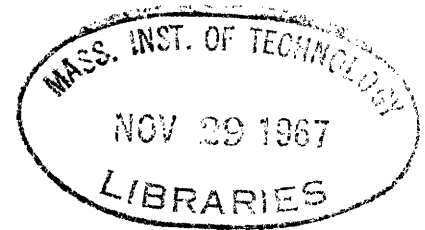


Archives



COMPUTER-CONTROLLED TACTILE DISPLAY

by

DAVID LEE PETERSON

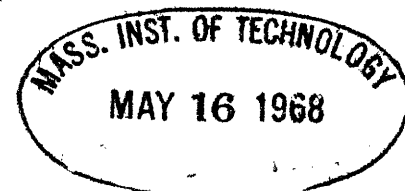
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Department of Electrical Engineering, June 19, 1967

Certified by _____ Thesis Supervisor

Accepted by _____
Chairman, Departmental Committee on Graduate Students

COMPUTER-CONTROLLED TACTILE DISPLAY

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DAVID LEE PETERSON

Submitted to the Department of Electrical Engineering on June 19, 1967 in partial fulfillment of the requirements for the degree of Master of Science.

ABSTRACT

This thesis describes the design and operation of a tactile display system built for use as a research tool in tactile stimulation. The system receives data from the PDP-1 computer and provides tactile stimulation through a device which applies 48 solenoid-driven poke probes to the fingers in a word-at-a-time Braille format, one Braille cell per finger. The display system is general enough to permit the use of stimulators arranged in other convenient formats. A set of subroutines is presented from which a variety of computer programs can be written to aid in investigating computer-generated tactile stimulation.

Thesis Supervisor: Donald E. Troxel
Title: Assistant Professor of Electrical Engineering

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TABLE OF CONTENTS

Title Page	1
Abstract	2
Acknowledgement	3
Table of Contents	4
List of Figures	5
1. Introduction	6
2. Background	7
2.1. Summary of Braille	7
2.2. Previous Work in Braille Displays	9
3. The Display System	11
3.1. Hardware	11
3.1.1. General	11
3.1.2. Stimulator	13
3.1.3. Display Control	15
3.2. Software	23
4. Concluding Remarks	26
Appendix	28
Bibliography	35

LIST OF FIGURES

Figure 1.	Braille Alphabet and Numerals	8
Figure 2.	Block Diagram of Display System	12
Figure 3.	The Stimulator	14
Figure 4.	Location of Stimuli...	14
Figure 5.	Block Diagram of Display Control	16
Figure 6.	Display Control, Local Display Input, and Lamp Display	17
Figure 7.	Sample Display Patterns...	20
Table I.	Summary of Subroutines	24

1. INTRODUCTION

This thesis is concerned with the design, construction, and operation of a computer-controlled tactile display system. In general there have not been a large number of experiments done with computer-generated complex tactual patterns [4]*. The system described here can serve as a research tool in experiments requiring complex tactile pattern presentation. Although the design of the system was kept as general as possible, its use in experiments to investigate word-at-a-time Braille presentation was emphasized in the construction and hence will be emphasized in this report.

After a brief summary of the Braille alphabet, the previous work in Braille displays that led up to this project will be reviewed. Then the individual units of both the hardware and software of the present system will be considered, followed by some concluding remarks about the system and suggestions for its future development and application.

*Numerals in brackets refer to the references listed in the Bibliography.

2. BACKGROUND

2.1. Summary of Braille

The Braille system is the conventional method of presenting written material to the Blind. It was introduced in 1829 by Louis Braille, and through several revisions has evolved into the present accepted Braille, called Standard English Braille. [2]

Figure 1 shows the Braille code. Each "cell" consists of six embossed dots arranged in two columns. Each dot can be either raised or not raised, so there are $2^6 - 1 = 63$ possible unique configurations for a cell having at least one dot raised. Each configuration can represent a letter, numeral, punctuation mark, special symbol, common group of letters, or whole word. A capital letter is indicated by preceding the corresponding Braille character by the capital sign (dot 6 only raised), while capitalization of an entire word is indicated by preceding it by two adjacent capital signs.

There are several levels or "grades" of Braille in use. Grade I Braille is a direct translation of the English text, with a one-to-one correspondence between the English letters and their Braille counterparts. Grade II Braille is moderately contracted, utilizing one- or two-cell contractions for about 185 common

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:  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.

Figure 1. Braille Alphabet and Numerals.

letter groups or words, and thereby reducing the average number of cells required from 5 to about 3.5 per word. Grade III Braille is very highly contracted, and is not commonly used. [2]

For the purposes of description of the display system, Grade I Braille will be used.

2.2. Previous Work in Braille Displays

In most of the previous work in tactile communication, only one letter at a time has been presented to the person, resulting in reading speeds of about 20 words per minute. Persons with normal vision read at about this same speed when restricted to seeing a single letter at a time, but their reading rate goes up to about 100 wpm when they are allowed to see a whole word at a time. Perhaps a blind person could increase his reading speed if he were able to "see", via tactile stimulation, a whole word (or group of letters) at a time. [6]

Troxel [5] and Williams [7] performed experiments using stimulators capable of presenting eight Braille cells at one time to a person, one cell to each of the eight fingers. Their preliminary investigations indicated that there is enough transfer of knowledge of the Braille code to the use of a word-at-a-time device to

justify more extensive experiments. The stimulator used in these previous experiments was controlled either pneumatically or electrically from punched paper tape, and was therefore somewhat limited in the speed and flexibility with which the stimuli could be presented. Thus, adapting the stimulator to on-line computer operation is a logical next step in facilitating the more extensive experiments proposed.

3. THE DISPLAY SYSTEM

3.1. Hardware

3.1.1. General

A block diagram of the display system is shown in Figure 2. The PDP-1 general purpose computer, and the CIPG Data Link through which it is connected to the rest of the system, are documented elsewhere. [1,3] The local display input is a set of 18 switches which permit operation of the display independently from the computer. The mode switch selects whether data is to be received from the computer or from the local display input. The display control operates on this data to set up the corresponding patterns on the stimulator. In "computer" mode the display control also receives and sends back supervisory signals to the computer. The stimulator presents the information to the subject; in this case a word-at-a-time Braille stimulator is used, but the system is sufficiently general to accommodate a variety of stimulator devices. The lamp display receives the same information as the stimulator, and serves as a monitor for the experimenter.

The stimulator and the display control will be considered in more detail in the following sections.

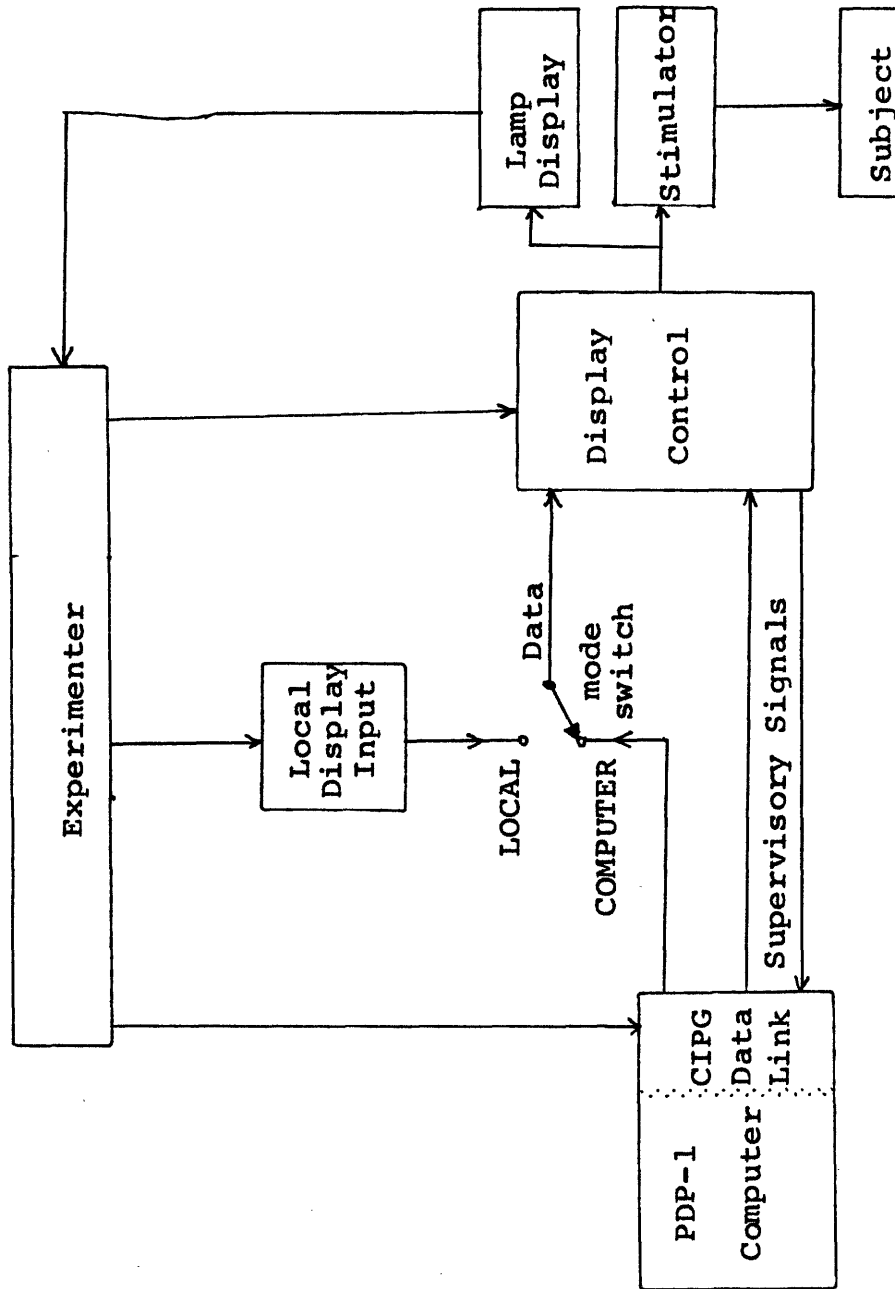


Figure 2. Block Diagram of Display System

3.1.2. Stimulator

The stimulator (Figure 3) is the same one used by Williams [7], modified by making the surfaces on which the lower portions of the fingers rest concave to facilitate proper finger positioning. The eight fingers rest on the stimulator units, one finger on each unit. The fingers (and corresponding stimulator units) are numbered "A" through "H", from left to right; i.e., "A" corresponds to the small finger of the left hand.

Each stimulator unit contains six solenoids and corresponds to one Braille cell. The solenoids are positioned so that the plungers stimulate the locations on the finger as shown by the small circles in Figure 4. The Braille characters are presented as they appear in embossed Braille, a raised solenoid plunger corresponding to a raised dot in Braille. The stimulator is adjustable to fit a variety of hand and finger sizes.

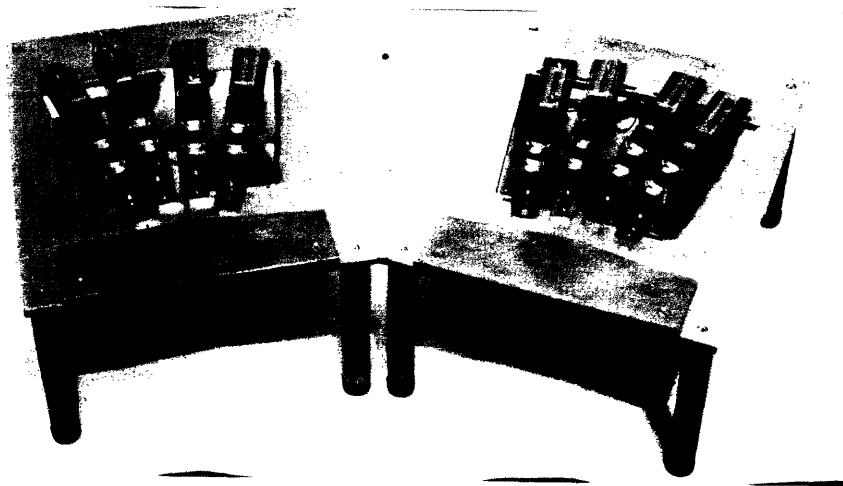


Figure 3. The Stimulator

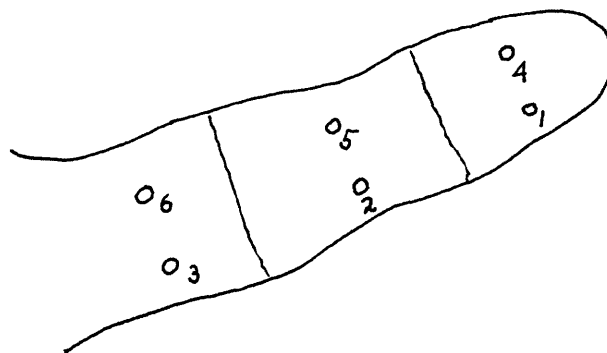


Figure 4. Location of stimuli, shown from underside of finger.

3.1.3. Display Control

A block diagram of the display control is shown in Figure 5. The display control, local display input, lamp display, and power equipment are shown in Figure 6. All circuits use Fairchild micrologic except the solenoid drivers which use transistor circuits to operate the 24-volt stimulator and lamp display.

The "supervisory signals" to and from the computer are required by the data link to indicate when the display system is selected and in use.

A copy pulse gates binary information from the 18 lines into the display control. Copy pulses can originate from executing the computer instruction "cpy", from pressing the "CPY" pushbutton on the face of the display control, from an external pulse generator connected to the "CYCLE" input, or through the high-speed recycle loop to be discussed below.

Binary information on the 18 lines, numbered 0 through 17, comes from either the local display input or from the computer, depending upon the setting of the mode switch. The data on lines 6 through 17 specify the pattern to be set up on the stimulator, while the data on lines 0 through 3 select the fingers to which the

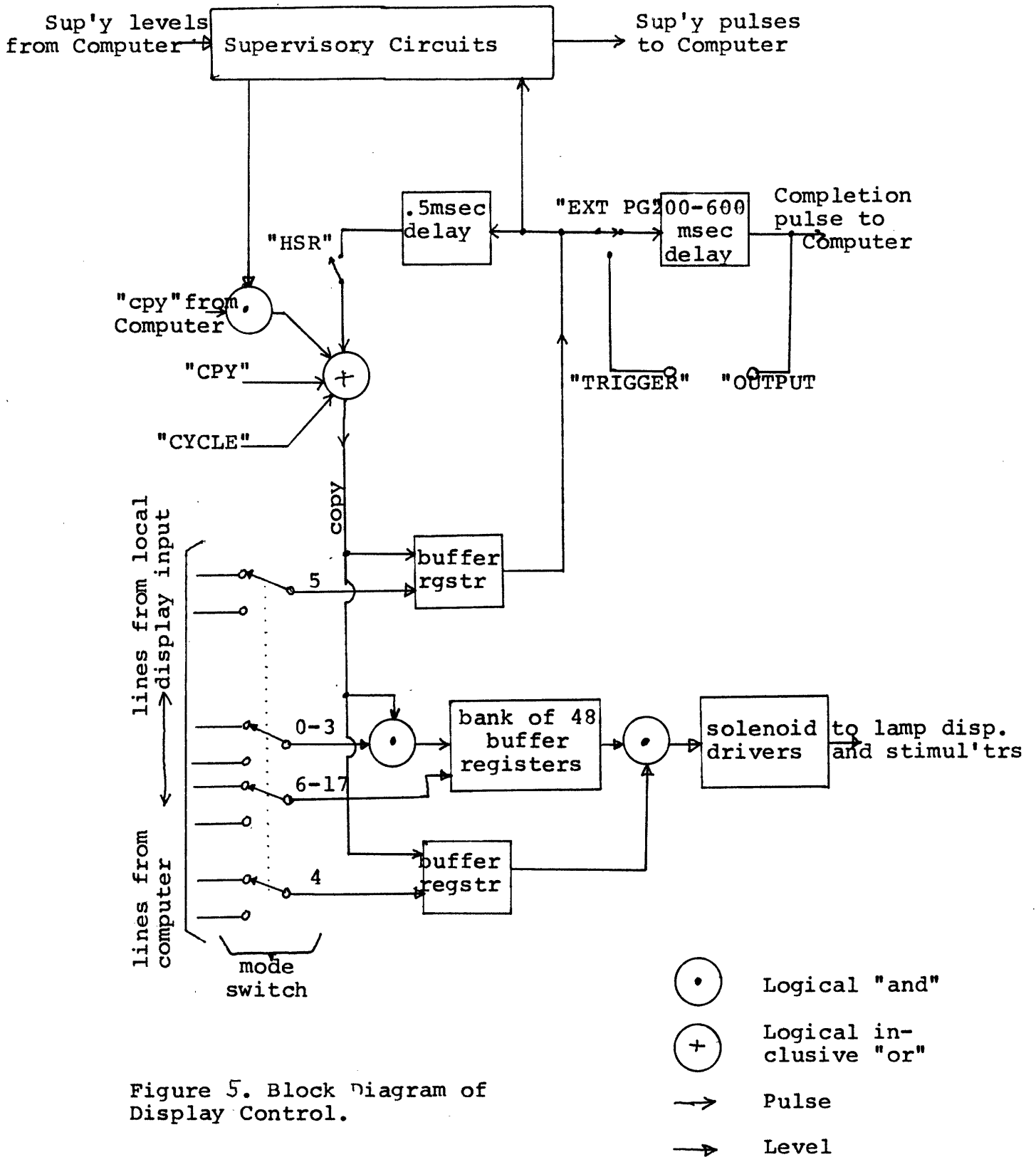


Figure 5. Block Diagram of Display Control.

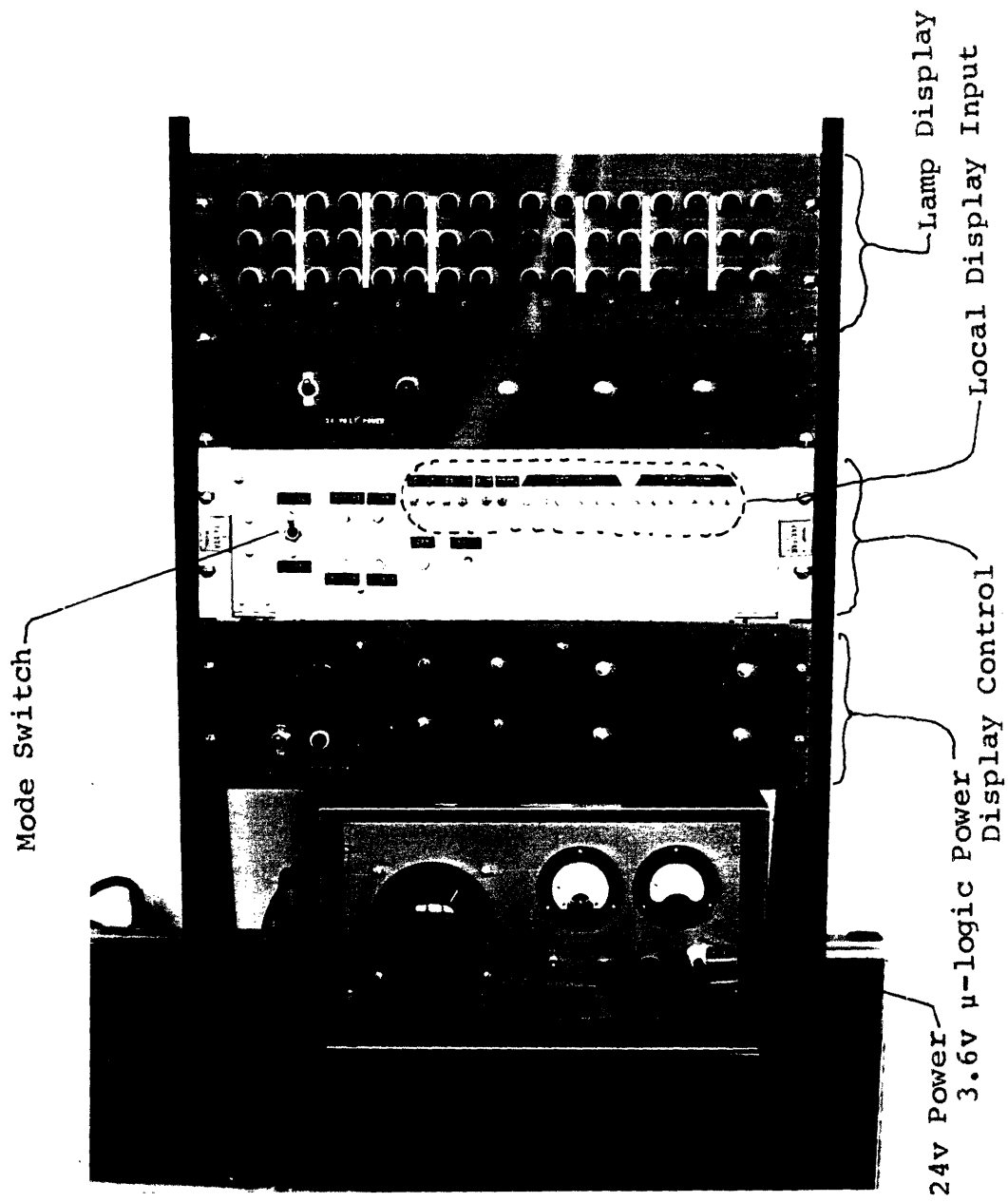


Figure 6. Display Control, Local Display Input, and Lamp Display.

pattern is to be applied:

Line 0-stimulus to be applied to fingers D and E

1-stimulus to be applied to fingers C and F

2-stimulus to be applied to fingers B and G

3-stimulus to be applied to fingers A and H

Line 6-dot 1

7-dot 2

8-dot 3

Pattern to finger(s)

9-dot 4

on left hand

(fingers A,B,C,D)

10-dot 5

11-dot 6

Line 12-dot 1

13-dot 2

14-dot 3

Pattern to finger(s)

15-dot 4

on right hand

(fingers E,F,G,H)

16-dot 5

17-dot 6

Each time a copy pulse is received, the buffer registers are updated in accordance with the information on the data lines 0-3 and 6-17. There are 48 buffer registers, one for each of the 48 solenoids in the stimulator. Thus, up to four sets of data from the data lines may be stored in the buffer registers before being displayed on the stimulator.

When line 4 is "on", a copy pulse causes the information stored in the buffer registers to be gated through to the solenoid drivers and the stimulator.

When line 5 is "on" and the mode switch is set to "computer", a copy pulse causes a completion pulse to be sent to the computer after a delay. In general, the computer does not allow another pattern to be displayed until it has received a completion pulse. The delay can be preset between 200 and 600 msec. If more variability is desired, an external pulse generator can be connected between the "TRIGGER" and "OUTPUT" coax connections, with the "EXT PG" switch placed in the "up" position. With the same switch configuration, but replacing the external pulse generator by a short piece of coax, the delay between the copy pulse and the completion pulse is reduced to about 20 μ sec, permitting the computer to have absolute control over the delay. This control is accomplished by inserting a delay loop in the computer program at a point after the computer receives the completion pulse and before it sends another pattern.

Closing the "HSR" switch ("up" position) and with line 5 "on" sets up a loop through which a copy pulse, once started, circulates at about 0.5 msec intervals. In local mode, this "high-speed recycle" allows the

experimenter to rapidly set up and alter patterns without having to repeatedly press the "CPY" button.

As an example of setting up a pattern, consider the following data on the lines (1 corresponds to "on", 0 to "off"):

LINE #	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
DATA	0	1	0	1	0	0	0	1	1	1	0	0	0	1	0	1	1	1

This data, when followed by a copy pulse, causes the pattern "011 100" to be stored in the portion of the buffer registers associated with fingers A and C, and "010 111" in the portion associated with H and F. If line 4 were "1" instead of "0", the pattern would also be displayed on the stimulator and would have the configuration shown in figure 7a.

PATTERN	●●	○○	●●	○○	○○	●●	○○	○○	○○
FINGER #	A	B	C	D	E	F	G	H	

7a)

PATTERN	○○	●●	●●	○○	●●	●●	○○	○○
FINGER #	A	B	C	D	E	F	G	H

7b)

Figure 7. Sample display patterns on stimulator (o corresponds to a raised solenoid plunger, ● to an unraised plunger).

The pattern in Figure 7b could be set up by the following sequence of operations in local mode:

1) set local display input switches to:

0 0 0 1 0 0 000 000 100 010

2) push "CPY"

3) set switches:

0 0 1 0 0 0 110 000 111 000

4) push "CPY"

5) set switches:

0 1 0 0 0 0 111 010 111 000

6) push "CPY"

7) set switches:

1 0 0 0 1 0 100 000 010 100

8) push "CPY"

The pattern is first stored in the buffer registers and does not appear on the stimulator until the "CPY" following the setting of line 4 to "1", i.e., not until step 8.

The information required in computer mode to set up patterns is similar to that provided by the local display input, each bit of the 18-bit computer word corresponding to one of the switches in the local display input. For instance, in programs using octal notation, the computer word equivalent of the switch

settings to produce pattern 7a (with line 4 a "1") is 263427. Furthermore, the computer instructions for, e. g., the PDP-1, necessary to set up the pattern in figure 7b are:

lio (040042 .

cpy

lio (106070

cpy

lio (207270

cpy

lio (424024

cpy.

3.2. Software

The software of the display system consists of a library of subroutines which can be used as building blocks to construct programs for specific tasks.

The subroutines currently planned or available are summarized in Table I. They are classified into Input, Processing, and Display subroutines. Input subroutines are used to read in data to the computer. Processing subroutines convert the data to a standard format which is then used by one of the display subroutines to present the necessary signals to the display control to operate the stimulator. Block diagrams and more detailed information for each of the subroutines are listed in the Appendix.

An example of a typical program is presented in Figure 8. This program receives text typed into the computer console. After each word of text is typed in, it is converted to the Braille code, and centered with respect to the eight fingers; the resulting centered Braille code is stored, and the next word of text can be typed in. After the desired text is completely typed in, typing a "center dot" on the console followed by any other character (except "/"), causes the coded text to be displayed, a word-at-a-time, on the

Subroutine Name	Abbreviation	Function*
Type-Input	TI	Text input from computer console.
Punched Paper Tape Input	PI	Text input from punched paper tape.
Pattern Input	PA	Non-text pattern input from computer console.
Word-Centering	WC	Centers up to 8 characters in an 8-position table.
Flex-to-Braille	FB	Converts flexo characters to their Braille equivalent.
Pile Buffers	PB	Piles up textwords in storage for use then a Display Subroutine is called.
Simultaneous Display	SD	Displays the pattern all at once.
Ripple Display	RD	Displays the pattern by a finger at a time; the pattern "ripples" across the fingers.

Table I. Summary of Subroutines.

* A glossary of terms used here is presented in the Appendix.

stimulator. Typing a "center dot" followed by a "/" causes the program to exit.

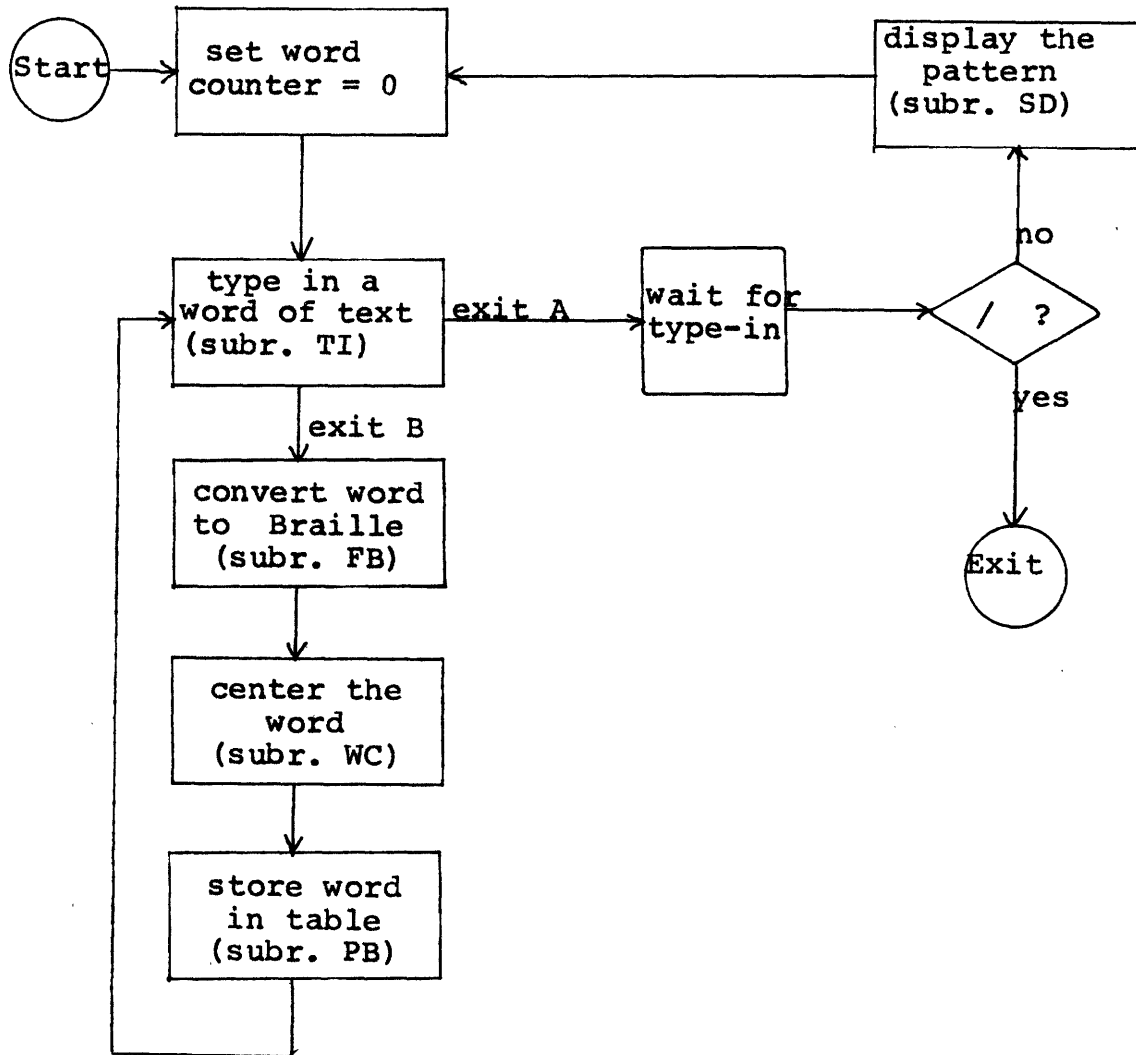


Figure 8. Typical program, built from subroutines (see Appendix).

4. CONCLUDING REMARKS

The display system described here is designed primarily as a research tool for tactile experiments to determine the feasibility of word-at-a-time presentation of Braille. Some of the questions an experimenter might be able to investigate using this apparatus are:

- 1) the relation between the complexity of the pattern and the time required to recognize it;
- 2) the number of cells which can be presented simultaneously (Troxel [5] found that a problem of crosstalk arises upon simultaneous stimulation of a large number of points.);
- 3) the effect of different sequencing arrangements (e.g., word presented cell-by-cell left-to-right, whole word presented simultaneously but repeated, etc.);
- 4) the effect of left-to-right centering of the pattern.

One way in which the conventional method of reading Braille differs from the word-at-a-time method described here is that in the conventional method the reader's fingers are active, while in the

present device the reader's fingers remain passively placed on the stimulator. This may be a significant difference and could be looked into by future experimenters.

An immediate application of this system would be as an output to a computerized reading machine for the Blind. By using a modified stimulator, the system could be applied to the study of tactual motion perception, etc.

The library of subroutines currently available is rather small; other subroutines may easily be added to accommodate future experiments and applications.

A very useful addition to the software of the display system would be a maintenance program which could be used by the experimenter to periodically check the system, via computer, for proper adjustment and operation.

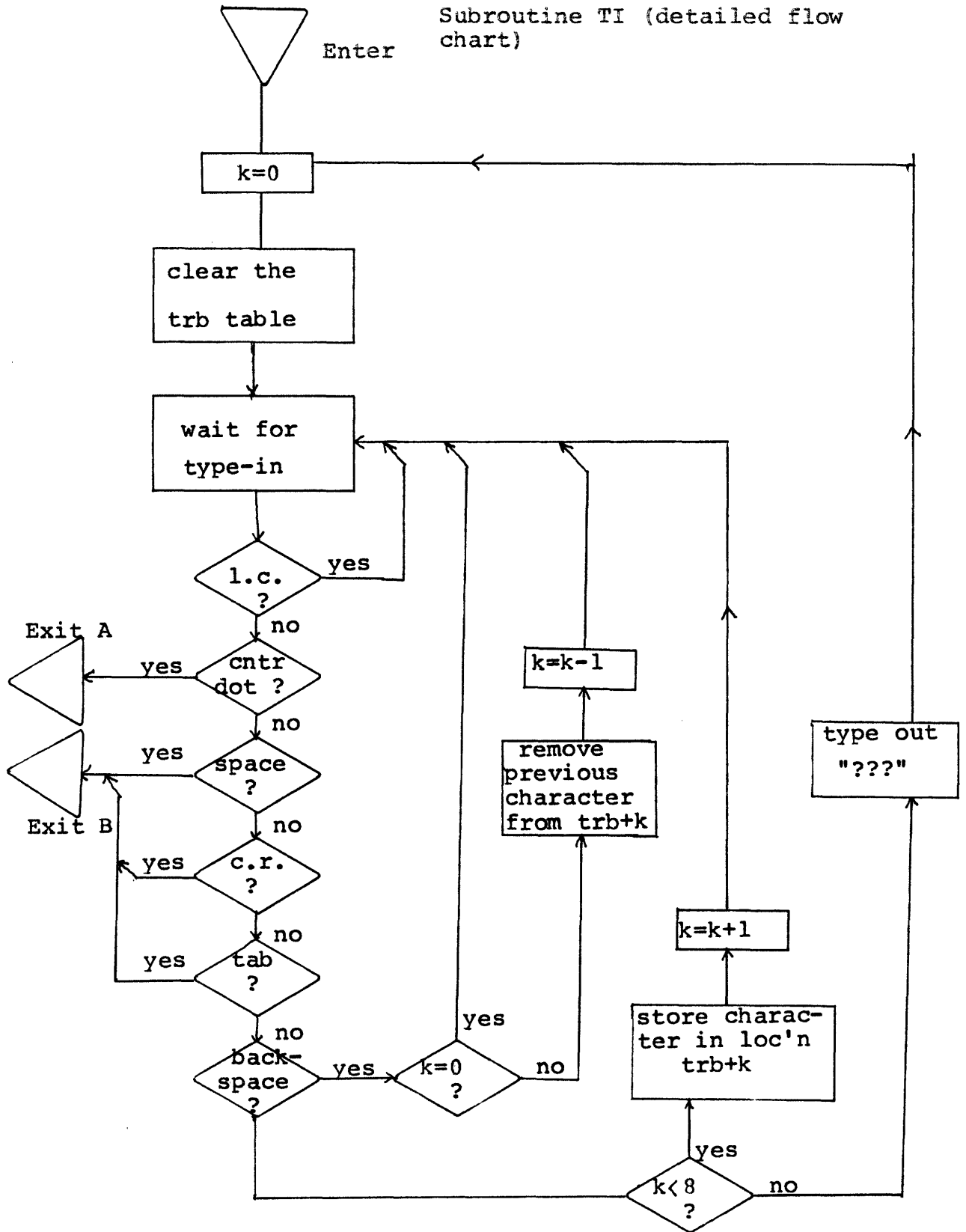
APPENDIX

Glossary of Abbreviations and Terms Used in the Subroutines

Character	One character of a textword.
Codeword	The first 6 bits of a computer word; i.e., lines 0-5.
Computerword	An 18-bit computer word.
Dataword	The last 12 bits of a computerword; i.e., lines 6-17.
Displayword	The 18-bit computerword, consisting of codeword and dataword, which is sent by the computer to the display control.
Displaypattern	A complete pattern on the tactile stimulator at any instant of time. Composed of as many as four displaywords. Corresponds to one Textword.
Patternsequence	A sequence of display patterns.
Textword	A word of text to be processed.

k	Number of characters in textword currently being processed.
n	Number of textwords in current patternsequence.
t2,t3	Time parameters of the display subroutines.
rep	Number of times a particular pattern is to be repeated consecutively.
buf	Storage table for displaypattern currently being displayed.
tab	Flexo-to-Braille conversion table.
teb	Storage table for several textwords.
trb	Storage table for current textword.

Subroutine TI (detailed flow chart)



Subroutine TI Notes

Input:

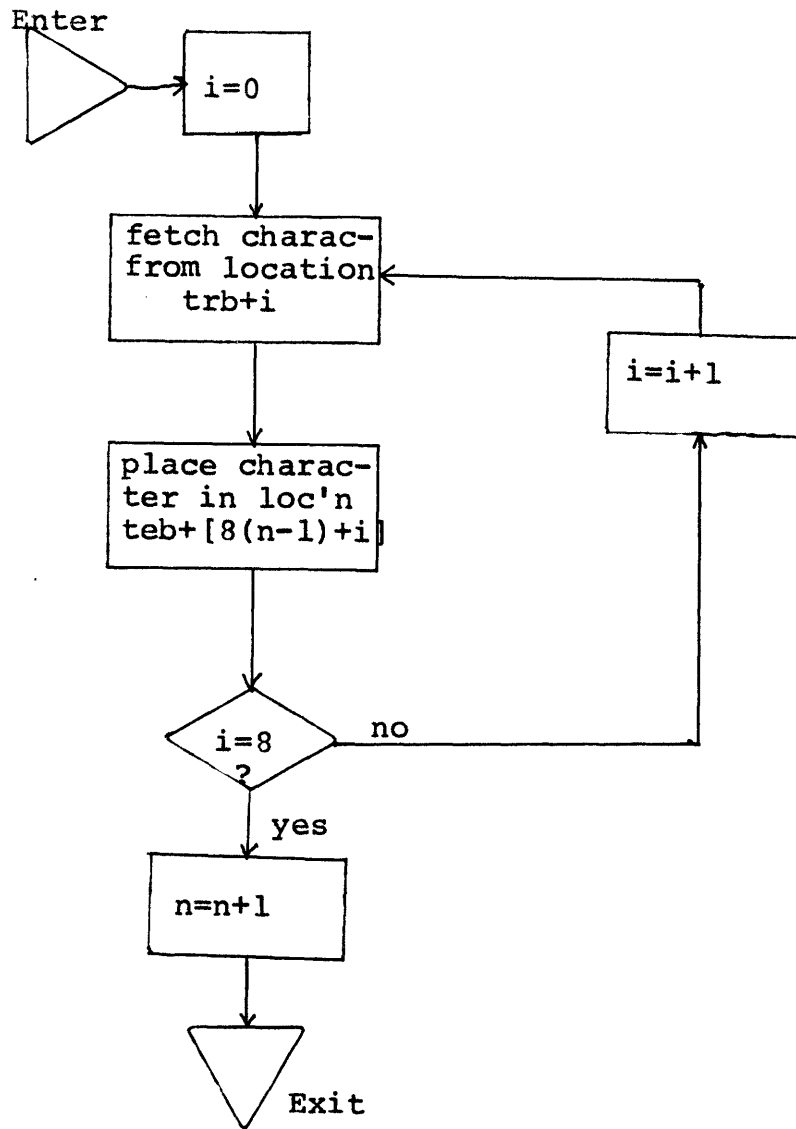
Typed input from computer console. Up to 8 characters per textword. Typing space*, tab, or carriage return (c.r.) terminates the textword and transfers control back to the main program via exit B. Typing the character center dot transfers control back to the main program via exit A. Typing backspace erases the previous character; backspace typed at the beginning of a textword is ignored. If more than 8 characters are typed in, the error symbol "???" is typed out, character counter k reset to 0, and the character buffer erased. Legal text characters are alphabetic, numerals, and "upper case". "Lower case" is ignored.

Output:

Textword is stored characterwise in memory locations trb through trb+7. Number of characters in textword is stored in memory location k.

*Underlined commands are those typed in by the experimenter.

Subroutine PB Flowchart and Notes



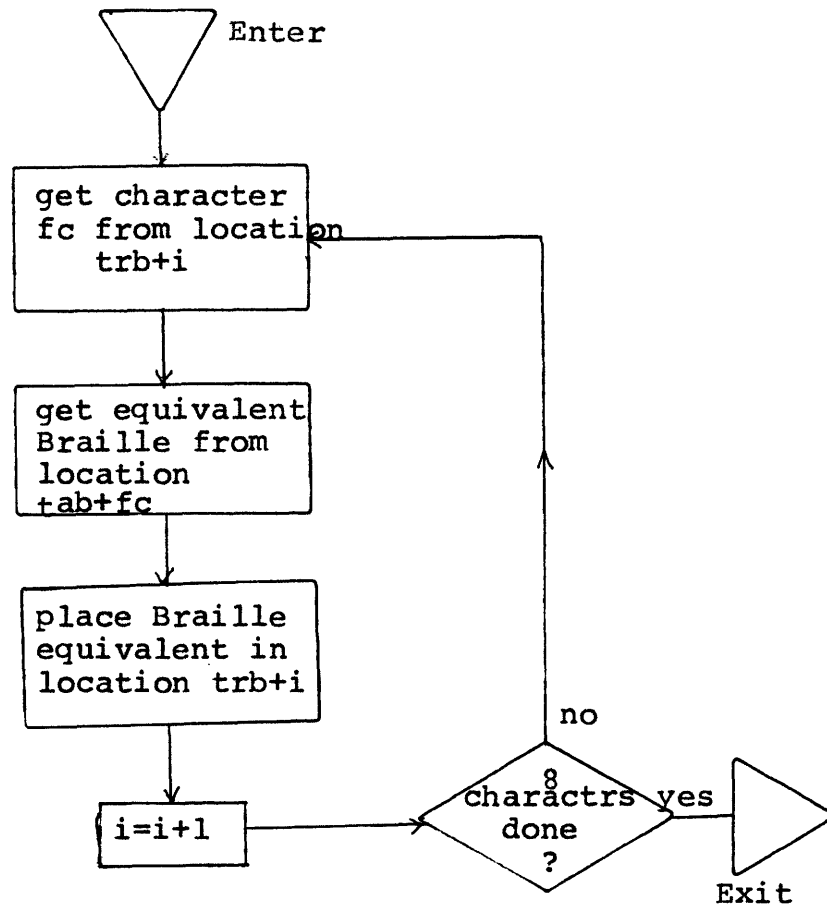
Places current textword into locations in table teb immediately following previous textword(s) in patternsequence.

Input: textword in trb table

word-counter n must be initialized to 0 at beginning of program.

Output: Patternsequence of textwords in teb table locations teb through teb+8n-1.

Subroutine FB Flowchart and Notes

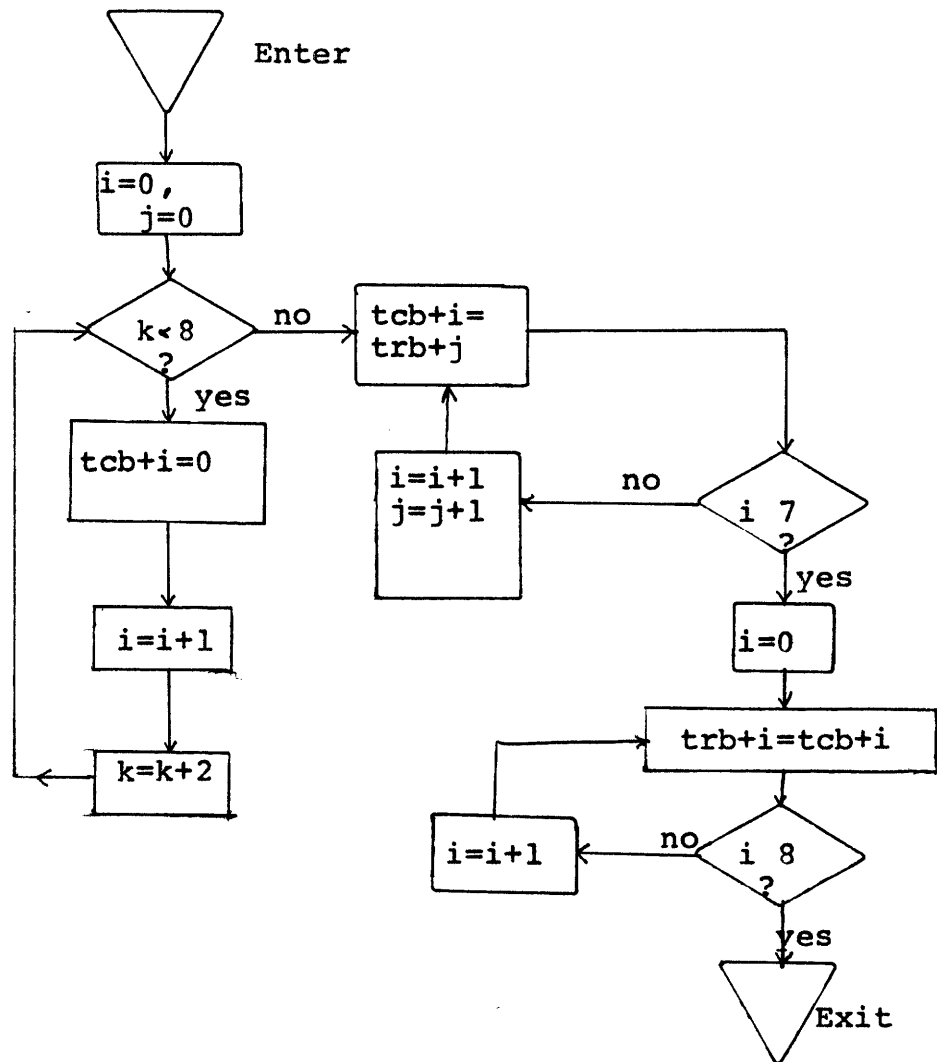


Takes each flexo character from trb table, converts it to the equivalent Braille, and returns the Braille to the trb table. Braille equivalent of character whose flexo code is "fc" is stored in location tab+fc.

Input: textword stored in trb.

Output: Braille equivalent of textword stored in trb.

Subroutine WC Flowchart and Notes

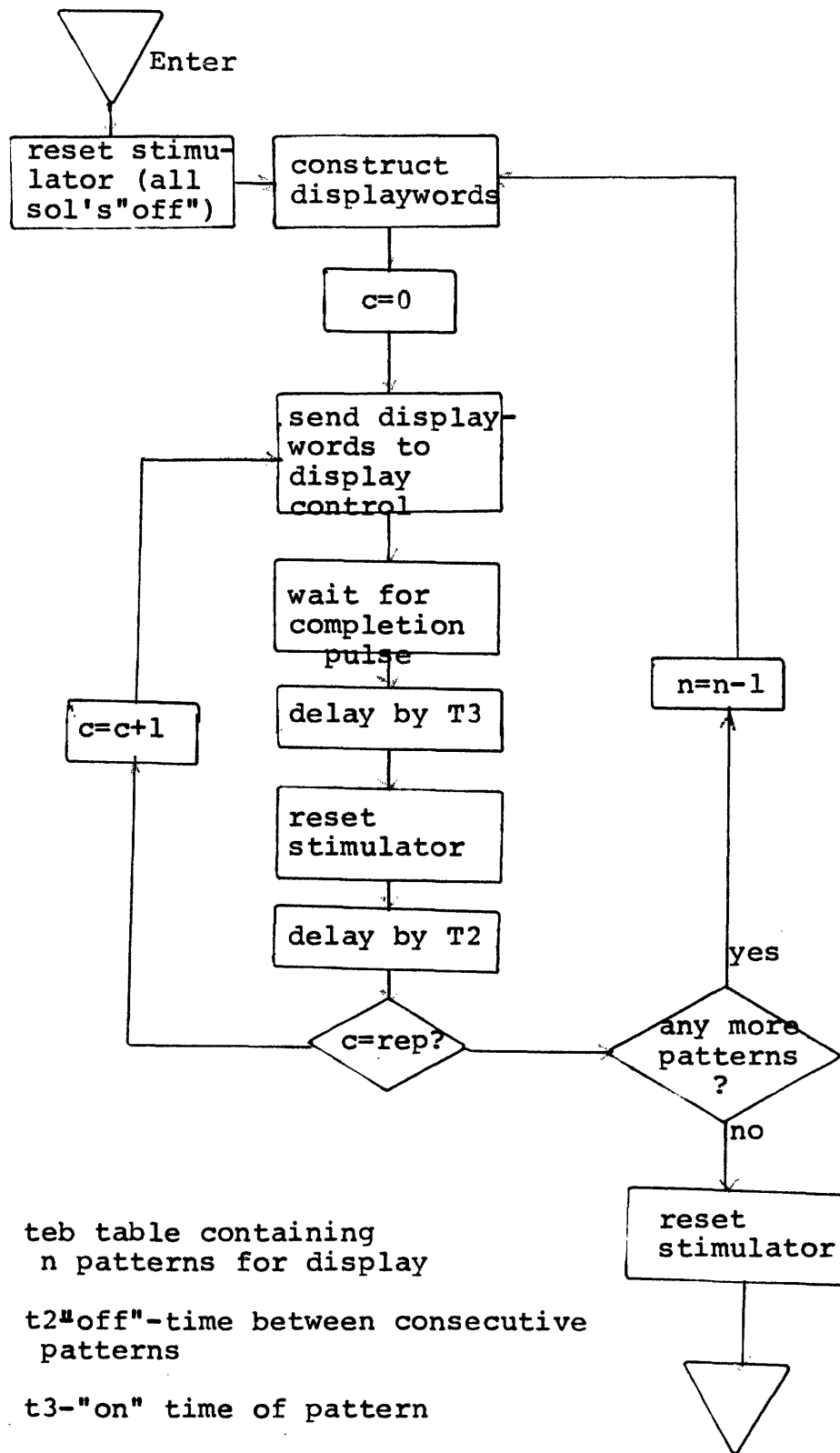


The textword in the trb table is centered and replaced in the trb table. Value of k is lost.

Input: textword, consisting of k characters, stored in locations trb through trb+k.

Output: textword centered in table trb.

Subroutine SD (simplified) Flowchart and Notes



Input: teb table containing
 n patterns for display

 t2"off"-time between consecutive
 patterns

 t3-"on" time of pattern

 rep-number of repetitions of
 same pattern consecutively

Output: to stimulator.

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