}{m_c} \tag{C.4}$$

Assuming that y_2, the radius of the exit tube, has been selected, the equation of the linear segment of the light pipe is:

$$y = m_o x + y_2 + m_o x_2 \tag{C.5}$$

where x_2 is defined in the figure. The equation of the ray reflected from the intersection of the parabolic and linear segments through the focus is:

$$y = m_c x \tag{C.6}$$

By manipulating Equations (C.2),(C.4), (C.5), and (C.6), it is possible to obtain the following expression for a, which completely determines the equation of the parabola:

$$a = \frac{m_o(m_o x_2 + y_2)}{1 + m_o^2} \tag{C.7}$$

The critical angle for any material can be obtained from the familiar equation for refraction:

$$n_1 \sin r + n_2 \sin i$$

By setting r = 90°, the critical angle, i_c, results:

$$i_c = \sin^{-1} \frac{n_1}{n_2} \tag{C.8}$$

The critical angle for plexiglas is 47.8°.

C.3 Design procedure and sample calculation

By using the equations derived above, the design of the light-pipe is quite simple. The following procedure is useful:

Procedure	Sample Calculation	
(1) Select y_1, y_2, θ_c:	$\theta_c \leq 47.8°$	Let $y_1 = 0.250''$, $y_2 = 0.025''$; $\theta_c = 30°$
(2) Calculate m_c:	$m_c = \tan\theta_c$	$m_c = 0.577$
(3) Calculate x_2:	$x_2 = \frac{y_2}{m_c}$	$x_2 = 0.043''$
(4) Calculate m_o:	$m_o = \frac{-1+\sqrt{1+m_c^2}}{m_c}$	$m_o = 0.268$

(5) Calculate a: $a = \frac{m_0(m_0 x_2 + y_2)}{1 + m_0^2}$ $a = 0.00914''$

(6) Calculate y_0: $y_0 = \frac{2a}{m_0}$ $y_0 = 0.0681''$

(7) Calculate x_0: $x_0 = \frac{y_0^2}{4a} - a$ $x_0 = 0.118''$

(8) Calculate x_1: $x_1 = \frac{y_1^2}{4a} - a$ $x_1 = 1.70''$

(9) The total length (excluding the lens and exit tube) is $L = x_1 + x_2$: $L = 1.74''$

APPENDIX D. BIBLIOGRAPHY

1. Loomis, M. M., <u>The Braille Reference Book</u>, Harper & Brothers, New York, 1942.
2. "IBM Computer is Programmed to Transcribe Braille" (technical information bulletin), Dept. of Mathematics and Applications, IBM Corporation, White Plains, New York.
3. "Instructions for the Use and Care of the Perkins Brailler" (instruction booklet), The Howe Press, Perkins School for the Blind, Watertown, Mass.
4. "The New Hall Braillewriter" (instruction booklet), The American Printing House for the Blind, Louisville, Ky.
5. "Tour Guide" (pamphlet), The American Printing House for the Blind, Louisville, Ky.
6. Wheeler, J. N., "Braille Comes of Age", (unpublished).
7. Milne, D. C., "Automatic English to Braille Translator" (invention disclosure), Nov. 7, 1959.
8. Feasibility Study of High-Scanning-Rate Photographic Storage Device, First Summary Report R. M. 7692-2, Dynamic Analysis and Control Laboratory, Mass. Inst. of Technology, Cambridge, Mass.
9. Rothfusz, R. W., "Development of a Megaword Per Second Reader for a Digital Photographic Storage", S. M. Thesis, Elect. Eng. Dept., Mass. Inst. of Technology, Cambridge, Mass., Feb., 1960.