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PREFATORY NOTE

The *Research Bulletin* of the American Foundation for the Blind is intended to be a means of publication for some scientific papers which, for a variety of reasons, may not reach the members of the research community to whom they may prove most useful or helpful. Among these papers one may include theses and dissertations of students, reports from research projects which the Foundation has initiated or contracted for, and reports from other sources which, we feel, merit wider dissemination. Only a few of these find their way even into journals which do not circulate widely; others may never be published because of their length or because of lack of interest in their subject matter.

The *Research Bulletin* thus contains both papers written especially for us and papers previously published elsewhere. The principal focus may be psychological, sociological, technological, or demographic. The primary criterion for selection is that the subject matter should be of interest to researchers seeking information relevant to some aspect or problem of visual impairment; papers must also meet generally accepted standards of research competence.

Since these are the only standards for selection, the papers published here do not necessarily reflect the opinion of the Trustees and staff of the American Foundation for the Blind.

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Since our aim is to maximize the usefulness of this publication to the research community, we solicit materials from every scientific field, and we will welcome reactions to published articles.

M. Robert Barnett
Executive Director
American Foundation
for the Blind

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SENSORY READING AID FOR THE BLIND*

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INTRODUCTION

There is need for a faster sensory reading aid for the blind (7). At present the only such system in general use is braille. This system is "read" by scanning tactually with the index finger a succession of spatial cells, each of which contains a configuration of raised bumps (or absence of same) in six positions in the cell. In the elementary braille system called braille Grade 1, each configuration, generally speaking, corresponds to a single letter of the alphabet. Since this obviously limits reading to a letter-by-letter flow it is undesirably slow. A faster system which is more difficult to master is called braille Grade 2 which uses abbreviations and encodes some whole words and common letter groupings into single cells. Even Grade 2 braille is not acceptable as the final answer for a sensory aid, however, because of its slow speed compared to visual reading. Normal prose can be read visually at approximately 300 to 400 words per minute, while Grade 2 braille is good for only about 70 to 90 words per minute. There appears to be a psychological deterrent in this fact, in that only a small percentage of blind persons (and this applies particularly to those who had sight at one time) are willing to embark on the long and tedious process of learning Grade 2 braille for a payoff of only 70 to 90 words per minute.

Assuming that a faster sensory reading aid is needed, a first step in looking for one is to examine Grade 2 braille to see why its speed is limited. Much investigative work has been done on this subject and on related questions of sensory information transfer. While the need for research on *many* aspects of sensory communication has been indicated, there was and still is a clear indication of the need for exploring at least those systems which 1) use the kinesthetic and tactual senses (movement and pressure) of the *fingers*, 2) employ a large number of independent sources of stimulation, and 3) use some redundancy reducing coding of English prose text.

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* This publication is based on a thesis submitted in partial fulfillment of a Degree of Electrical Engineer at the Massachusetts Institute of Technology, Department of Electrical Engineering.

Some comments are appropriate concerning the above three aspects. First, of the many types of sensory stimuli conceivably useful for communication, movement of and pressure on the fingers have been shown to be conducive to exploitation far beyond what has already been done, perhaps being even the highest speed method ultimately feasible (1). The factors of convenience and esthetic effect enter here also when finger operated devices are compared to other possible systems such as, for example, one with buzzers attached to the chest (4).

Second, concerning the idea of using a large number of independent sources of stimulation, it seems apparent that a system using many fingers would have the same advantage over braille that touch typing has over one-finger "hunt-and-peck." There are strong experimental indications that the use of many fingers is a promising way to go.

Third, the matter of the redundancy of English prose text arises from the fact that a visual reader moves his eyes in quantum jumps rather than in a smooth flow; this is interpreted to mean that a person reduces prose redundancy for himself by scanning for "chunks" of information (2). The state of research in sensory aids for the blind does not yet provide for any such scanning capability by which a blind person can smooth out the information flow in the vicinity of his maximum desired value for the type of text. Accordingly, attempts to increase speed using a nonscannable sensory reader have embodied the idea of *coding* for maximum information transfer at a high but constant rate. As will be seen, the stenotype code has this feature.

It is the above three factors which have suggested the use of a stenotype machine in reverse. The stenotype machine will be described in more detail later. It is a device which looks like a small typewriter with an unusual keyboard, whose keys cause a Roman type to print on an adding-machine-like paper roll. Trained stenotypists transcribe from voice to paper by depressing one or more keys simultaneously, causing the printing of letters on the paper in an almost phonetic code at approximately an average of one word per line (a new line feeds at every stroke of the keys). In order to be considered a qualified stenotypist for normal secretarial or stenographic work an operator must be able to take at least 125 words per minute, and in order to be qualified as a court stenographer an operator must be able to take at least 200 words per minute. Experts can take 300 or sometimes more, contests involve speeds over 350.

In this research project the stenotype machine is operated in reverse. That is, a message is properly encoded on punched paper tape, which is fed into an electronic decoder and keyboard actuator in such a manner that *the keys of the machine move up and down as if the succession of words constituting the message* *were being transcribed by a disembodied operator.* The subject, a trained stenotypist, keeps her fingers in the proper "rest position" on the keyboard, notes the key actuations, and responds by saying the words which would be thus transcribed if she were operating the machine herself. It will be seen that the stenotype machine is peculiarly well suited to this technique. Three modes of operation were used for the familiarization process: one-shot operation by foot pedal operated by the subject; one-shot operation by foot pedal operated by a monitor; and continuous operation by external control signal of variable recurrence rate.

The research described herein has consisted of:

1. The manufacture of a suitable number of sample tapes by conversion of stenotype takes using the Flexowriter and TX-0 computer.

2. The design, building, testing, and operation of a decoder which takes coded punched paper tape and converts it into actuating signals for the electromechanical actuation of the keys of a stenotype machine keyboard.

3. The conduct and analysis of information transfer using the system as a sensory aid for a "blind" person who in this case is already a stenotype operator.

THE STENOTYPE MACHINE

A good collateral description of the stenotype machine and stenotype in general can be found in Reference 3, which describes experiments in the translating of stenotype code by computer into English prose. Figure 1 gives a picture of the machine, which is like a small typewriter with 23 keys. It is operated somewhat like a typewriter in that all fingers of both hands are used to actuate the keys. The main differences are: 1] the paper output tape of the stenotype machine makes one line feed per character set depressed, that is, one line feed at each distinct depression regardless of the number of keys depressed (see Figure 2 for a sample of the output); 2] each character prints in its own distinct horizontal position on the line (thus, the character *K* is always printed in third place from the left of the line, regardless of when or with what other keys it is struck); 3] not all characters of the English alphabet are represented by individual keys with names (for example, there is no *X* or *V*, which are represented in code by the combination *EU* and the single letter *F*) and some characters are represented by more than one key - *S*, for example (see Figure 3); 4] one finger may be required to operate two (contiguous) keys at a time and the physical design of the keyboard facilitates this; 5] numerals are not printed by discrete keys but by the simultaneous striking of a numeral bar and certain letter keys; and 6] the keys

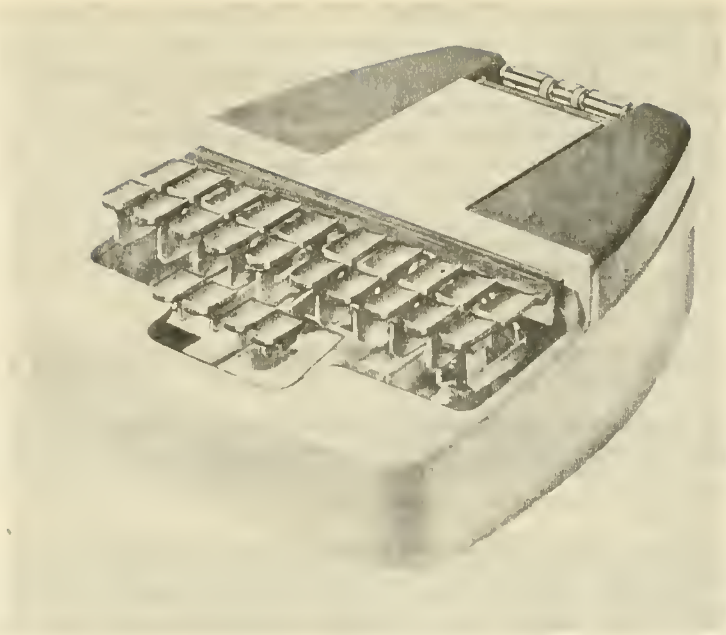

Figure 1. The stenotype machine

which are actuated are chosen in accordance with an almost phonetic shorthand-type code (more on this code later).

Work done by Bliss (1) using a sort of abstract typewriter in reverse, and by Troxel (7) using a six-finger coding of poke probes, suggested the use of the stenotype keyboard which has certain made-to-order features. One obvious advantage was that the machines themselves are "off the shelf" and easy to acquire, thus reducing the time and energy required to manufacture the mechanical part of the system. In addition to this the stenotype keyboard provides the ideal means for using a large number of independent sources of stimulation and requiring a binary choice as opposed to a choice among three, four, or more values. When the stenotype machine is used *each key* can furnish an independent stimulus, concerning which the only decision is between *down* and *up*. Using the stenotype machine in this way also follows the suggestions by Bliss, Troxel, and others that more fingers be used.

There is one subtle but important feature of stenotype operation which is pertinent to its choice as a research tool. Using a normal typewriter, an operator rests her four fingers of each hand on the eight keys of the "rest position." To actuate any keys other than the "rest" keys she must lift the appropriate finger and then translate it horizontally before striking the desired key. This is a difficult process to make function in reverse.

```
          E
 T    R   EU        D
                   S
   PW     E        S
 T      O
          EU  P L
 T     A  EU      T
       A
S         E  R    T
   P H  O    RPB
 T P       U    L
  K W  A        L T
 T P H            T
  K    A   U    L
            F P L T
   PW      U
       A
 T        EU   B G
     HR   EU
     H A   U  PB  T
                 G
 T P H  O E       T
          E
     HR    U        D
                    D
              P L
            F P L T
 TKPW  A  EU  PB
   P      E       T
          E  R
   P       U R     S
                    D
                   S
```

Figure 2. A sample of stenotype output

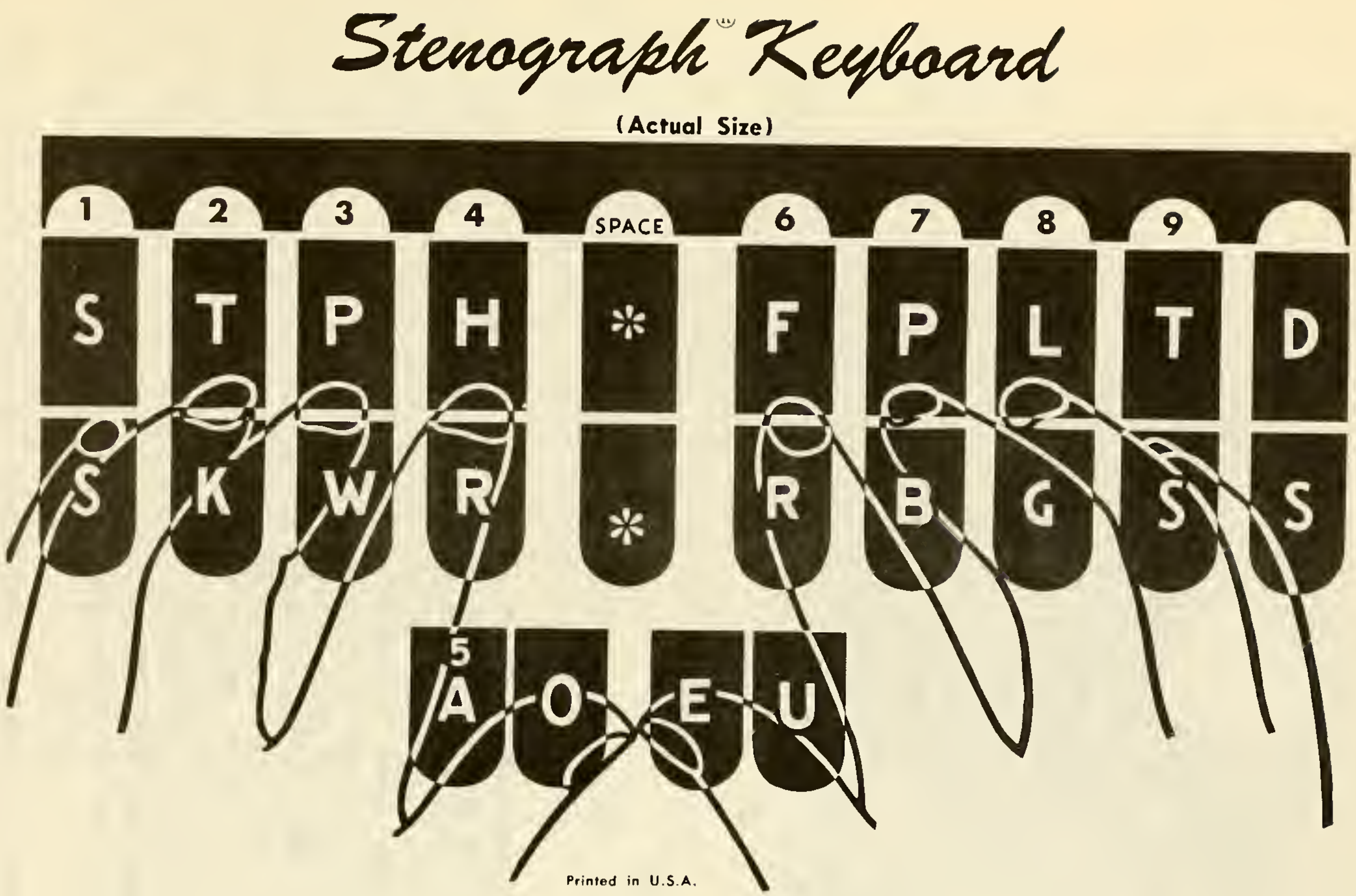

Figure 3. The stenotype keyboard

Bliss' experiment is an approximation in that a key is moved under the subject's finger in the direction her finger would move were she to be typing the letter. Added to the fact that the Bliss "keyboard" is only a gross facsimile of a typewriter keyboard, it can be seen that a certain amount of the subject's typing familiarity is probably lost in the necessity for adaptation. In stenotype operation, on the other hand, the "rest position" (see Figure 3) has each finger and the thumbs of both hands resting on the gap or slot between two contiguous keys, which can be operated either separately or simultaneously (by depressing the *slot*, as it were). The only keys not so covered are the asterisk key, numeral bar, and right hand *D/S* pair. The asterisk key is used to flag an error and was not needed for this purpose in the research project. The numeral bar can be eliminated by the simple device of representing all numerals in their spoken form, a technique used by many operators for convenience in any case. The right hand *D* and *S* keys are used only for the final "*ds*" and "*ts*" sounds in words. As will be seen, use of text involving these characters caused confusion since the right hand *D* and *S* keys cannot be sensed from the rest position; use of these keys was avoided in the speed trials and suitable recoding could eliminate their need whatsoever.

Further comments on how features of the machine affected this research will be found in the section on the experiments.

THE STENOTYPE CODE

The stenotype code was first formulated by John Ireland in 1914 for its present purpose, namely, the transcription of speech into a standard machine shorthand. Even before the days of information theory and high speed digital computers, Ireland was able to devise a code which would achieve high channel capacity by roughly equalizing the amount of information per stenotype character, by assigning fewer characters to the most used sounds and more characters to the least used sounds. It is remarkable that the consonant and vowel sound assignments and the word abbreviations originally made have stood up almost without change until this day. To my knowledge there has been no analysis of how well the stenotype code does average out the information rate; one interesting phenomenon along this line, however, is the apparently uniform speed at which stenotype operators strike the keys, suggesting that there may be a certain amount of line-by-line averaging of information rate also.

The stenotype code is essentially phonetic and operates generally on a one-syllable-per-line basis, except for abbreviations of single words or whole phrases. There are three groups of characters: 1] the *beginning* consonants (*S*, *T*, *K*, *P*, *W*, *H*, and *R*), 2] the vowels (*A*, *O*, *E*, and *U*), and 3] the *final* consonants (*F*, *R*, *P*, *B*, *L*, *G*, *T*, *S*, *D*, and *S*). Note that some English letters find their counterparts in two stenotype characters (*T*, *P*, and *R*), while there are three stenotype characters representing *S*. As can be seen in Figures 2 and 3, the two *T*'s, etc., are not the same stenotype characters at all, and their stenotype meanings are distinct, as the next paragraph will explain.

Characters of the first group are used exclusively for the *initial* sound of a syllable if that sound is in the nature of a consonant. Any such sound is represented by one of these keys or by a combination of two or more. Thus, the first *p* sound in "pipe" is represented by the left *P*. There is no *L* in the first group, though, and an initial *l* sound, as in "lift" is represented by the combination of *HR*. All possible initial consonant sounds have a representation by *some* set of the first group. The less frequent the sound in English, the more stenotype characters will be used to represent it. This same description carries over in the second group, the vowels. Since a new line will be used for each syllable (exclusive of abbreviations and some contractions), only one vowel sound (at most) is necessary in each line, and it is given by a single vowel key or a combination of vowel keys. Thus the *i* sound in "lift" is given by *EU*. Characters of the third group are used for *final* consonant sounds. Combinations of these are also employed to represent less used final consonant sounds. Punctuation marks have their coding also, usually an easily-fingered combination (for example, a period is *FPLT* and a comma is *RBGS*). As mentioned before, numerals are obtained by striking the numeral bar (see Figure 3) in conjunction with an adjacent key. For more specific information please consult Appendix D which contains lists of words used in the experiment.

The coding is many-to-one *from* English *into* stenotype code, and is almost standardized. There are really only two codings which are important, and these are almost identical. The basic coding is learned by all stenotype operator students. Theoretically there is complete standardization in this coding. Any operator should be able to transcribe any other operator's tape. In practice, as can be imagined, personal individualities develop. These almost never advance to the stage which would make it difficult for one operator to transcribe another's tape, since phoneticity is still preserved and context is usually available. In this research it was discovered that such variations hindered the learning process when the machine is used in reverse as a sensory aid. More will be said on this when the experiments are described.

The second important coding scheme is called Barry Horne, after its creator. This coding embodies more contraction in the nature of abbreviations and also more vowel sound combinations for greater phonetic precision. It is used for faster work, such as court reporting. This again is generally standardized, although individual variations do creep in. A more advanced operator who has mastered Barry Horne usually does not revert to the simpler code even in slower transcriptions. The subject of this experiment is fluent in Barry Horne, and it was found that the mixture of Barry Horne tapes with tapes made by less advanced operators caused difficulties.

While the code is almost a well defined mapping of English into stenotype, the reverse is not true. First it is obvious that the phonetic nature of the code results in the possible mapping of isolated lines of stenotype tape into any one of a set of homonyms or near-homonyms. For example, the stenotype line *TPHOT* can mean either "not" or "note" in the simpler code (although in this, as in most similar cases, Barry Horne eliminates ambiguity by transcribing "note" as *TPHOET*).

The choice among all such possibilities is made by context. A more subtle level of difficulty arises in the case of words or syllables which may be either words in their own right or abbreviations of sets of other words. A still greater difficulty arises from the fact that many English words are multisyllabled. Unless the word is so common (in general or in the professional context of the transcription) that it is abbreviated as a whole, it will be represented by two or more lines, one for each syllable. It can easily be seen that cases can arise in which one line can be interpreted equally well as either a word in itself or as a part of a multisyllabled word. In extreme cases three lines of stenotype could mean one, two, or three separately-sized words, each with its own homonymical possibilities. The upshot of all this is that the transcription from stenotype into English has all the features of translation between two natural languages, a fact which gave Galli so much trouble (3). For our purposes the problem is not so great. Ultimately the sensory aid would be used for reading in context; in the meanwhile the learning process was facilitated by suitable choice of text and technique, as will be seen under the experiments.

THE EXPERIMENTAL SYSTEM

The experimental system is shown in block diagram form in Figure 4. The decoder portion is shown in more detail in Appendix A. The main system components are tape and tape reader, decoder, key actuator, machine, footpedal or square wave generator, and operator. System components are further described as follows.

Tapes

The data tapes were made as part of the project. Since it was intended to actuate at least 19 keys (the "rest" keys; note that 1 key [initial *S*] is a double, hence only 19 and not 20) independently and simultaneously, it was necessary to provide three

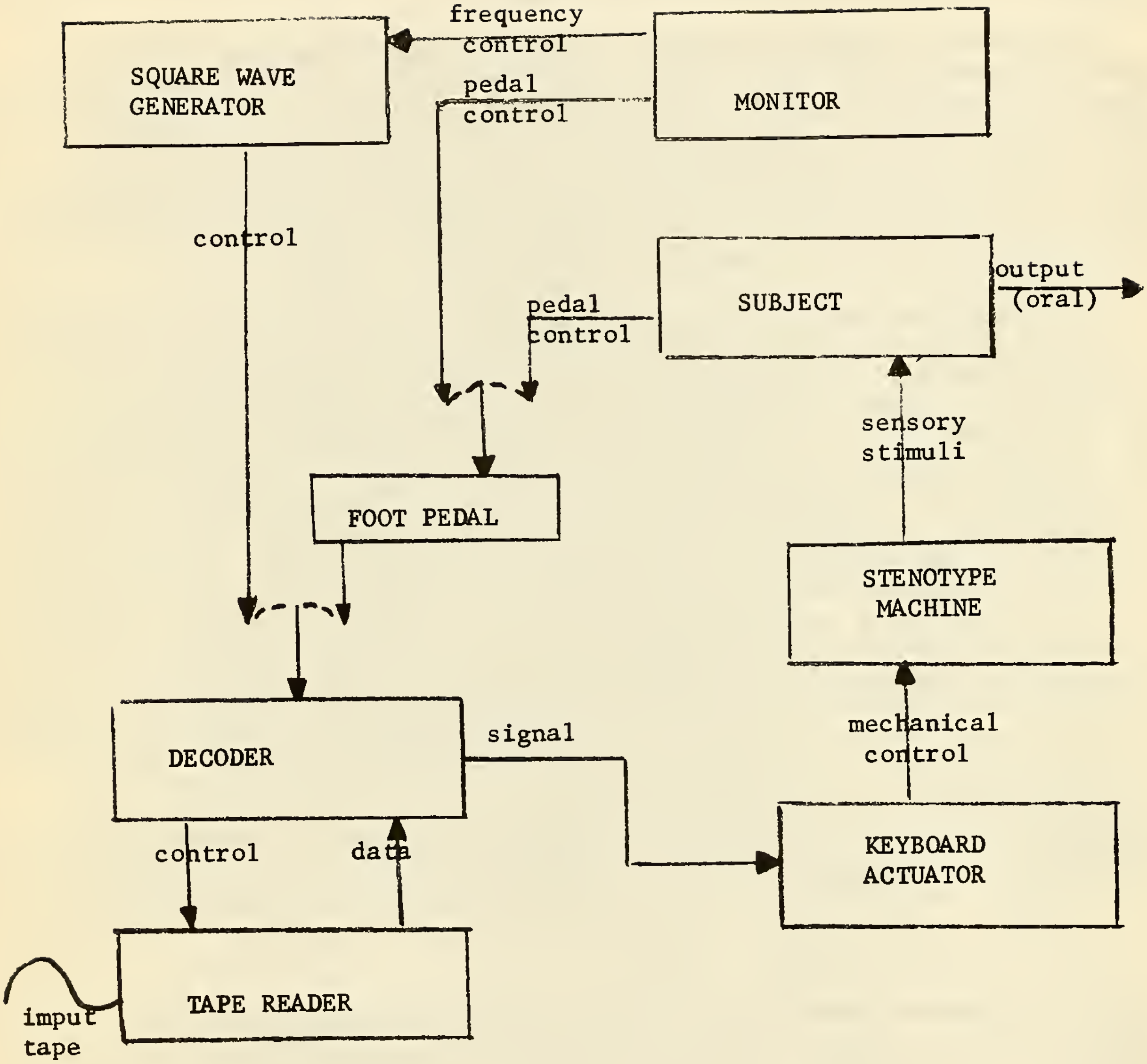

Figure 4. The experimental system

lines of 8-hole tape to represent each character set. The assignment of stenotype characters to paper tape hole numbers and line numbers is given in Appendix B. Each three lines of data are followed by an empty fourth line, a feature which actually proved unnecessary since gated readouts were used rather than continuous (thus eliminating the need to move away from the final data line at the end of a set). The tapes were obtained by punching a 7-hole tape on a 7-hole Flexowriter, then using the TX-O to convert that input tape into an 8-hole data tape. The program used for this purpose is given in block diagram form in Appendix C. It is assumed that the complete program itself is of no future interest since it involved a "juryrig" created to permit the TX-O Computer to punch *8-hole* tape.

Tape Reader

This is a standard 8-hole Invac tape reader. It is caused by internal or external strobes to mechanically move the tape one line and read out the punched holes as signal levels in appropriate channels. This experiment used external strobes from the decoder.

Decoder

The primary purpose of the decoder is to route the signals from the eight different holes of three different lines of tape to the appropriate key actuators with the proper timing so that all keys of a line actuate together, let up together, and continue to do this in accordance with the selected mode (one-shot or continuous with variable speed). A block diagram of the decoder is given in Appendix A. It operates as follows. Depression of the pedal (or positive-going signal from the square wave generator) begins a cycle of four successive "step-and-readout" control signals to the tape reader. Each line of tape is read into three banks of NCR gates; gating strobes cause the proper bank of flip-flops to be set from each line of tape. Driver banks cause keyboard actuators to pull keys down as soon as the flip-flops are set. This results in a "wave" of keys going down from left to right in three sections. The sections are actuated approximately 65 milliseconds apart. This seemed to cause no difficulty to the subject, but would obviously be eliminated in a more sophisticated system by a set of AND gates and one final gating strobe. Releasing th pedal (or negative-going signal from the square wave generator) causes all flip-flops to reset and all keys to return by spring action to the "up" position.

Keyboard Actuator

The keyboard actuator is merely a bank of 24-volt dc solenoids with the proper pull force and throw distance. All keys except the number bar can be actuated. The actuator is mounted a distance below the keyboard and connected to the keys by wires. This was necessary in order that the physically large solenoids could pull the keys down without binding the solenoid plunger by a slant pull. This method was selected because of its mechanically simple construction. Both it and the rather crude spring returns on the plungers were clumsy and subject to malfunction. Possible improvements will be suggested in a later section.

Machine

The machine used was a standard stenotype machine removed from its carrying case and screwed onto a platform. Wires loop over the key end of each key arm and drop down to the actuator plungers. The machine prints its stenotype tape when operated as if it were being used for its ordinary purposes.

Foot Pedal and Square Wave Generator

The foot pedal was a converted sewing machine pedal with two microswitches, one to start the readout sequence and one to reset the whole system. The square wave generator is a standard laboratory item (any will do) which feeds into the same inputs of the decoder as does the foot pedal; an inverter makes the negative-going side of the square wave into a positive strobe for reset purposes.

Operator

The operator for this experiment was Miss Saundra Lee Potter, of North Attleboro, Mass. Miss Potter was completing her second and final year at the Stenotype Institute of Boston. At the beginning of the experiment Miss Potter had an official speed of 175 words per minute (these official speed tests are given using English prose). She anticipated qualifying at 200 words per minute or better by the end of the spring term, and thus effectively might be said to have had a speed of 200 words per minute during the last part (speed tests) of the experiment. While alert and interested, Miss Potter appears to have no peculiarities in her stenotype technique which would make this experiment less than representative.

THE EXPERIMENTS

Procedures

The first necessary task was to familarize the operator with the equipment and the purpose of the experiments. This was simplified by the fact that as operator she could sit and place her hands in the normal transcription positions, thereby being free to concentrate solely on the key movements. Because of the jutting out of the tray of solenoids it was necessary for her to sit sideways rather than the normal straight ahead; this added a fatique factor but nothing more.

The next step was to try different input texts and look for "bugs" both in the texts and in the system as a whole. A number were found and eliminated; others were found but could not be eliminated. These will be described - but first a word about the texts.

The simplest text was the Dewey list of 1000 most used English words. Obvioulsy the operator was familiar with these words. The difficulty became evident immediately, however, that many of these words were multisyllabled and required more than one line. In the learning process the operator could not rely on context and had as yet no facility of temporary mental storage (the "copying behind" that serves Morse code operators so well). She would respond as if each syllable were a word in itself, and since some represented no known words, a confusion factor was introduced.

At this time she was actuating the foot pedal herself. She tended to search the keybank manually for depressed keys. This violated the intention of the experiment, which required that she recognize each set of depressed keys as a *pattern*. Consequently the mode of operation was change to that one in which the experimentor operated the pedal and later to automatic operation at variable speeds.

Some of these 1000 words, which had been transcribed by a number of different students at the Stenotype Institute, were put into the simple code, while others used the Barry Horne. Also a number of personal idiosyncrasies had crept in. To avoid this, for practice purposes at least, a tape was used which was made from the jury charge of an old trial record which had been transcribed by the operator herself. This had the advantage of familiar coding and the disadvantage of repetition on the one hand and use of unusual technical terms on the other. It helped to build up speed, however.

With the idea that a possible evaluation of communication capability could be obtained by the use of a reading comprehension test consisting of a short story with questions pertaining thereto, tapes were made from four such short reading comprehension tests. These proved to be unsuitable. The stories presented difficulties of comprehension when read in English. The construction was not always simple, and a number of words were used which were not familiar to the operator; this would have caused not trouble in transcription but caused much confusion going in the other direction. The operator had not at this stage worked up enough competence to be able to evaluate word possibilities from content, which made such texts almost impossible to use as reading comprehension tests.

All of the above texts contained some words which used the stenotype final *D* and *S*. These are not sensed in the rest position. The remaining word remnants in some cases were understandable in themselves, and in these cases no harm was done. In other cases, however, some of the word remnants meant nothing in themselves; this caused confusion which slowed the process down drastically when the operator was using the foot pedal and disrupted succeeding words when the experimenter was using the foot pedal. During the lead time, while more suitable tapes were being formulated and manufactured, the above troubles were avoided by the simple expedient of telling the operator when a word was beginning which required more than one line and when a final *D* and *S* was used. This was acceptable during the familiarization process but obviously would not do in any evaluation for the record.

When the foot pedal was used the operator tended to try to keep the current word in actuation until she was sure that she understood it and until she was sure that she had noticed every key depressed. It turned out that the characters sensed by the little fingers of each hand were easily missed, and these include the initial *S* and final *S* sounds, which often can be deleted from a word and still leave a genuine word behind. Thus in the interest of error-free operation she would want to take the time to feel for all keys on a positive basis. This was contrary to the intent of the experiment and would effectively prevent the build-up of any significant speed. Therefore, after a few days of familiarization, the experimenter began to use the foot pedal exclusively and to operate it at a speed which "pushed" the subject and which prevented her from searching physically with her fingers. The next step was to build a constant speed keyer, using a square wave generator of variable frequency and an inverter, as described in the Experimental System. As the subject built up speed this mode seemed more effective by far than the foot pedal. One possible reason for this, apart from the good effect of predictable regularity in itself, is that this mode caused the keys to be in the "up" or restored position for slightly more than half the total time, whereas the tendency when operating the foot pedal is to actuate a new line immediately after letting up on the pedal following the previous line.

In the length of time available for the experimentation it appeared most practical to concentrate on observing the maximum possible speed which would be achieved using single words. It is difficult at best to evaluate human communication systems in terms of channel capacity or bit rate. This was not attempted. On the other hand it is certainly desirable to produce results which could in some manner be related to other results using other systems. This was attempted, using three lists of selected English words.

These three speed lists included words found in one or more of the original familiarization texts. No multiline words were used. No multiword lines were used either (such as *O..T* meaning "on the"). No highly technical words or unusual words were used.

No words were used which required the final stenotype *D* and *S* characters. The lists included a mixture of Barry Horne and elementary coding; this was inadvertent since the experimenter did not at the time understand the full significance of the difference. The lists are given in Appendix D.

It will be seen that there are *three* lists: a *hard* list an *intermediate* list, and an *easy* list. The easy list is almost exclusively composed of words which require four or fewer stenotype characters, of which the four- and five-character words use one or two double character, single sound combinations. The intermediate list contains words generally of from four through six characters. The hard list is mostly five and over. There was no attempt to pick words on a scientific basis except as involves the restriction mentioned above. The hope was that the lists would be long enough to prevent memorization. Scrambled versions were made for each of the lists. The final time trials were performed using versions of the tapes which has not been used before, thus requiring the subject to identify each word independently and without benefit of context.

The subject and the experimenter went over each list slowly and visually to see whether they could agree that the list were coded and manufactured properly and to refresh the subject's memory of some of the elementary codings which were different from her Barry Horne coding. The subject then practiced on all three lists, trying for high speed each time, using different scrambled versions. Her speed began to increase markedly. It was rewarding to note that she was apparently responding to the *pattern* as sensed in one chunk rather than to the collection of individual characters searched for and found. Another encouraging fact was that she was beginning to store sequences of words in temporary mental storage while she was still trying to figure out the first word of the sequence, then responding with the whole sequence in a burst. Close observation revealed that this was not a result of mental storage of the sequence from a *previous* run. This new mental storage facility suggested returning to context samples, but time did not permit. Instead, the experimental goal was set up to achieve the maximum speed on each list. This would hopefully give some quantitatively useful results.

Results

A number of different types of *errors* were made. These ranged from the simple omission of the beginning or final sound of a word to the loss of the entire word by the missing of a curcial stenotype character of a highly encoded consonant sound. These errors obviously have much different significances, so that it would be difficult to give meaning to an error rate. Accordingly, it was decided to operate *essentially error-free*. By "essentially" it is meant that no more than two of the first kind of error described above would be tolerated in a given list. It turned out that the error rate increased very fast as the speed increased above a certain breakpoint. This breakpoint became higher with practice, of course. Using this error criterion, the maximum speeds achieved were as follows:

Hard List (No. 3). . . . . .31 words per minute

Intermediate List (No. 2). . . . . . . .40 words per minute

Easy List (No. 1). . . . . .62 words per minute

The above speeds were achieved after 8 days (12 hours) on the word lists. While not conclusive of anything, they are definitely encouraging and suggest further work along the same lines.

SUGGESTIONS FOR THE FUTURE

In the context of sensory reading aids for the blind the speeds achieved in this experiment are significant. It is recommended that more research be done using the stenotype machine (possibly modified) and the stenotype code (also possibly modified). The preliminary nature of this project resulted in equipment which is not optimum by any means. There are a few obvious improvements which I believe would cause an immediate jump in reading speed.

First, the mechanical portion of the equipment is too delicate. The spring returns on the solenoid plungers are not positive-acting. What is indicated here is a mechanical actuator which moves the keys firmly and positively both up and down. This will permit the operator to rest her fingers on the key slots with considerable pressure; the initial finger tissue deformation will increase with the result that when the keys drop the change will be more surely noticed. In communication terms the sensory signal-noise ratio will increase.

Next, the decoder should be modified so that all "set" flip-flop outputs are gated into the drivers simultaneously at the end of a readout cycle. This will eliminate the present "wave" effect and should contribute to the *pattern* recognition capability of the subject.

If a general purpose digital computer can be made available to work as part of the system many interesting mode variations can be tried. For example, many timing changes can be made. Using an external square wave generator means that the "off" time is always a [illegible correction - Ed] the "on" time. While this can be changed by using the multivibrator circuitry, more flexibility can be obtained by using a computer to do the timing. It would be very interesting to try a refinement in which the duration of the prose word presentation is made to vary inversely with the operator's expected familiarity with (or anticipation of) the word. This would approximate the manner in which a visual reader slides quickly over the first few simple words of a phrase such as "on the big old steam engine..." Later on it might be possible to give the reader the capability of rewinding the data tape to get a second look at a difficult portion.

In the future it might be desirable to change the electronic portion of the system completely to achieve greater versatility, greater compactness, or both. It can be imagined that the printing of the present machine strikers could print *magnetic* stenotype characters on the stenotype tape, which could be used directly to operate the reverse system. Thus a truly blind stenotype operator would have an immediate capability to operate in reverse on the same machine at the same sitting. Or possibly the use of magnetic tape would permit the construction of an entire system in the physical dimensions of the present stenotype machine itself. Of course, more research of a basic nature is desirable before great modifications are made. It is suggested that the services of more subjects be obtained and more data be produced from which a more advanced system can be designed and built.

APPENDIX A:
THE DECODER - BLOCK DIAGRAM

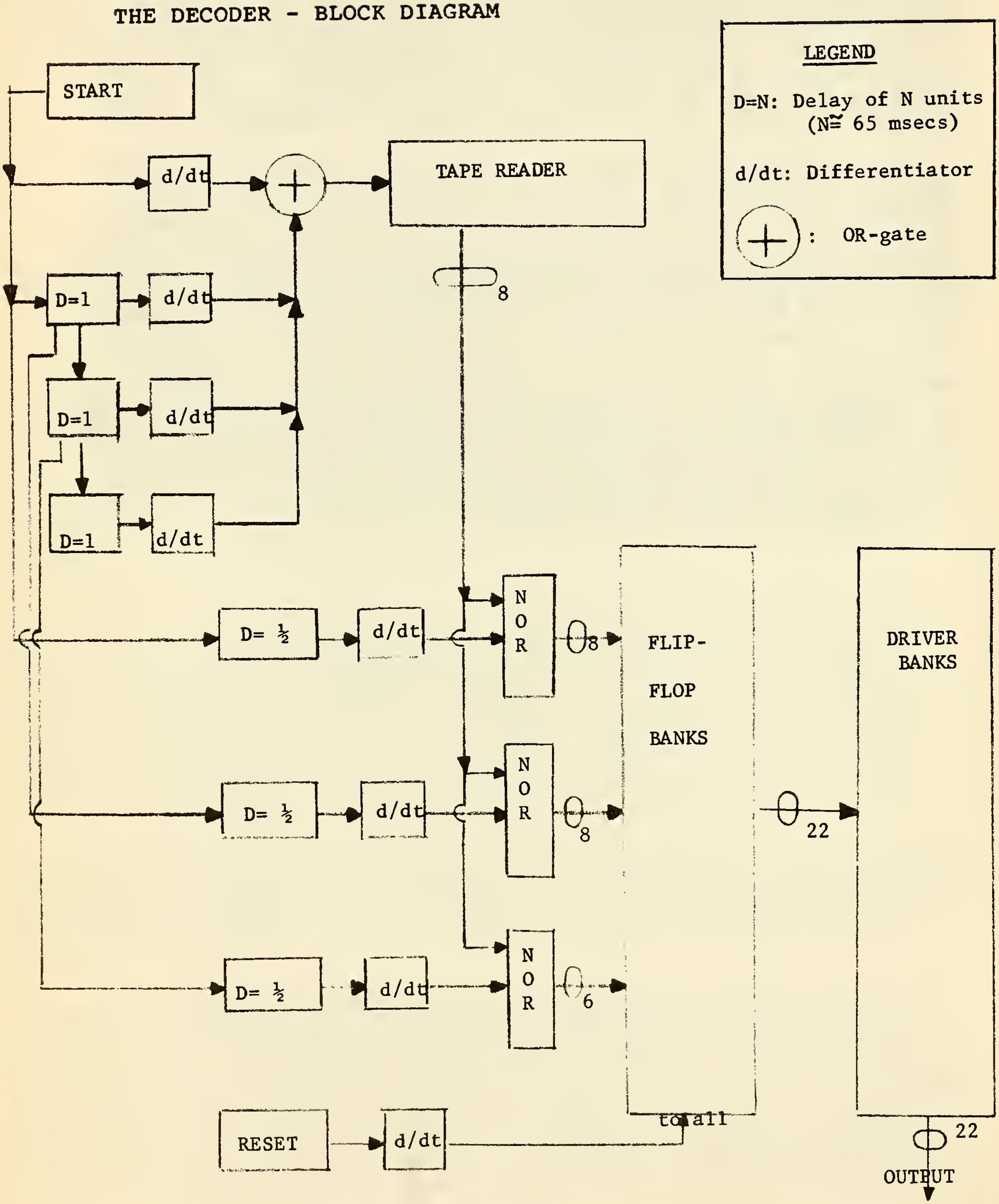

Figure 6. The decoder-block diagram

APPENDIX B:
TAPE CODING - INPUT AND OUTPUT

TABLE 1

TAPE CODING - INPUT

Stenotype Character (in order as on machine)	S	T	K	P	W	H	R	A	O	*	E	U	F	R	P	B	L	G	T	S	D	S
Flexowriter Character (used for input tape to TX-O)	S	T	K	P	W	H	R	A	O	8	E	U	F	1	2	B	L	G	3	4	5	6

TABLE 2

TAPE CODING - OUTPUT

Stenotype Character (in order as on machine)	S	T	K	P	W	H	R	A	O	*	E	U	F	R	P	B	L	G	T	S	D	S
Tape Line Number	1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3	3	2	2
Tape Bit Number	1	6	2	7	3	8	4	1	2	6	3	4	5	1	5	2	6	3	7	4	7	8

APPENDIX C:
THE TAPE CONVERSION PROGRAM

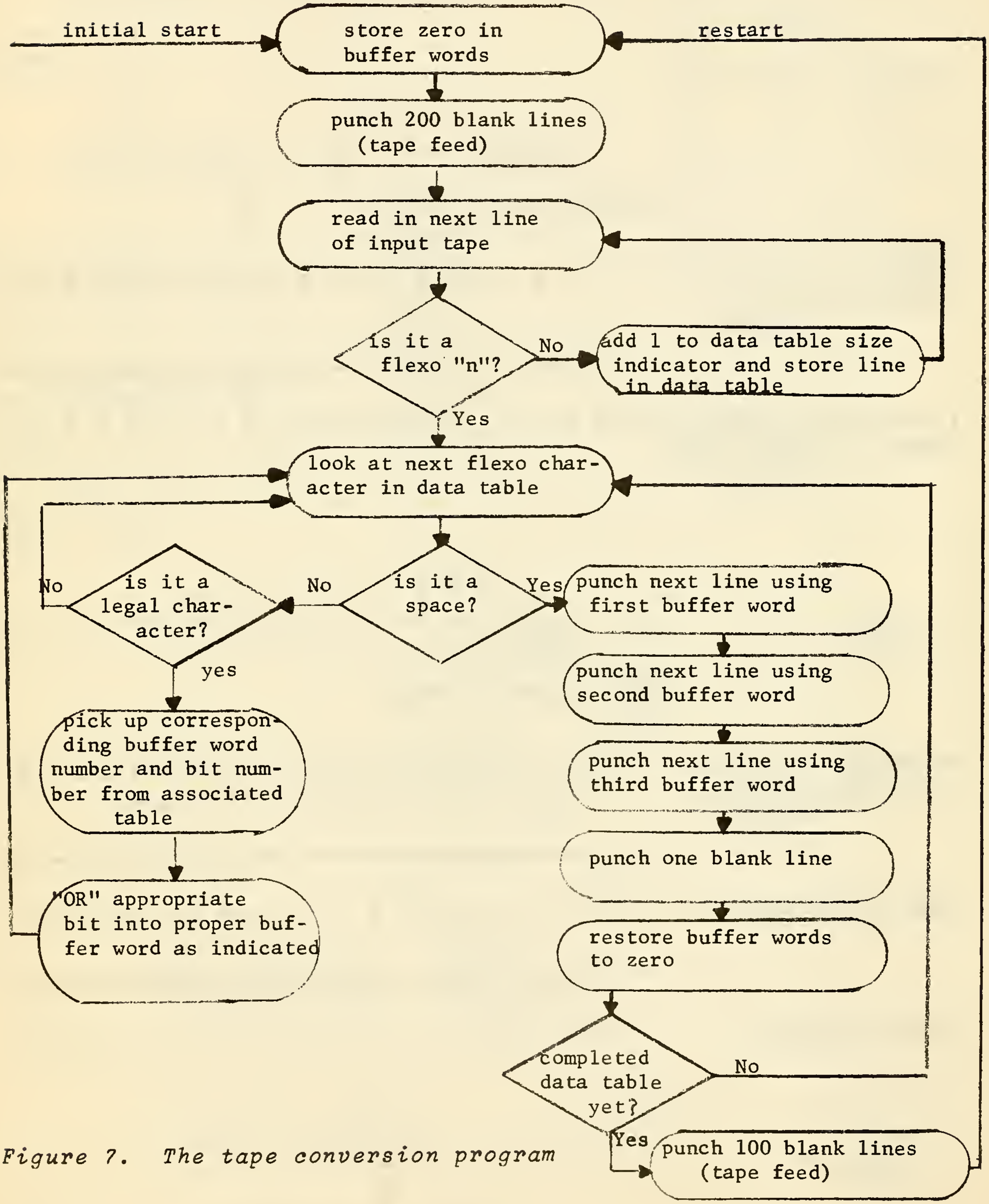

Figure 7. The tape conversion program

APPENDIX D:
THE WORD LISTS*

TABLE 3

EASY WORDS

Steno	English	Steno	English	Steno	English
WAS	was	F	of, have	F	of, have
PEUP	pipe	AEUR	air	TPHOT	not
APB	and	TO	to	AT	at
OUT	out	TPUL	full	TH	this
HER	here	A	a, an	R	are
RUPB	run	KAUL	call	WE	we
SES	seize	TPH	in	KRO	crow
ROR	your	WEUS	wise	PWU	but
SHO	show	THA	that	THE	they
WH	whether	T	the, it	AUL	all
PUB	public	HRAEU	lay	OR	or
HREF	leave	S	is, his	WEU	which
PROL	properly	SUPL	sum	L	will
SOL	sole	EU	I	TPR	from
KAR	car	TKEF	deaf	HAS	has
ST	street	TPOR	for	WOPB	one
WEUF	wife	B	be, been	OUR	our
SRU	view	OB	object	B	be, been
SKG	asking	WAS	was	TPHO	no

* The reader should note that these lists should be considered as representative only since, through no fault of the author, it may well contain many errors in transcription - Editor.

TABLE 3

(Continued)

Steno	English	Steno	English	Steno	English
PHOF	move	RE	remember	THR	there
AOT	another	AS	as	W	were, with
PWF	before	SEUT	sight, sit	SO	so
ROL	roll	O	on	PHEU	my
HEUL	hill	KAOL	cool	TP	if
SUF	sufficient	W	were	PHE	me
TES	test	E	he	WA	what
SOPL	some	ROS	rose	WO	would
PHOF	move	U	you	HO	who
SAEU	say	PWEU	by	WE	we
T	it, the	REUP	ripe		
UP	up				
..PLS	himself	TPHU	new	KWR	why
WAR	war	EPB	even	SET	set
UR	your	REUT	right	HEU	high
..TS	its	HREUF	life, live	HOL	hole
UP	up	TA	take	OF	off
TKO	do	WR	where	SAU	sew
OUT	out	OPB	own	SOG	something
BG	can	LS	also	AG	age

TABLE 3

(Continued)

Steno	English	Steno	English	Steno	English
..PB	than	G	go, gone	TPOR	for
SHE	she	THRE	three	EUS	eyes
PHA	may	THEU	think	HRAU	law
PW	about	TPAR	for	EUS	eyes
OFR	over	EFP	each	FG	having
PWF	before	HOPL	home	OP	open
KO	could, company	PUT	put	REL	real
FR	ever, every	ALS	always	SHO	show
HOU	how	PRE	present	SK	ask
US	us	PER	perfect	ABL	able
WEL	well	PES	piece	HOP	hop, hope
SAE	say	HAF	half	HRAO	look
AF	after	TAO	too	TRU	true
HER	her, hear	URS	yourself	TPHOR	nor
PHOS	most	TPU	few	HROS	loss, lose

TABLE 4

INTERMEDIATE WORDS

Steno	English	Steno	English	Steno	English
THEPL	them	EUPBT	interest	SEFRL	several
TPHEU	any	KWRER	year	PWRES	breast
WHEPB	when	TPET	feet	SEUBGS	six
HORS	horse	TKPWET	get	TPELG	feeling
TPELT	felt	POUR	power	REFPG	reaching
TKUPL	time	PHOF	move	TKPWAF	gave
PHEUS	miss	PWES	best	SHEUP	ship
PHEPB	men	SHAOT	shoot	PURS	purse
TPEUR	fire	HREUPB	line	SEPB	seen
PHUS	must	THEUBG	thick	KWALT	quality
PEPL	people	PHRAS	place	APLT	amount
THOT	thought	HAPEU	happy	TEUBG	particular
THES	these	SEUPBS	since	TPHES	necessary
PHEUT	might	TPAPL	familiar	HAUPBT	haunt
POPB	upon	TKPWOT	got	PWAOBGS	books
HUPBG	hung	THEUBG	thick	TPHOET	note
KOPL	come	WARPL	warm	TPHOPB	none
TPHREU	fly	TPHL	until	TPHLU	flew
THEPB	them	WHEUT	white	TPRE	free
TKER	dear	WEPBT	went	TABGS	tax
SRAEL	valley, vale	PAEUL	pail	WAES	ways
HREUBL	liable	PUFRP	pump	ROPBG	wrong

TABLE 4

(Continued)

Steno	English	Steno	English	Steno	English
TPHEFR	never	HREF	left	PHABG	make
AUBL	automobile	TPET	feet	RAES	raise
HAPG	happening	STEL	steel	TPWUPL	number
TKOUPS	down	TPHEUT	night	PHOEPB	money
KWRER	year	SPHAUL	small	SKWRUS	just
REUR	require	TAEBG	taken	TPHEUG	anything
HROPBG	long	TPHUF	enough	TPOEL	folly
KAEUR	care	HAPBL	handle	PREUS	price, prize
PWEUS	business	TKPWUPB	gun	SKPLS	seems
PERPB	person	TAOL	tool	KRAER	contrary
WORBG	work	STAPB	stand	KPHRET	complete
TPHLS	unless	TPHRAT	flat	SRAL	value
PWABG	back	TPHRAPL	name	RULT	result
WEUTS	witnesses	PHRAEUS	place	TKPWBE	degree
KWRET	yet	SEUGS	situation	SEPBT	sent
TKOPBT	don't	TPHOEUS	noise	SKBGS	sex
SHORT	short	SOG	something	WEURB	wish
SAPL	same	BRAFF	latch	SAEUPLE	same
ABGT	act	SEPBT	sent	TKPWEUPB	begin
TPHOG	nothing	TKREU	dry	HRERPB	learn
PAERTS	parties	HRPL	almost	HREUPS	line
TWEPB	between	KRHOS	close	SKEUL	skill
TPHOU	now	TKPWEUF	give	TKOG	doing

TABLE 4

(Continued)

Steno	English	Steno	English	Steno	English
PARBG	park	KORS	course	PHOPLT	moment
WOPBS	once	TKAOR	door	SEPBS	sense
PHOGS	motion	TPHAGS	nation	OFPB	often
STAEU	stay	KHREUBG	click	SPHAUL	small
TPAEUT	faith	TUFP	touch	TRAOPS	troops
KWEUT	quite	PHABGS	maximum	PWHRAOPL	bloom
PWAEUR	bare	TPEUS	physical	HARTS	hearts
THOU	thousand	PRAPS	perhaps	PEFP	peach
PWEULT	built	KHROR	color	ROBG	rock
TEUPLS	times	SPEGS	special	PWARUS	base
TPHRO	flow	HREUPB	line	SOFT	soft
REUPL	rim	HRAF	laugh	KAUGS	caution
PWARPB	barn	TPAEUR	fair, fare	TKPWET	get
WAPET	want	PWOEU	boy		

TABLE 5

HARD WORDS

Steno	English	Steno	English	Steno	English
TKPWRAT	great	KPHRAEUPBT	complaint	SKWRUS	just
TRAFLS	travels	TKPWEUFPB	given	TPEUBGS	fix
TPEURS	first	PERPLT	permit	STAPLT	statement
SOEPB	season	PWRAEUBG	brake	TPAFRTS	favorites
TKOUPB	down	ROEPBL	reasonable	SKWREPB	general
STROPBG	strong	SPHAUL	small	SAEUPL	same
KWRERS	years	KAUGS	caution	KWFBGS	qualifica-tions
SPHOBG	smoke	PERFB	person	TPHAGS	nation
TPKLT	felt	TARPS	taken	TKPWEURL	girl
HROPBG	long	PROL	properly	PWHRAOPL	bloom
STRUBG	struck	PHORPBG	morning	KPWEUPBGS	combination
STAEUT	state	KHRAEUPL	claim	STRAEUT	straight
SKWRUS	just	TPHUF	enough	TPHUPL	number
PHAFP	match	SEUFRPL	simple	TPHEUG	anything
KWRET	yet	TPHLS	unless	PHEULS	miles, millions
WORBG	work	TKAPSLGS	damages	SPEGS	special
SHAEUBG	shake	TKRKBGT	direct	PHABGS	maximum
THEUPBGS	things	TKPWEPB	gun	TPHREU	fly
TKPWRAS	grass	TKFT	testimony	KUPBS	instant
STPHAFP	snatch	TKPWEUPFB	given	PWOU	bow
TPHRAEUPL	flame	SKUR	secure	SKWROEUPB	join
TPROPBT	front	TPABGT	fact	SROEUS	voice

TABLE 5

(Continued)

Steno	English	Steno	English	Steno	English
TKPWAEUFB	gain	TKRAUPB	drawn	TKPWOFT	government
PWURB	bush	PERPLTS	permits	TPARPL	farm
KWRET	yet	SRKBG	vehicle	KHEURPB	children
PWHRAEUS	blaze	PHOGS	motion	HAPBS	hangs
THPOG	nothing	TPHRFRLS	never-theless	SKWREUR	jury
STAPBG	standing	HREUPB	line	TPHOEPB	KNOWN
HAPG	happening	STKEPBT	accident	TPROFBT	FRONT
KAEUPL	came	SEFRB	serve	SPNEURL	entirely
THEUBG	thick	STREPL	STREAM	TKURG	during
TKPWURB	gush	THEUPBG	THING	SEAOT	shoot
TKREUPBG	drink	SPOUT	spout	TRAUF	trough
KWRIPBG	young	TPORG	fork	TPEPBS	fence
KWALT	quality	REFPG	reaching	HREUPS	lips
HRARPBLG	large	SEUGS	situation	KOEPBT	couldn't
SPOFB	responsi-ble				

SUMMARY

In pursuit of the long range objective of providing better sensory reading aids for the blind, research has been done into the tactual and kinesthethic information transfer process itself by using a stenotype machine operated in reverse. A system has been designed and built in which punched paper tape, coded from stenotype output tape, feeds a decoder, which in turn provides signals for a key-actuator console to move the keys of a stenotype machine. A stenotype-trained subject has been taught to "read" the output (key movements under the fingers) as if she were operating the machine in its normal mode and to respond by saying the words presented. Advantage has been taken of the fact that the subject was well versed in the stenotype code (a sort of redundancy-reducing phonetic shorthand using ordinary typed letters) by making the output key movements correspond to the same code, with minor restrictions.

After initial familiarization, speed trials were made using three lists of English words. The words used were such that the stenotype coding of each word was one stenotype line long (to eliminate probable confusion with a series of shorter words), and words which required a final *D* or *S* stenotype character were not used (since the hand would have to move to sense these two keys); with these exceptions the words were picked at random from all the stenotype tapes available. Each list was presented in various scrambled versions in order to make recognition word-by-word independent and context-free. After 8 days (12 hours) of practice on the word lists the subject was able to read the hard list at a rate of 31 words per minute, the intermediate list at a rate of 40 words per minute, and the easier list at a rate of 62 words per minute, all these speeds being essentially error-free.

At the end of the experimental period, the subject's speed was increasing rapidly. Indications are that with more practice and with a system somewhat modified to eliminate some unnecessary difficulties and to exploit greater speeds, the ultimate rate limitation is possibly much higher. The results suggest that multifinger stimulation and sophisticated coding are promising avenues of further research.

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the final copy with her customary competence and good cheer.

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Thanks to all the people in the Research Laboratory of Electronics who have been so friendly and helpful.

And thanks to the United States Air Force, which through its Institute of Technology has permitted this work.

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A PHOTO STYLUS FOR MECHANICAL SENSING OF IMAGES*

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INTRODUCTION

Research on sensory aids for the blind is concerned with providing substitutes for some of the functions dependent on the visual sense through the application of modern technology. One of these functions is the acquisition of information from printed, written, and pictorial material. Some of this information can be made available to the blind by translation to braille, Talking Books and other systems involving employment of a sighted reader. There are many disadvantages to these systems - expense, space requirements, and lack of privacy being but a few. Some of these disadvantages could be avoided by a system which produced, automatically, a suitable nonvisual output directly from visual material. Even if it enabled only slow speed reading such a device would be valuable, for instance in reading bills or private correspondence. There is also a need for devices to translate other types of information such as diagrams.

The principle elements of a system to convert a visual pattern into a form which can be perceived by nonvisual senses are: an optical probe to examine the pattern, a processing section for the signals produced by the probe, and a display controlled by the output of the processor. Four classes of systems listed by Freiberger and Murphy in a review article include: (i) simple optical probe,** (ii) direct translation of the pattern, (iii) intermediate (partial recognition) and (iv) recognition (5). The last term refers to a machine in which the processor actually recognizes the characters from the probe signals and may be arranged to give a code output or even speech. Such a machine is extremely difficult to realize if it is to handle a variety of forms and sizes of characters, and is limited to alphanumeric material. In a direct translation system the visual pattern is transformed into a corresponding pattern in another

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* This publication is based on a thesis submitted in partial fulfillment of a Master of Science degree at the Massachuetts Institute of Technology, Department of Electrical Engineering.
** In these devices there is no processor. The probe signal controls the output directly.

medium, and the blind person has to recognize the symbols from this. A much simpler processor is possible, and in principle it could be used for pictorial material. There are at least three sensory channels capable of pattern recognition; the auditory sense for a temporal sequence of tones and intensities; the tactile sense for a spatial pattern of stimuli; and the kinesthetic sense for a sequence of motions of a member of the body. Direct translation devices have been developed using the first two (4, 6, 8).* The kinesthetic sense has been exploited with simple probes (7)* and also some code-reading systems (1).*

The kinesthetic sense plays a vital role in handwriting. Even a sighted person may demonstrate by closing his eyes while writing that visual feedback is of secondary importance. Many blind people can write legibly depending on kinesthetic feedback alone. It is known that the reverse process, i.e., recognition of symbols by tracing their shapes, is possible. The Visagraph type presentation could be used in this way by tracing the lines of letters embossed on aluminum foil with the fingertips (6). This form of tracing is unsatisfactory, however, because of the way finger motion is controlled. There are delays associated with mental registration of a tactile sensation, indicating whether or not the strokes is being followed, and with corrective motor action. If the finger can be constrained to move along the line or edge, some of this delay can be avoided and more rapid, positive tracing results. This can be achieved with large deep letters or by using a fine stylus with suitably formed relief.

Providing an embossed replica entails some difficulties and is not necessarily the best way to convert the visual pattern for kinesthetic tracing. The constraint required on the finger or stylus is a force in the plane of the pattern perpendicular to the edge being traced. A system constructed by Davis applied a force to a hand-held probe proportional to the brightness over which the probe is located (3). Although this device is not suitable for edge tracing because the force is in a single nearly constant direction, the principle may be extended to a two-dimensional system. To regulate the force in such a system the gradient (strictly the first difference) of brightness may be used as parameter. Direction may be retained by resolving the gradient in two orthogonal directions and applying forces to the stylus in similar directions by a suitable mechanism (such as an X-Y plotter). By proper manipulation of the signals, an additional component of force parallel to the edge may be generated, which may assist the operator in tracing the edge. Line tracing, by constraining the stylus to stay "inside a line," is also possible.

* These are examples only; Reference 5 gives a fuller list.

The subject of the present thesis is a system to apply appropriate forces to a stylus to enable tracing of shapes in a visual pattern without an embossed replica. A television camera is used to scan the pattern, eliminating the need to locate the probe above a visible image. The brightness gradient is determined directly from the video signal by sampling and differencing, and forces are applied to the pen of an *X-Y* plotter which serves as the "stylus." The system is designed as a tool for investigation of the psychophysical and technical problems involved.

Preliminary trials with blind and blindfolded subjects indicate that character recognition is possible with this system. The system functions satisfactorily, but a number of improvements are suggested.

THE PHOTO STYLUS SYSTEM

General Principles

The system developed in this thesis reproduces a two-dimensional visual pattern as a mechanical force pattern which is sensed when a probe is moved about in the display. The desired relation of the magnitude and direction of the force to the characteristics of the pattern depends on the way the probe is to be operated. For simply locating lines or edges, the force might be perpendicular to the edge and in such a direction as to push the probe either to the dark or light side of the transition. Assuming dark lines on white paper, a force towards the light side would stop the probe when it was brought up to the edge. In between lines the force should be zero. It is harder to specify what the force should be when the probe is on a dark area, but the requirements are simplified if it is also zero.

If the edge is to be traced a component of force parallel to the edge is required. This can be provided by the operator, who would also apply some force into the edge to maintain orientation and contact. A parallel component could also be provided by the device by rotating the direction of the force relative to that of the edge, an angle less than 90 degrees.

A force perpendicular in the reverse direction would keep the probe over to the black side of a transition. There would be two opposite transitions close together in the case of a line, and the probe would be kept between them, enabling the lines to be traced. The relative merits of these modes are discussed in a later section.

A suitable parameter to determine the required force is the difference of brightness between adjacent areas. By considering two pairs of areas adjacent in different directions, for example at right angles, the direction of the edge may be determined.

The differences may be thought of as components of the brightness gradient averaged over a small area. This is illustrated in Figure 1. A single area is divided in two ways to provide the necessary pairs.

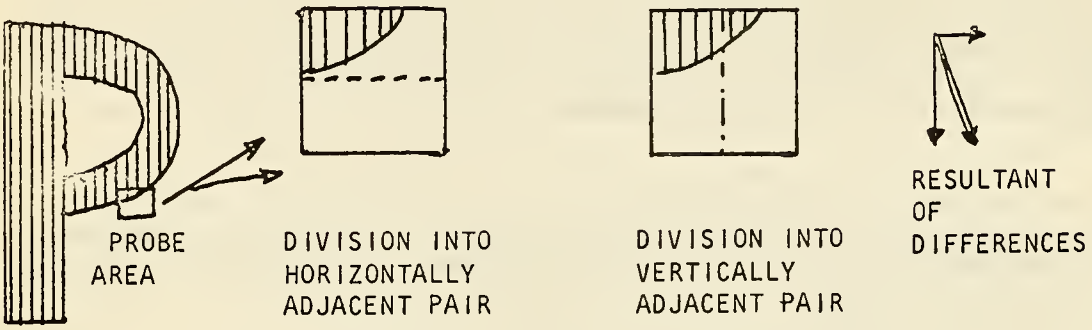

Figure 1. Optical probe: production of brightness "gradient" signals

These brightnesses could be measured by an array of four photo detectors attached to the probe, which would be located over the visual pattern. Precise optics would be needed to obtain high resolution, and there might be characters too small for kinesthetic recognition. Davis describes the use of a television camera scanning the image to obtain an enlarged reproduction displayed on a monitor (3). A television video signal contains all the necessary information for direct determination of brightnesses. The coordinates of a point on the raster are equivalent to horizontal and vertical deflection currents or voltages. A point is scanned once each frame and with sawtooth scanning waveforms the instant at which this occurs can be indicated by coincidence of these waveforms with known dc levels. The video signal at this instant is a measure of brightness of the point. Points which are horizontally adjacent are scanned in direct sequence, while those which are adjacent vertically are scanned one line interval apart and have identical horizontal deflections. It is thus possible to select a point by simply dc voltages in a coincidence detector and to sample regions about that point by gating the video signal in a suitable time sequence. Very high resolution and signal/noise ratio are possible with modern cameras. The dc voltages may be those produced by potentiometers coupled to the mechanical display, so that the stylus position is related to the point of the image being sampled. No visual image need be produced beneath the mechanical unit.

A force output transducer for this system must be able to apply two components of force simultaneously, at right angles to the stylus, wherever it is located in the display area. To obtain a force perpendicular to the edge (i.e., in the same direction as the gradient) each force component should be proportional to the corresponding gradient signal. Rotation of the force to other angles can be obtained by combining fractions of both gradient signals to control each force, according to the expression

$$f_x = g_x \cos \theta + g_y \sin \theta$$

$$f_y = g_y \cos \theta - g_x \sin \theta$$

where f_x, f_y, are the signals to control the forces and g_x, g_y, are the gradient signals. θ is the angle of rotation of the force vector from the gradient vector. A reasonably linear gradient signal to force transfer characteristic is needed if the resultant of the two force components is to have the proper direction. Magnitude of the force is not critical, although when the line following mode is employed the force has to be overcome to move the probe from symbol to symbol. Ideally there should be little inertia and friction as these interfere with operation of the probe and might mask the forces due to the pattern. In a practical system these effects might be reduced by the use of feedback. A transducer would measure the force applied to the fingers through the probe, which would be compared to the required force signal from the video sampling unit, the output transducer being controlled by the difference.

The system may exhibit instability in certain regions of the pattern which is an element in the overall feedback loop. This is due to the effect of delay in the sampling system, combined with the inertia of the moving parts. Additional damping through velocity feedback is one way to overcome this.

A system incorporating these principles was designed and constructed. Figure 2 shows a block diagram. A television camera is used to scan the image at rates of 60 fields per second, with approximately 262.5 lines per field. Sawtooth voltage waveforms generated outside the camera were compared with voltages indicating the respective coordinates of the stylus in the display, and a trigger signal generated when coincidence on both axes occurs, once each field. This signal initiates the generation of a series of pulses of short duration (compared to a line period) occuring over a span of several lines. The pulses are combined in four sets, each set representing a small rectangle on the television raster, and controlling the action of a gate. The gates admit the video current during the pulser periods to capacitors which charge up by an amount dependent on the average brightness in the rectangle. The voltages on the capitors are compared in pairs in difference amplifiers. A matrixing unit allows various proportions of the resulting difference voltages to be added in either polarity. The added signals are fed to chopper amplifiers which control servomotors in an *X-Y* plotter modified for the purpose. The slide-wires of the plotter are used to give the position voltages for comparison with the sawtooth signals. These are also differentiated to give velocity signals which are mixed into the input to the servo amplifiers.

The electronic circuits, exclusive of the television camera and servo amplifiers, were constructed on a number of plug-in cards (labelled UC1 to UC8) and a control panel (UC41), all housed in a steel cabinet which also contains the power supply unit (UP31).

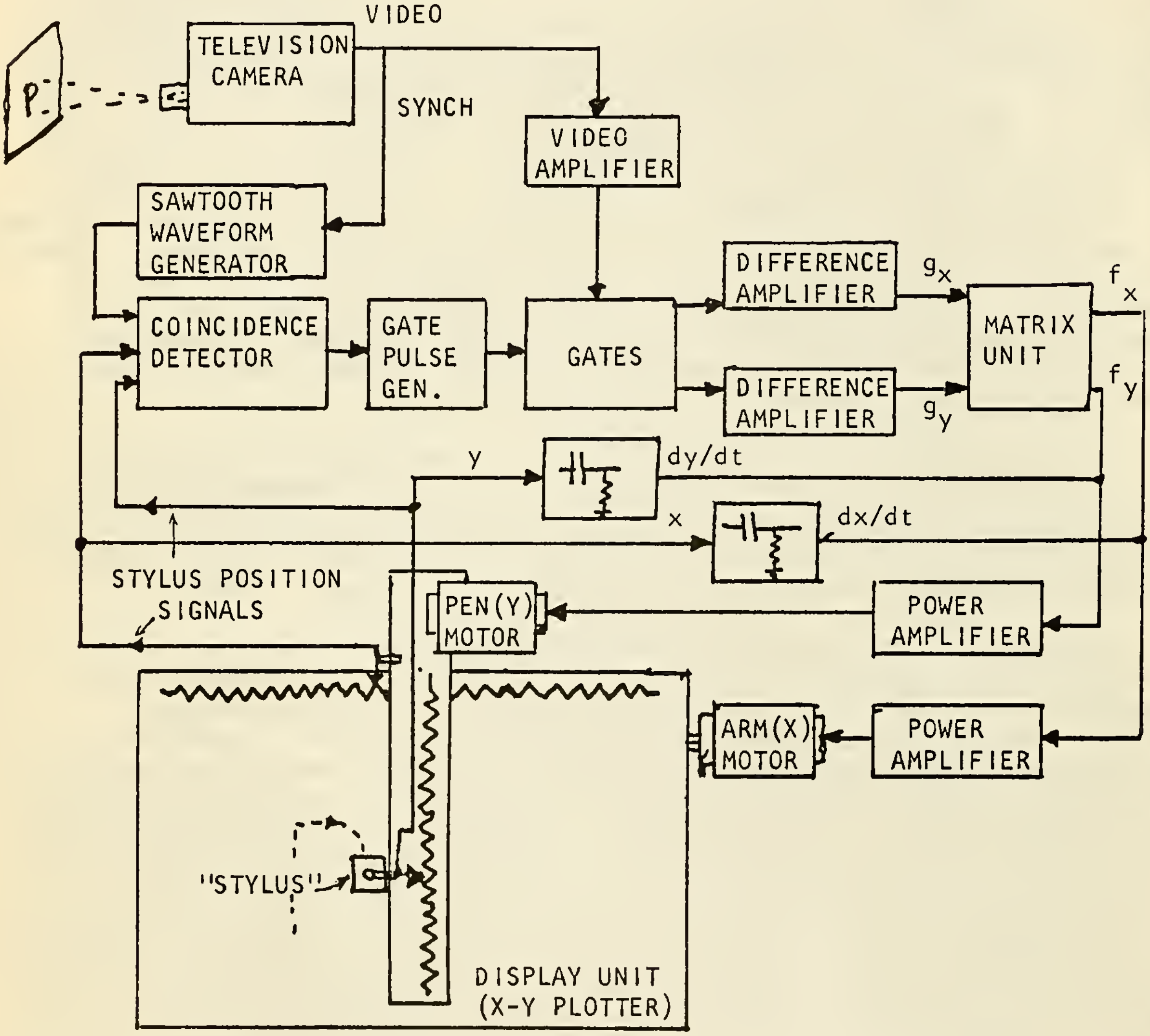

Figure 2. Block diagram of the photo stylus system

Position Detection Circuits

This section comprises circuit cards UC1 and UC2 and the slide-wires VR111 and VR112 in the display unit (refer to Figures 3 and 4).

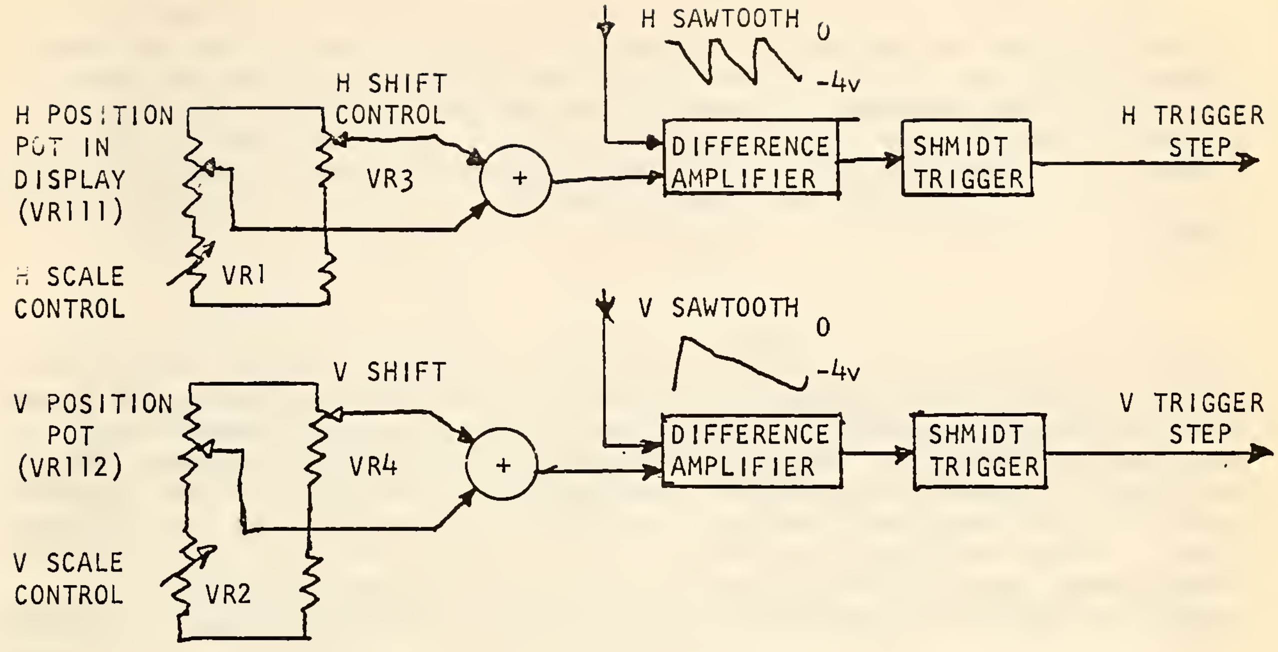

Figure 3. Block diagram of position detector

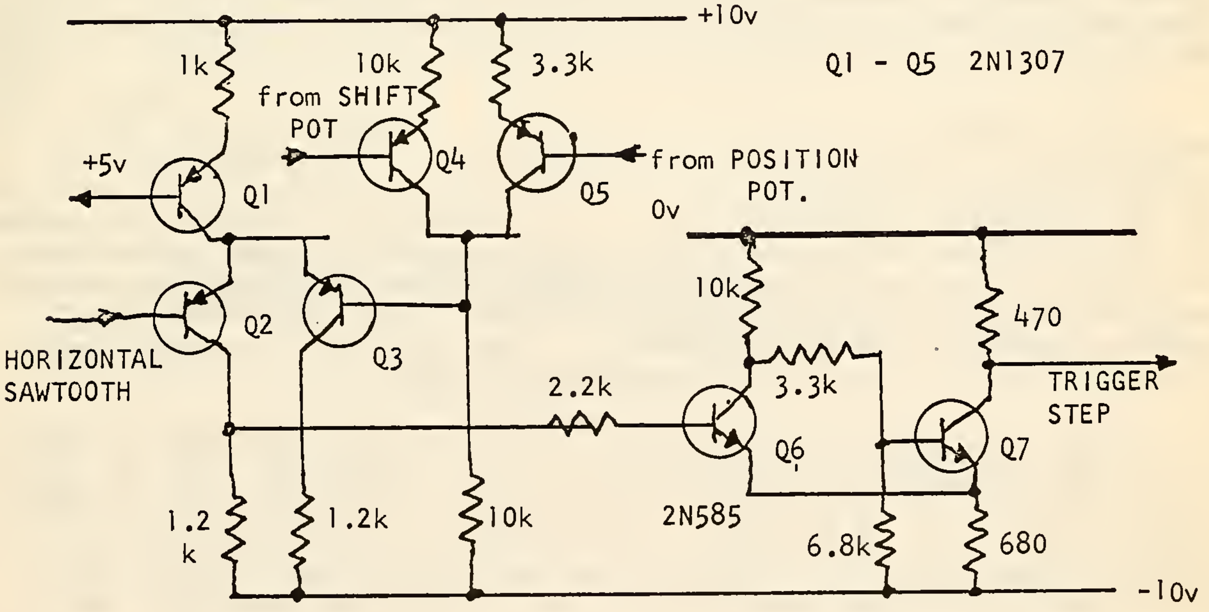

Figure 4. Block diagram of position detector (one channel)

The function of these circuits is to relate the position of the optical probe on the image to that of the stylus in the output display. The optical probe is a small sampling area on the television raster defined by the pulses generated by the Gating Sequence Unit (see next section). Its position on the raster is controlled by the times, from the start of a scanning field and a scanning line respectively, at which the pulse sequence is initiated. The output of this section is a trigger pulse at each of these instants.

Linear sawtooth voltages, synchronized with the line and frame scanning in the camera, are generated in another unit (see below). Their instantaneous values (except during flyback) therefore denote the times referred to above. In the display unit are two slide-wires, one aligned with each of the two axes of motion of the stylus. Wipers mechanically coupled to the stylus pick off voltages indicating distance from one end of each slide-wire. These voltages are compared with the sawtooth voltages in difference amplifiers. When coincidence occurs in one of the axes, the required pulse is produced by a Schmidt trigger circuit.

Figure 4 is a schematic of the horizontal circuit. The vertical circuit is similar. The transistor Q1 supplies a constant current of 4.8 mA to the difference amplifier comprised of Q2, Q3. The voltage at the base of Q3 is the result of summing, in the 10 kΩ resistor, currents proportional to the position voltage (from VR111) and a shift voltage, controlled by VR3. The latter permits centering of the display. The scale of the display may be varied by changing the total voltage across VR111 by means of VR1.

The voltage on the base of Q3 will lie between 0 V and -5 V depending on the position of the probe and the setting of the shift control. The sawtooth starts at 0 V, so that Q2 is cut off. As the sawtooth drives the base of Q2 negative, a point is reached at which the two bases are at approximately equal potentials, at which the collector potential of Q2 rises to -7 V, Q6 conducts, and the Schmidt trigger Q6, Q7 switches - the collector of Q7 rising rapidly from -2.5 V to 0 V. The Schmidt is reset during flyback when the base of Q2 returns to zero.

Some trouble is experienced in the horizontal circuit when the probe is near the beginning of a line, and the base of Q3 is close to 0 V. This is due to hysteresis in the Schmidt trigger: the collector of Q2 does not go low enough to switch off Q6. This problem does not occur in the vertical circuit, and could be avoided by slight redesign of the horizontal sawtooth generator (see below).

Precautions were taken to minimize any effect that variations of V_{be} with temperature might have on the relation of V_b

(Q2) to position voltage V_b (Q5). This would not affect operation, since it would simply represent a translation of the image relative to the display, but it would be undesirable when these voltages are used for analysis of psychophysical experiments. The precautions include selecting the trigger point for Q6 for equal currents in Q2 and Q3, and the use of low gain in the summing transistors of Q4 and Q5.

The Gating Sequence Generator (Circuit Card UC3)

Image brightness gradient is determined through sampling of four small areas of the image, by selective gating of the video signal, and by comparing certain combinations of the samples for vertical and horizontal differences. The gate sequence generator produces a series of gating pulses for this purpose.

Four monostable multivibrators are used to provide a common set of waveforms from which the pulses required to control each gate are derived through a logic network.

Figure 5 shows the raster and Figure 6 an enlargement of the section in which the sampling area is located. The pulses provided by the multivibrators are labelled A, B, C, and D. The A and B pulses correspond to the scanning of small sections of each line; C and D pulses each correspond to the scanning of a group of lines. In Boolean algebra nomenclature, AC (the intersection of pulses A and C), BC, BD and CD are the four sampling areas. Figure 7 shows the areas to be sampled by each of the four gates.

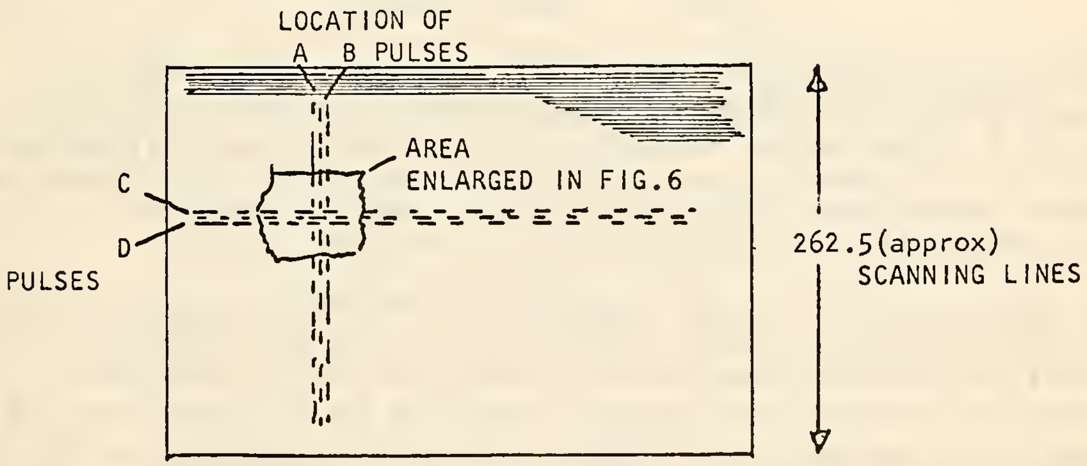

Figure 5. Television raster

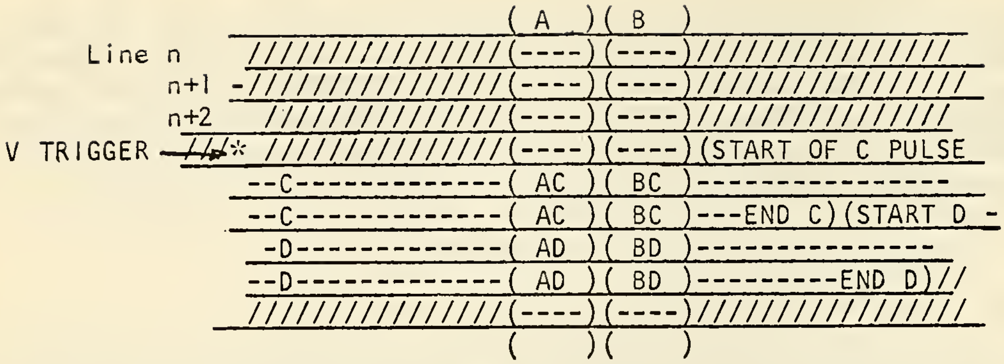

Figure 6. Enlargement of area around "optical probe"

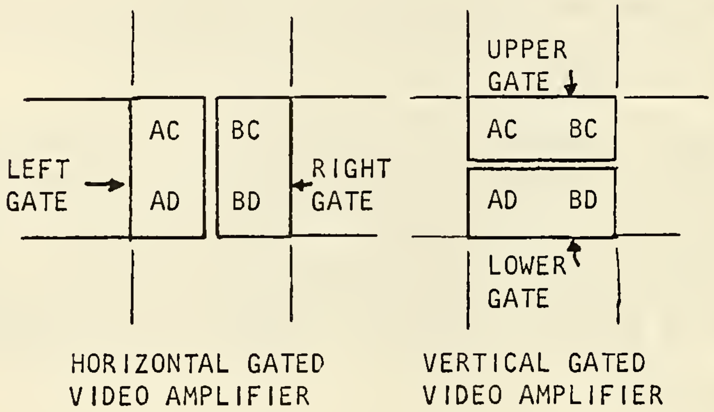

Figure 7. Areas sampled

Referring to Figures 8, 9, and 10, the horizontal trigger pulses are differentiated to trigger multivibrator A. The duration of the A pulse may be varied by interchanging capacitors C_A, from 0.25 to 2.50 μsec. Since a line is scanned in 63.50 μsec and the vidicon camera used can resolve about 300 elements per line, there are about 1 to 10 elements in the sampling period.

The negative-going pulse appearing at the first collector is used to drive the diode gates. Multivibrator B is triggered when this transistor switches on again through the 20 pF capacitor. C_A and C_B must be matched approximately but the 20 kΩ pots, VR6 and VR7, permit fine matching of A and B pulses. The adjustment of these pots is rather critical, there being regions at both extremes at which the multivibrators will not operate. This could be improved by using a fixed resistor in series with a smaller pot.

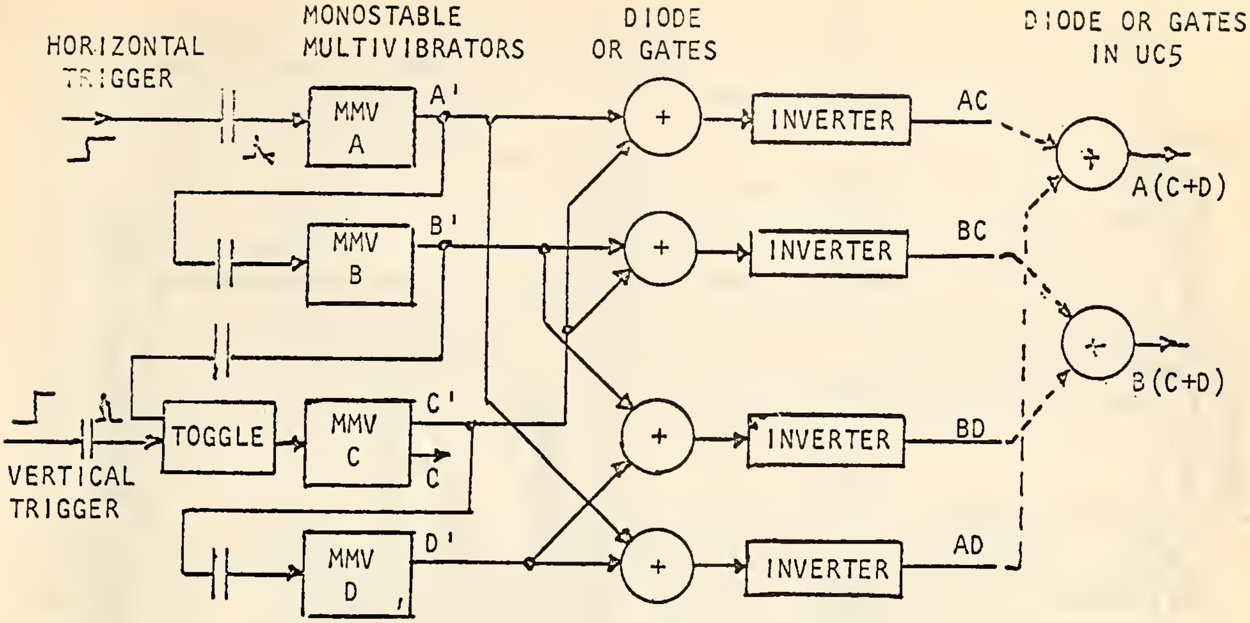

Figure 8. Block diagram of gating sequence generator

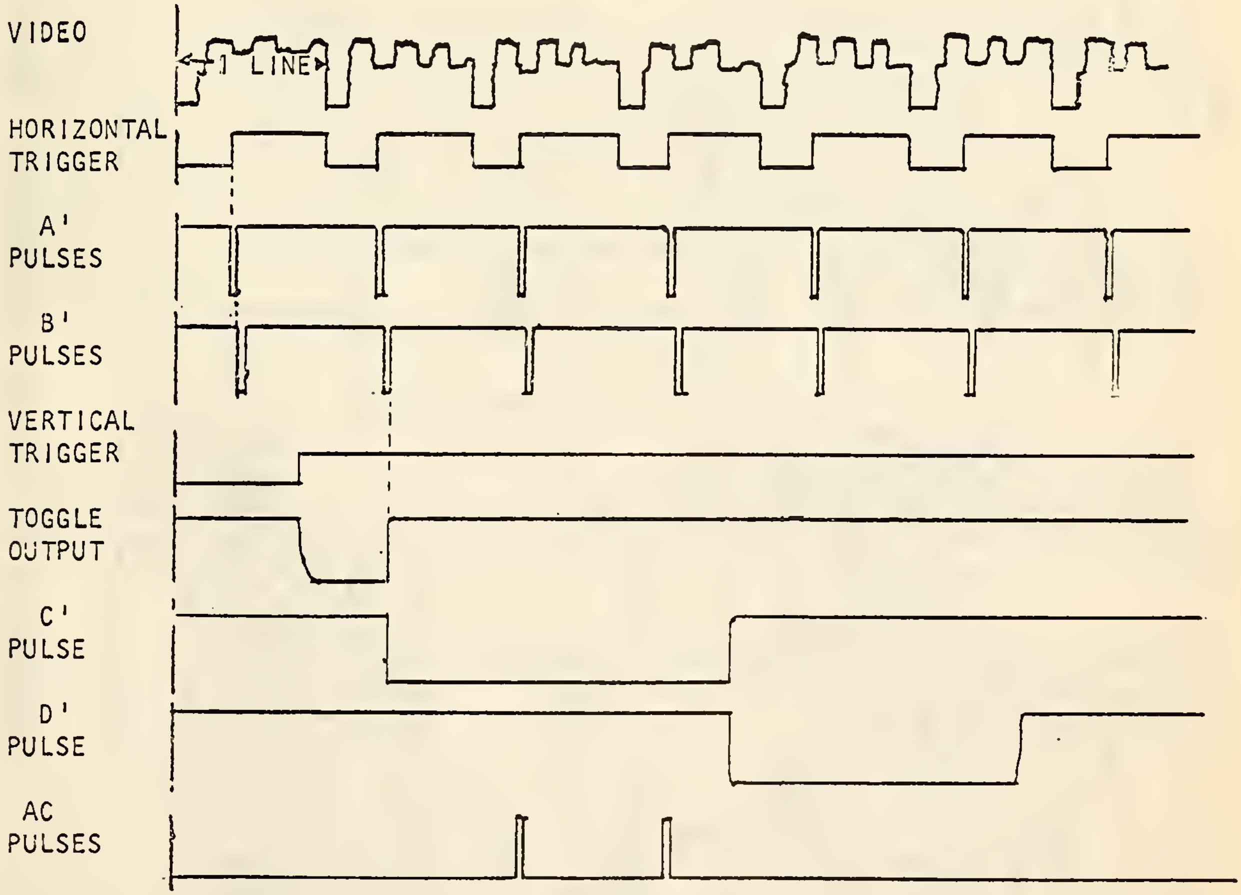

Figure 9. Waveforms illustrating pulse sequence

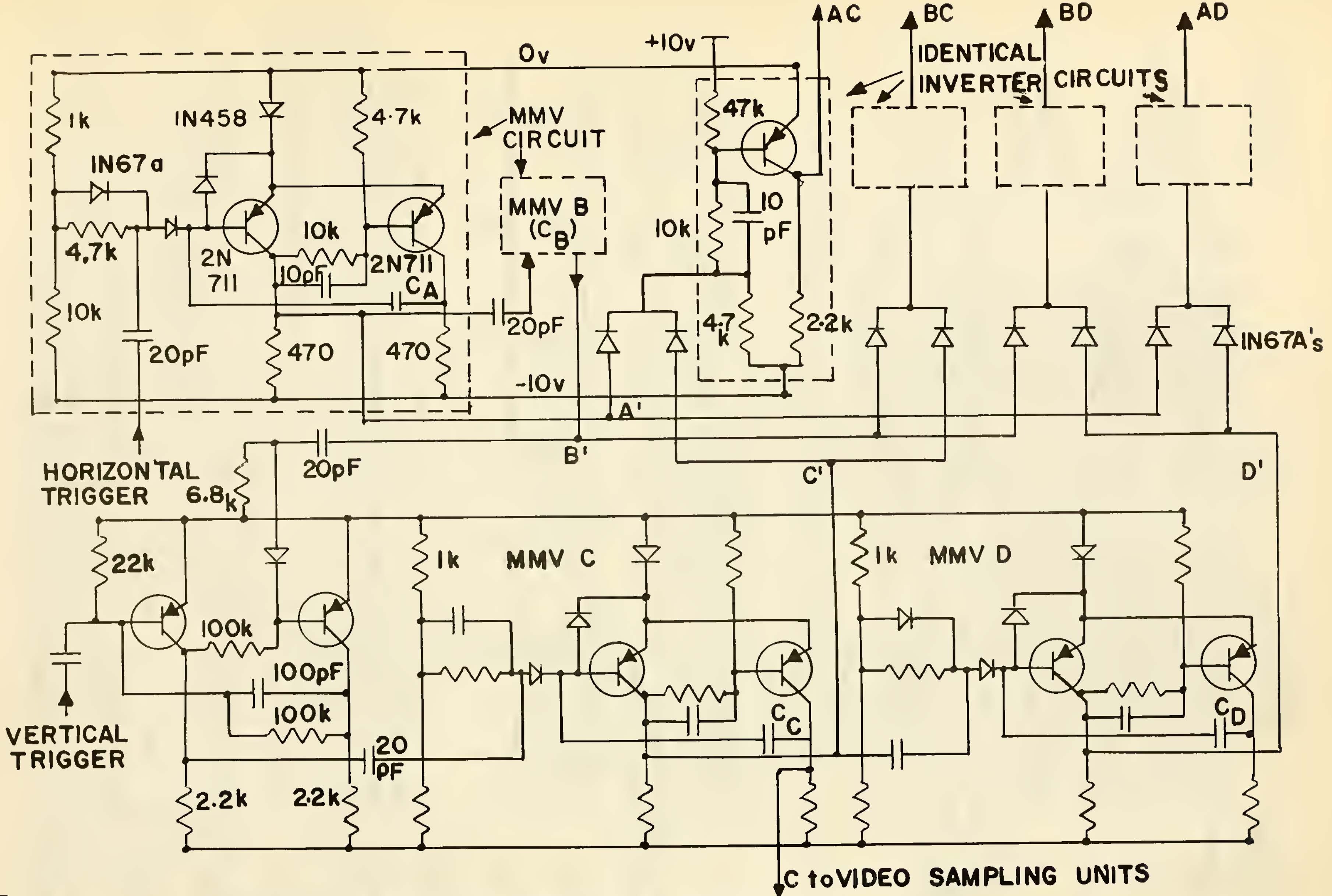

Figure 10.

SCHEMATIC OF GATING SEQUENCE GENERATOR

G.T.

The vertical trigger pulse may occur at any time during a line, including in the middle of an A or B pulse. If the C pulse was triggered at this instant it would be possible for unequal areas of the raster to be compared, giving rise to spurious gradient signals. To avoid this condition the toggle was included to synchronize the start of pulse C with the end of the next B pulse after the vertical trigger occurs. The positive-going voltage at the end of pulse B sets the toggle with the first transistor conducting. An output pulse appears only if the toggle had been reset by the vertical trigger pulse. The .002 μF capacitor and the 22 kΩ resistor provide a delay so that if a B pulse comes too soon after the trigger pulse, the toggle will wait until the next B pulse occurs. This ensures that the full amplitude of swing will occur at the first collector.

Multivibrator D is triggered by the end of the C pulse. Since the C pulse always starts just after a B pulse its duration is not critical. If the maximum resolution is desired C is adjusted for about 90 μsec so that it ends between the first and second horizontal pulses. D is then adjusted for about 60 μsec. The waveforms illustrated in Figure 9 are for two A and B pulses per C pulse.

The convention is used that -10 V represents a *0*, and 0 V a *1*. The gates are turned on by a 1. There are several alternative ways of arriving at the required gating pulses from the A, B, C, and D waveforms. The negative pulses A', B', C', and D' are used, and it was decided to put two "or" gates in tandem (Figure 8) which allows the use of an inverter between them for pulse shaping, and which also avoids loading the multivibrators. The inverter conducts only when both diodes are reverse biased. The 47 kΩ bleeders to +10 V ensure that negligible leakage occurs when the inverters are cut off.

The Video Amplifier and Sawtooth Generator (Circuit Card UC4)

This unit converts the video voltage produced by the television camera into drive currents for the video sampling units and generates sawtooth waveforms synchronized with the scanning circuits in the camera (see Figure 11).

The composite video signal from the camera consists of negative-going synchronizing pulses of about 1.0 V amplitude, plus from 0.3 V to 0.5 V of video signal with white going positive about a mean level of some -3.0 V. The required input to the gating circuits is a current proportional to brightness, and since the level of the video signal is unsuitable the ac soupled amplifier (2N706) and a dc restorer were used. The latter clamps the top of the inverted synchorizing pulses to 0 V. To obtain greater percentage video modulation of the drive current, the clipping control VR12 and 1 kΩ resistor keep the emitters of the 2N7115 at a voltage just less than the dark level,

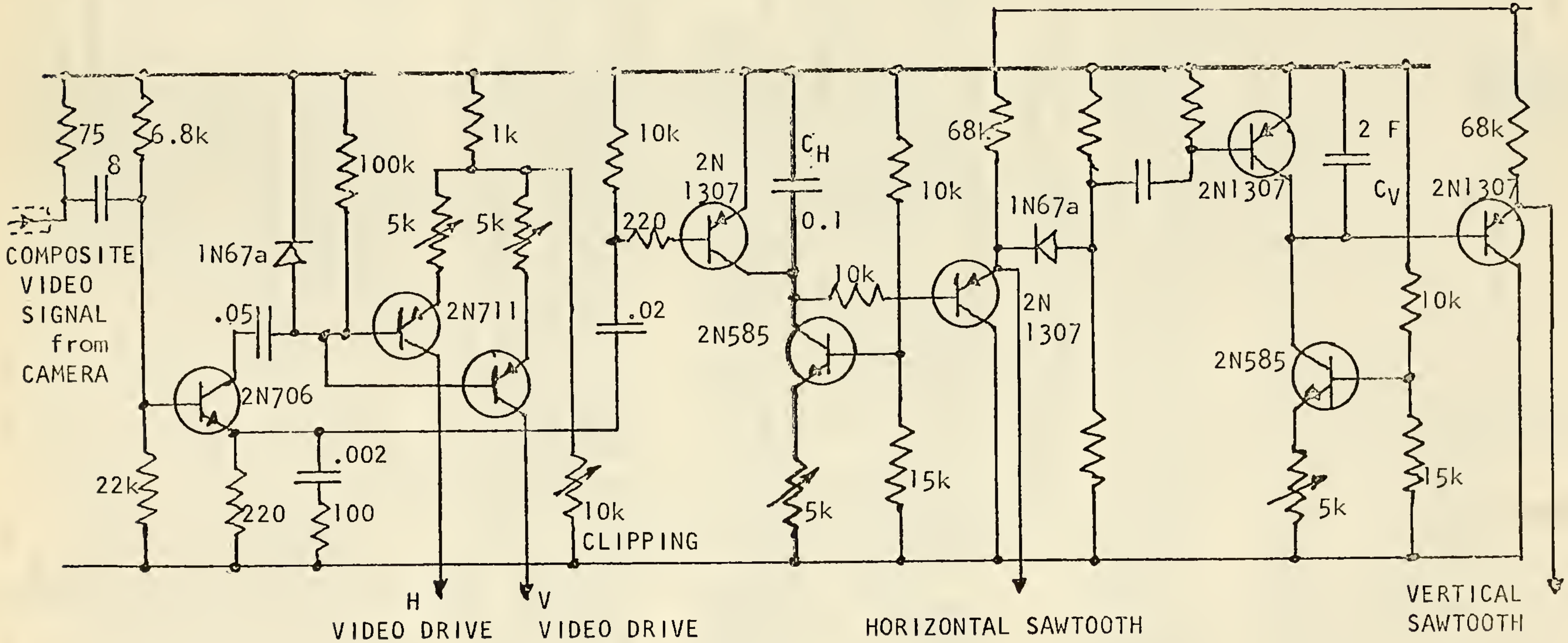

Figure 11. Video amplifier and sawtooth generator

and the output current is then zero until the base goes more negative. Thus synchronizing pulses do not appear in the output. The 5 kΩ pots allow a 6 to 1 variation in gain.

The signal from the camera exhibits considerable fall-off at high frequencies, and this was found to give rise to an apparent gradient for some distance to the right of edges (Figure 12). A shunt peaking capacitor was connected across the emitter resistor of the 2N706. This increased the noise level considerably, so a combination of the capacitor (.002) and a 100 Ω resistor were used to limit the high frequency boost. The remaining noise does not affect the output unduly because of the integration used in sampling.

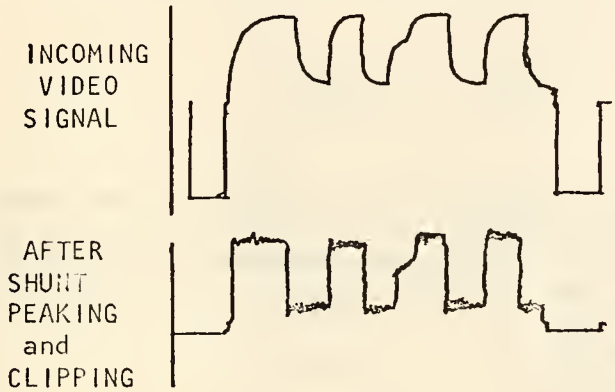

Figure 12. Improvement of video

To provide the sawtooth voltages an arrangement was chosen which does not use synchronized oscillators. By using the synchronizing signals directly to control the discharge and start of charging of the capacitors C_H + C_V, more exact synchronization of the sawtooth voltages with the camera is obtained.

Actually the leading edge of the synchronizing pulse does vary somewhat with the video waveform, but this edge controls only the end of the line. The start of the line agrees very well with that in the camera. There is a problem resulting from this difference which was mentioned in connection with operation of the Schmidt triggers above. One solution would be to allow the sawtooth to start during the blanking period, but this would detract somewhat from the accuracy of synchronization. A better method would be to add a small positive pedestal to the sawtooth during blanking, to ensure that the Schmidt trigger was turned on.

The vertical sawtooth is triggered by a pulse derived from the horizontal waveform. During the vertical synchronizing pulse capacitor C_H charges up continuously until 2N585 is saturated (Figure 13). This waveform is clipped so that during normal lines the diode does not conduct. This method is only possible

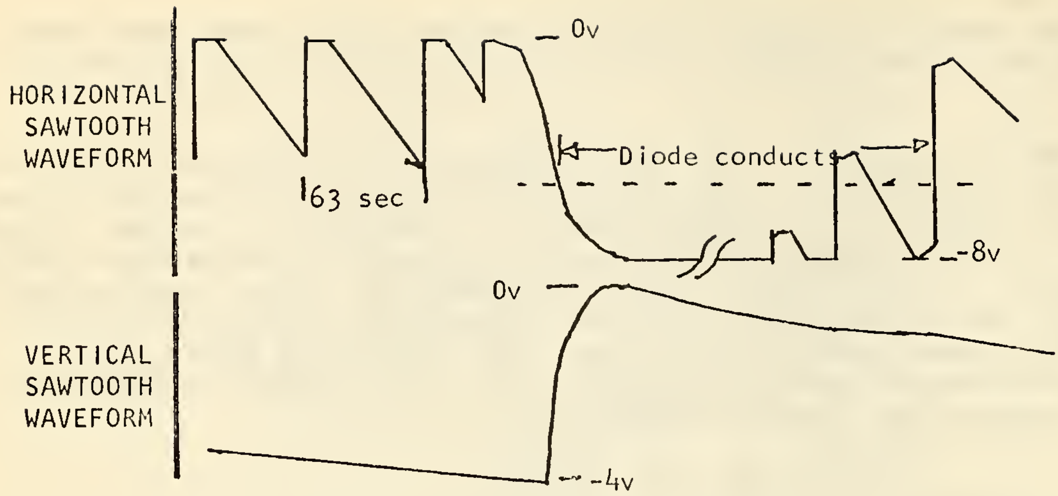

Figure 13. Sawtooth waveforms

with cameras which do not provide equalizing pulses. The vertical sawtooth starts before the end of the blanking pulse so that the corresponding Schmidt trigger is always turned on, even for probe positions on the first few visible lines.

The Video Sampling Units
(Circuit Cards UC5 and UC6)

In these two identical units, voltages are derived which are proportional to the horizontal and vertical components of brightness gradient. In each unit a video signal from a current source is gated into one of two capacitors during selected periods of each frame. The charges are held on the capacitors between samples and a difference amplifier compares the voltages. Just before each new sample the capacitors are discharged.

To avoid a large ac component in the difference output the leakage currents on the capacitors must be kept nearly equal, and it is therefore desirable that they be small compared to the capacitor charge. Since the charging time may be as little as 1/16,000 of the sample repetition period, a large charging current (50 to 100 mA for peak signal) and a low base current (1 to 2 μA maximum) in the transistors following the capacitor are necessary.

It is essential that the capacitor charges be matched at all signal levels so that no spurious difference signal is generated in zero-gradient condition. This can be ensured by using a common source for both capacitor currents. A special gating circuit was devised which permits this. In Figure 14 the gate transistors Q2 and Q3 are operated in common base by the gating pulses appearing at R1 or R3. When the bases are at -10 V only a small

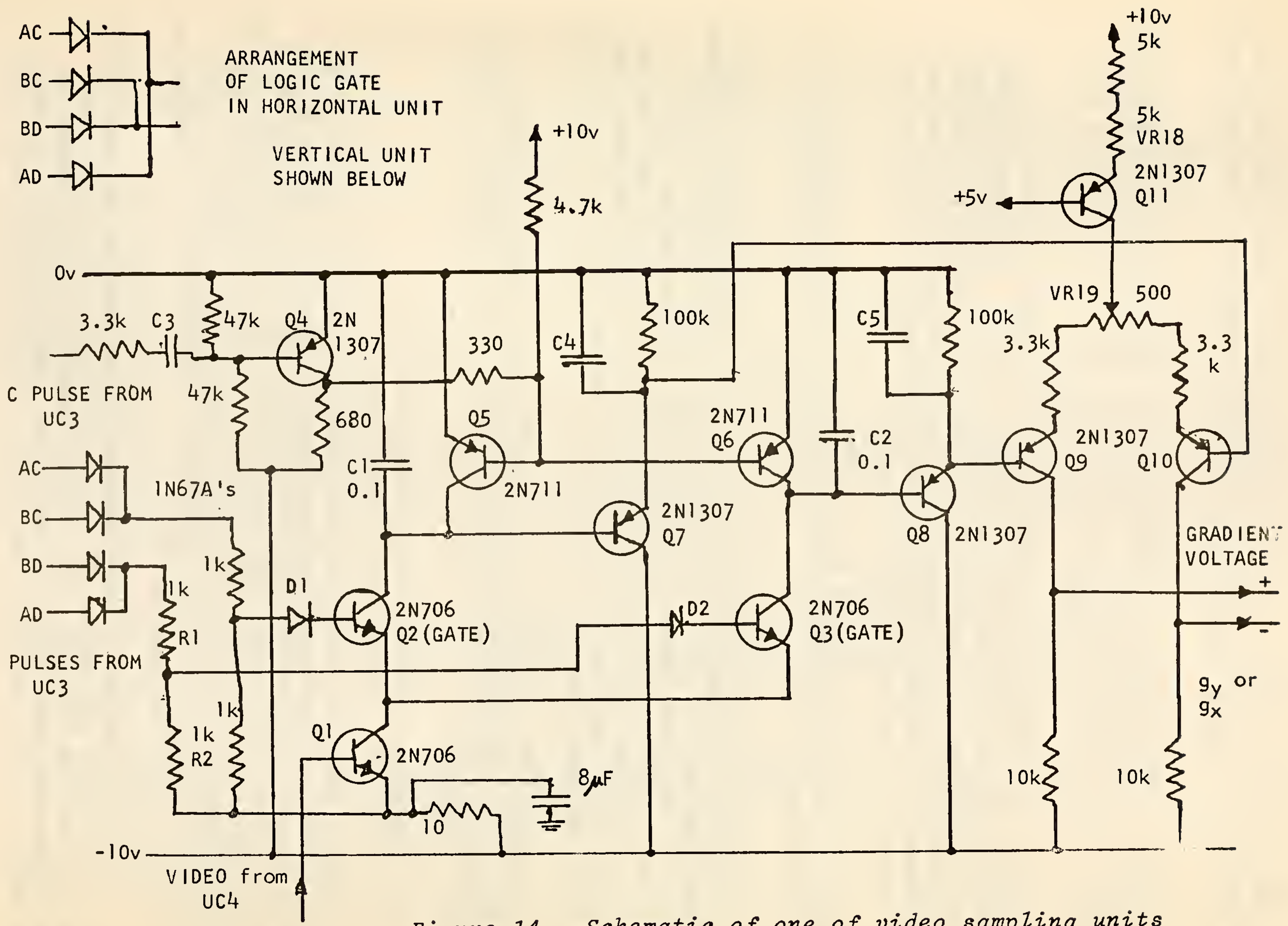

Figure 14. Schematic of one of video sampling units

leakage current flows. A 1 pulse from the gate generator at R1 raises the base of Q3 to -5 V, which allows ∝ times the collector current of Q1 to flow into C2. Diode D2 protects Q2 against excessive V_{beo} when Q3 gated on.

Only the difference in the α of Q2 and Q3 affects the matching, and if this difference is nearly constant it can be compensated for by matching the capacitors and by a fine balance control on the subsequent difference amplifier.

Just before the first sampling pulse in each frame, the capacitors are discharged by driving Q5 and Q6 into conduction. The positive-going slope of the C pulse on the normally off side of multivibrator C cuts off Q4 for about 20 μsec, this cut-off is determined by the time constant of C3 and R5 in parallel with triggered, Q4 collector returns to ground and Q5 and Q6 are cut off again in time for the first sample.

The emitter followers (Q7 and Q8) are used to reduce the drain on C1 and C2 which direct connection to the difference amplifier would cause.

A problem arises when the capacitors are discharged, for the difference voltage falls to zero, and since they do not charge up again simultaneously, a transient difference signal occurs which may be quite large in bright areas of the image. This is overcome by capacitors C4 and C5 which hold the previous levels of C1 and C2 during the sampling period. The time constants can be quite long compared to the sampling period and still be shorter than the sampling interval.

The difference amplifier is conventional, with a constant current provided by Q11 for maximum common mode rejection. This is especially important if single ended output is used. This point is discussed further in the next section.

Output, Feedback, and Control Section (Circuit Card UC8 and Control Panel UC41)

Each video sampling unit provides push-pull outputs in the form of voltages varying from some negative dc level in proportion to one component of the brightness gradient. In this section voltages, varying about zero volts and suitable to drive chopper type servo amplifiers, are derived from the gradient signals, and velocity feedback is added to provide damping (see section below). Controls to which access is necessary in operation are located on the front paned (see Figure 15).

The level change is accomplished by the adders Q1 and Q2, Q3 and Q4. Coarse adjustment (for zero volts at J47 and J48 when the gradient is zero) is made by adjustment of the currents in the difference amplifiers in the video sampling units (by VR16 and VR18). VR41 and VR43 provide fine control during operation.

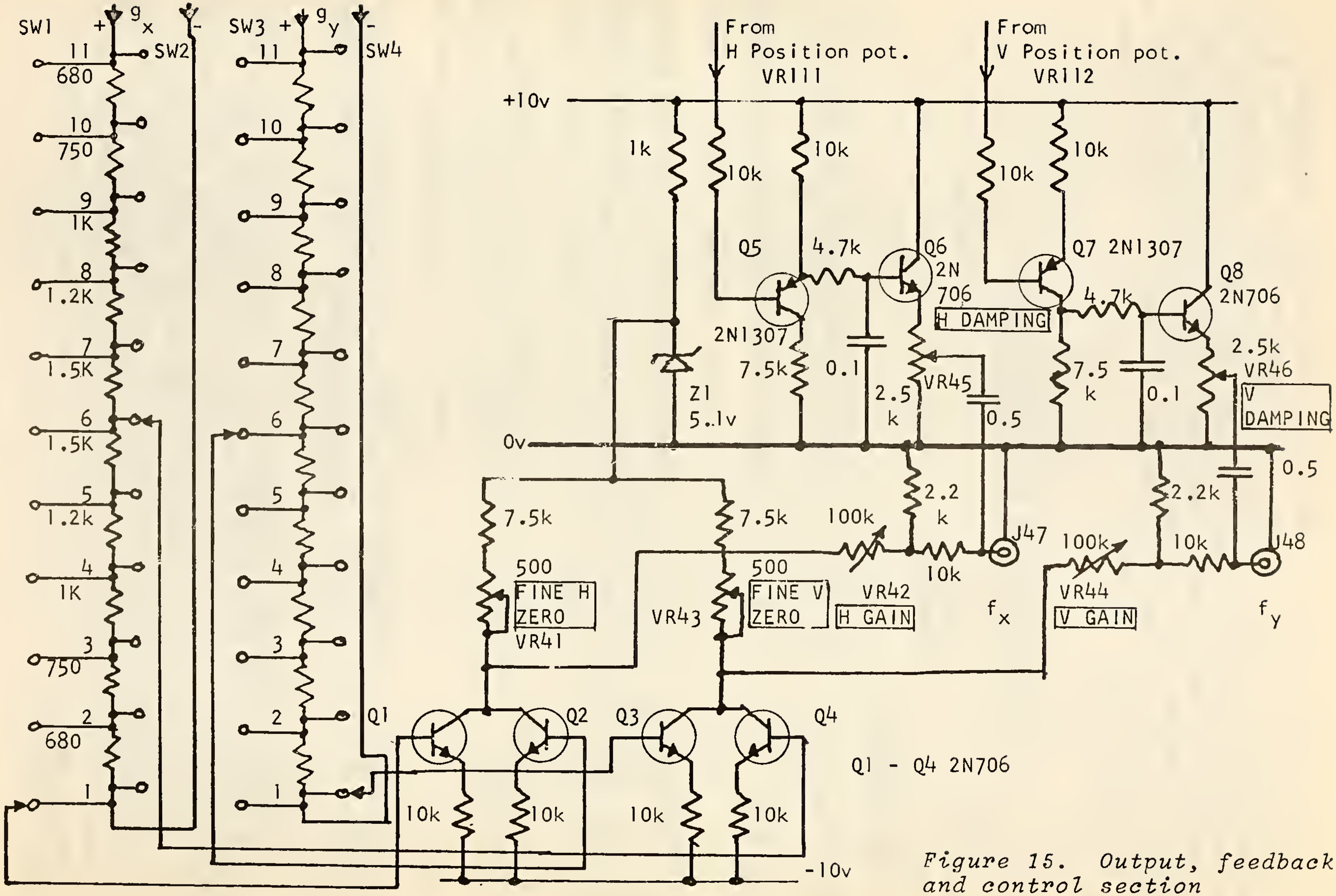

Figure 15. Output, feedback, and control section

Each divider chain is connected between the two phases of a difference amplifier in the video sampling unit. By means of taps selected by rotary switches SW1 through SW4 various fraction are available, positive, negative, or zero (position 6), for selection of the force vector according to the expression in the section on General Principles above. The intermediate steps are chosen to allow 15-degree increments without the overall gain being affected (see Table 1).

TABLE 1

SWITCH SETTINGS FOR VARIOUS ANGLES OF ROTATION OF THE FORCE VECTOR

Position				Angle (degrees)	Effect
SW1	SW2	SW3	SW4		
11	6	6	11	0	Force perpendicular to edge for tracing outside black areas
11	5	7	11	15	Clockwise tracing, outside black
10	4	8	10	30	Clockwise tracing, outside black
9	3	9	9	45	Clockwise tracing, outside black
8	2	10	8	60	Clockwise tracing, outside black
7	1	11	7	75	Clockwise tracing, outside black
6	1	11	6	90	Not usable (force all parallel to edge)
11	7	5	11	-15	Counterclockwise tracing, outside black
1	6	6	1	180	Force perpendicular to edge for tracing inside black areas (line following)

Velocity feedback is obtained by differentiation the position voltages, the time constant being determined by the 0.5 μF capacitors and 2.2 kΩ resistors across the chopper inputs. The 10 kΩ resistor provides additional attenuation for the force signals so that the very high gain of the servo amplifier can be used to simplify the feedback circuit, Q5 and Q7 are buffers and Q7 provides phase reversal for the vertical feedback loop. This is needed because the sense of the vertical scanning in a television system is the opposite of normal *Y*-axis deflection used in the recorder.

Display Unit

The display unit comprises the force output transducers, a stylus, and position measuring potentiometers. An *X-Y* plotter, Type 1100E (manufactured by Electronic Associates Inc, Long Branch, N. J.) was used for this function. In this device the two axes of deflection of a pen are controlled by separate servomotors. The *X* deflection is obtained by a motor driving an arm supported on roller bearings at the upper and lower ends along tracks parallel to the *X* axis. The arm carries a second motor which drives a pen assembly in the *Y* direction by means of a wire and pulley arrangement. The *Y* slide-wire, VR112, is contained in the arm; the *X* slide-wire, VR111, is mounted under one of the tracks and contacted by a wiper attached to the arm.

Access is provided to numerous points in the internal circuit through jumpers on a connector (P11). It was possible to isolate the slide-wire circuits from the servo amplifiers so that these could be used in the manner required in this system. The connections made to this plug and the slight modifications necessary in the internal wiring are detailed in Appendix B. In particular, the lead network used for clamping in normal operation was disconnected, as it does not provide the desired effect in the present circuit.

In operation the pen holder (or some suitable projection attached to it) is grasped by the fingers of the operator. The servomotors operate near stall under most conditions so that the torque they produce, resulting in forces on the pen and arm, is more or less a linear function of the input voltage.

Figure 16 is a photograph of the equipment, showing the stylus attached to the pen holder on the *X-Y* plotter. Figure 17 shows two sample circuit cards.

Monitor Output

To enable sighted persons conducting experiments to monitor the quality of the television signal and the position of the probe, a monitor is usually attached to the system. This is a standard oscilloscope (e.g., Tektronix 535-A). A television image is produced on the screen by applying an amplified video signal to the cathode ray tube's cathode, with suitable deflection waveforms. In addition, a marker is required to show the position of the sampling area. The most satisfactory way found to produce the marker was to apply the combined gating pulses (A+B), (C+D) to the vertical deflection. This results in a black area when the spot is deflected during the pulses. A light area appears higher up the screen but this does not interfere with monitoring.

Circuits to provide the necessary outputs are contained on Card UC7. A schematic is shown in Figure 18. All gating pulses

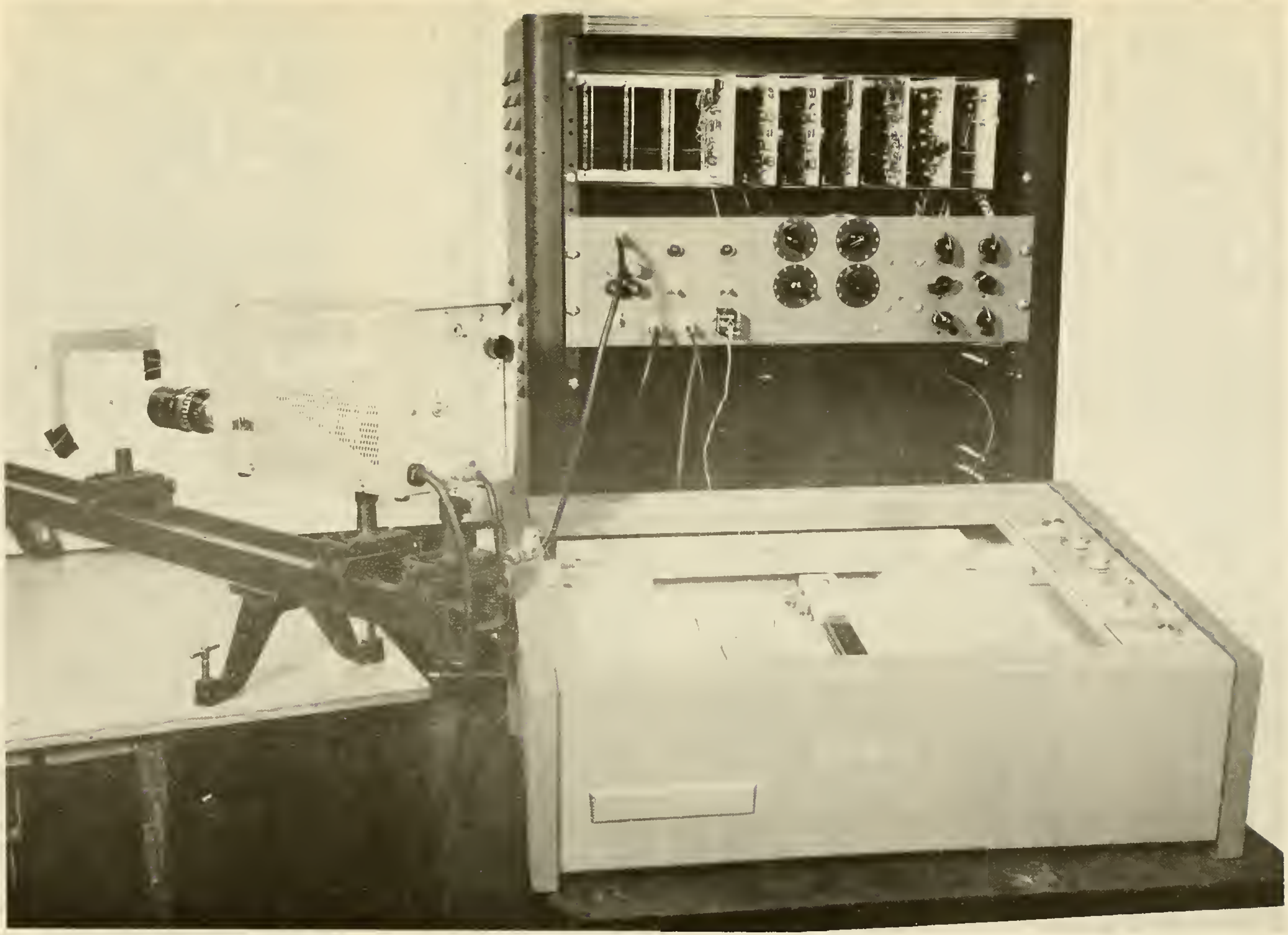

Figure 16. General view of equipment: left - television camera; right top - control circuits; right foreground - X-Y plotter

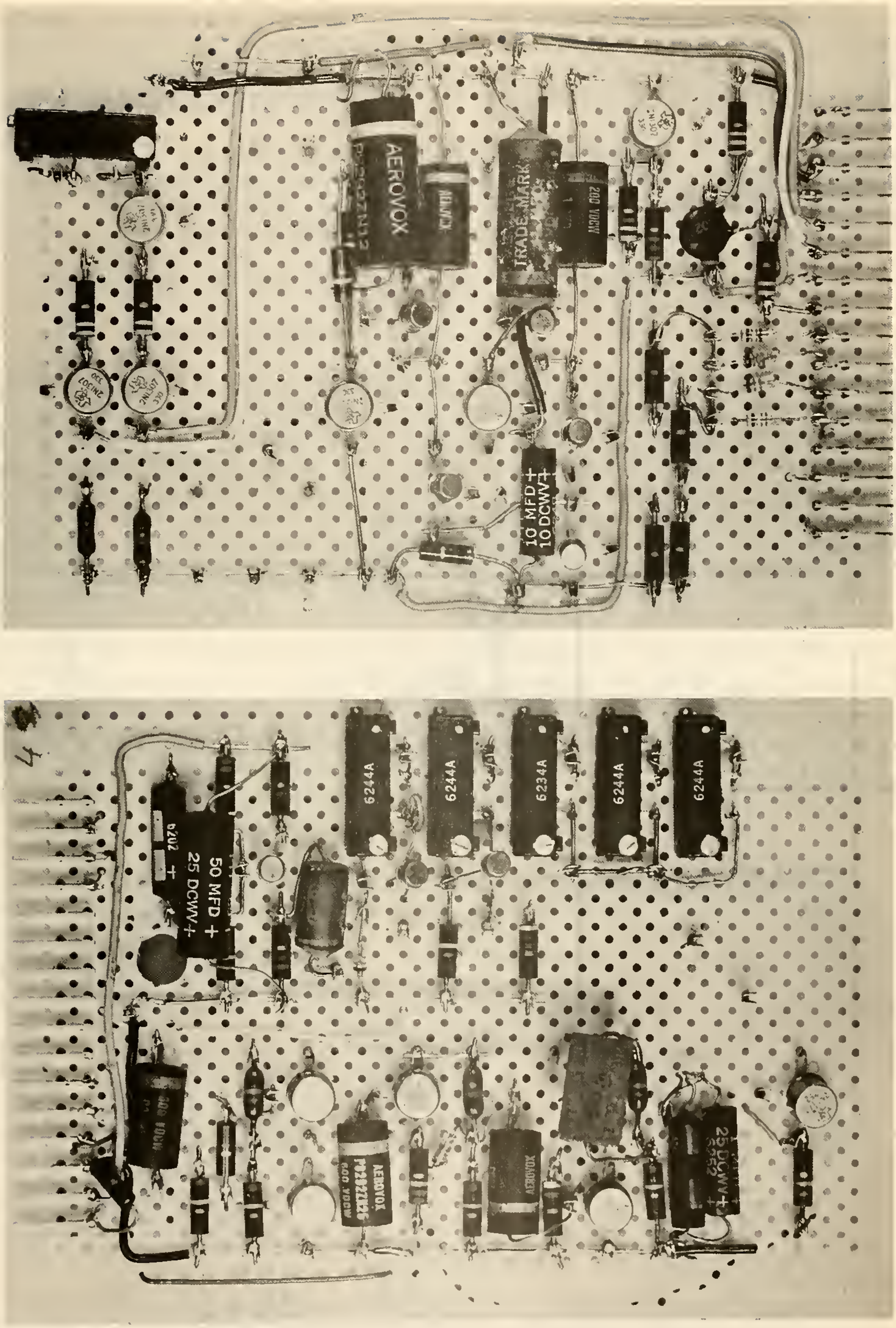

Figure 17. Close-up of circuit cards

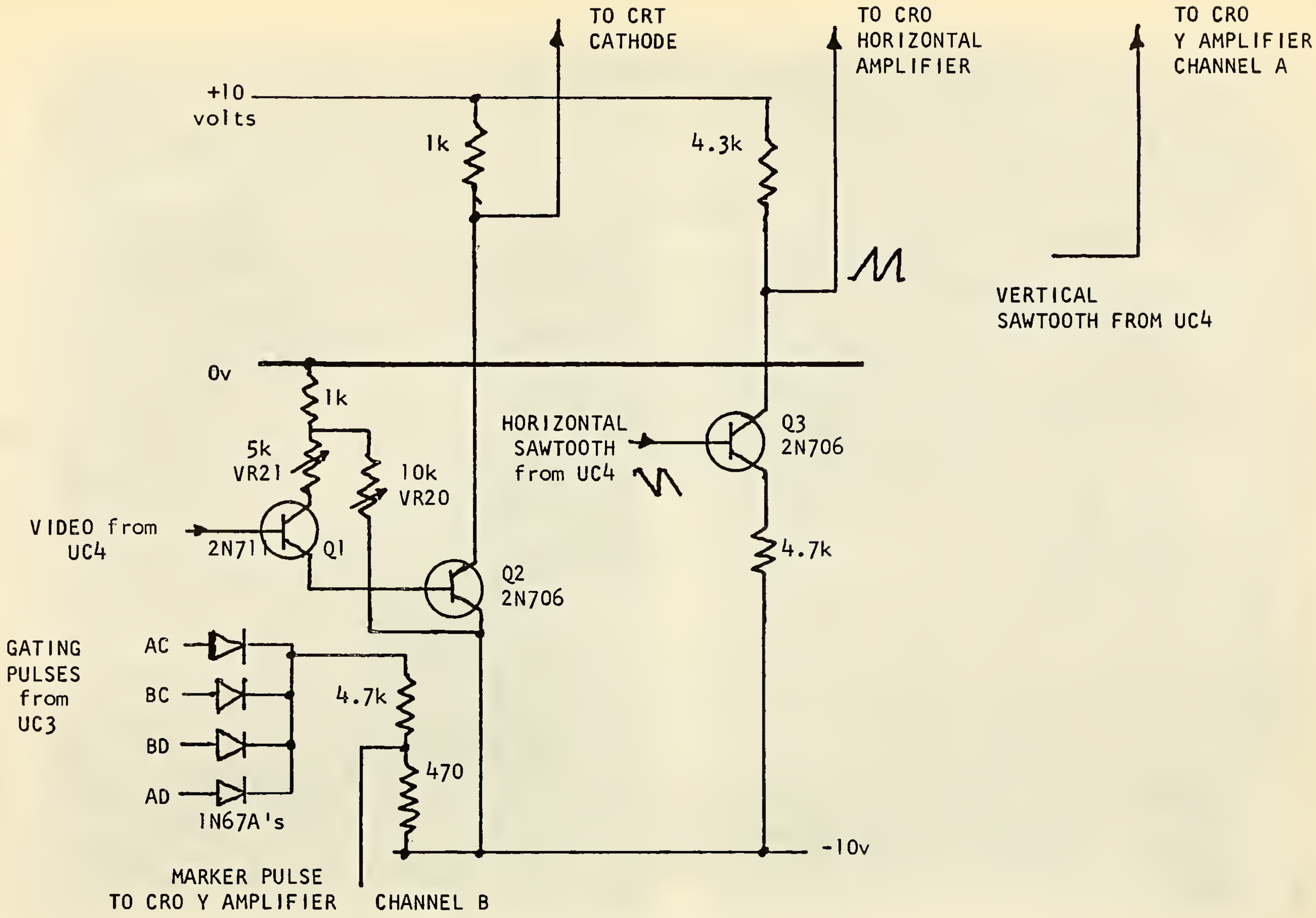

Figure 18. Schematic of monitor output unit

are added through the diode adder. The inverter Q3 provides the necessary positive-going horizontal sawtooth. For the vertical sweep a negative-going sawtooth can be used because of the inversion of normal television scanning (downward instead of upward).

About 20 V peak to peak potential is needed for good contrast in displaying a television signal on the Tektronix oscilloscope. VR20 controls clipping of the synchronizing pulses, and VR21 allows gain adjustment of the video driver stage, Q1.

ANALYSIS OF THE SYSTEM AND ITS OPERATION

The Overall Feedback Loop

The photo stylus system described in this thesis is a closed loop servo, in which the input is a displacement produced by the human operator, and the output is a force. A block diagram of this system is shown in Figure 19. The force produced for a given displacement depends on the visual pattern and will vary with position of the stylus. To obtain some idea of the parameters affecting stability, the unique conditions giving rise to a linear force displacement relation, illustrated in Figure 20, will be considered.

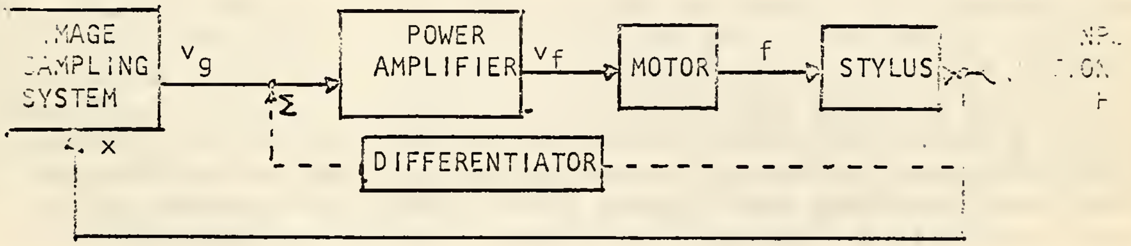

Figure 19. Block diagram of servo system

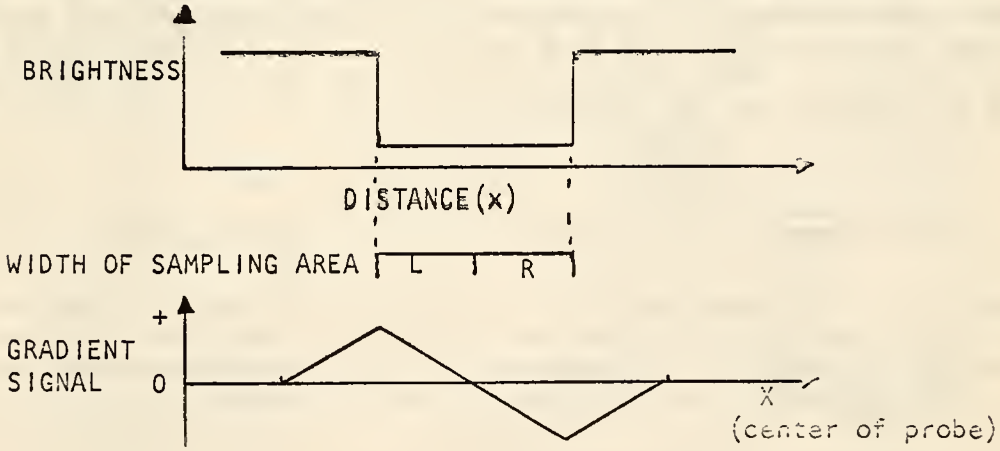

Figure 20. Conditions giving rise to linear forces: displacement relation. Top - cross-section through line in image. Bottom - gradient signal as a function of probe position

The conditions are that the stylus is located on a line parallel to one axis, of the same width as the sampling region. Assuming line tracing mode, a force $k\Delta x$ will be produced when the stylus is displaced Δx from the equilibrium position. The constant k depends on the contrast (assume maximum) and the setting of the gain control. In Figure 21, the effect of all the inertia, mass, and friction in the system is shown lumped into a single term of the form

$$\frac{1}{Ms^2 + Bs},$$

to simplify the treatment. A delay, T, is introduced because of the sampling process, the chopper, and the ac servomotor. This may well be in excess of 1/60 sec. Using the Nyquist criterion, it is found that the system is stable for

$$0<k<\frac{B}{T}.$$

It is observed experimentally that the value of gain at which oscillations occur is too small to provide a satisfactory feeling when on a line or edge. The case treated above is probably the worst, for on a narrower line the gradient signal is reduced, while on a wider line there is a dead zone between reversals of sign of the gradient; the latter gives a nonlinear k having a lower effective value on the motion of the stylus. Oscillations can occur with other modes in similar conditions, but when outside edges are traced these conditions rarely occur (e.g., in spaces between lines which are close together).

The velocity feedback loop was introduced to increase the effective value of B, and thus to permit higher gain to be used. Feedback compensation is preferable to cascade networks because it avoids the varible gain and sampling delay in the image processing sections. The characteristics of the system with damping are discussed in the next section.

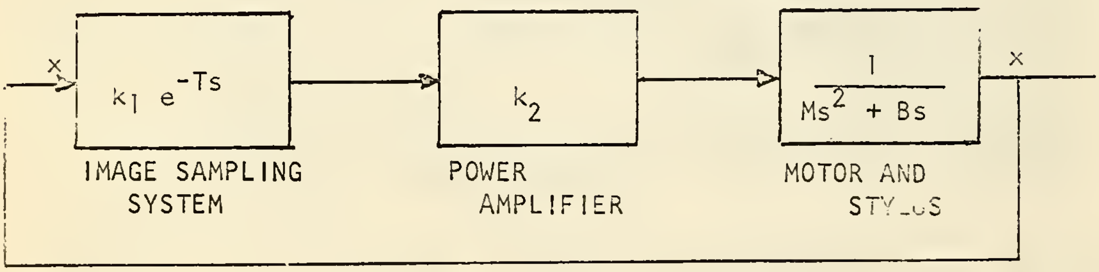

Figure 21. Block diagram of servo loop for linear condition

In the original concept it was proposed to use a display unit loaned by the Department of Mechanical Engineering instead of the *X-Y* plotter. This has a different mechanism to provide the two-dimensional drive which involves considerable mass in the moving parts. To reduce the effect of this mass and of friction on operation of the stylus, a system was devised in which the forces actually felt by the operator would be measured and used on a feedback compensation loop, giving in effect a power-assisted motion. A measuring head consisting of a vertical cantilever and a pair of displacement transducers attached to it at right angles was constructed. Because of difficulties associated with the 400 cycle supply needed to operate this unit, however, it did not perform as intended and the *X-Y* plotter was used instead. Although the force feedback loop could not be used (a different force measuring system would be needed because of the lack of rigidity of the pen mount) the mass and friction are tolerable without it.

Operation of the System

There are a number of ways in which visual patterns might be traced with the aid of the photo stylus. The most obvious is line tracing (equivalent to groove tracing with an embossed pattern). In this mode the force vector is rotated 180 degrees from the gradient vector, and the stylus is pulled onto a line when it is brought near the line. Lines forming letters may be traced, and when one has been recognized the stylus is pushed hard enough to overcome the maximum force which the system can give (depending on the gain setting), to bring it into the white area. This is especially suitable for tracing longer lines such as those in circuit diagrams.

Unfortunately this is the condition in which the oscillation problem is most serious, and when the damping is increased sufficiently to overcome it at its worst, the stylus can hardly be moved at all.

In the simple edge tracing mode ($\theta = 0$), relatively little damping is needed for normal letter spacings. It remains to be seen how well a subject can learn to recognize letters in this way, since the path of the stylus around the outside of a letter is longer and less related to writing than for line tracing.

Partial rotation of the force vector seems to be helpful in speeding up tracing. Since the desired path of the stylus is along the edge it is logical to provide a component of force in this direction. However some perpendicular force must be retained to enable the operator to maintain contact; $\theta = 90$ degrees would be quite useless. Angles greater than 90 degrees are not satisfactory. The stylus is kept on the line as for line tracing, but the parallel component will reverse direction for slight motions about the equilibrium position.

The quality of the television signal is more critical than was expected. Shading, a fault common with vidicon cameras, results in a spurious gradient signal, as do defects such as high and low frequency fall-off. These are particularly troublesome where details come close together, as between letters such as AB, where a "bridge" may be sensed at the bottom of the gap.

Suggestions for Further Work

A series of tests with suitable subjects is contemplated which will establish the capabilities of this system. More important at this stage, however, is the determination of basic parameters for pattern recognition and the mechanisms of perception. It may be that a useful system for practical use will evolve from this project, or that different systems may be suggested as a result of the experiments carried out with it.

A number of improvements might be made both for the present system and for any practical device which might be based on it. In the former category, it might be advantageous to make the alternative display unit operational, perhaps with the power-assist feature, or to design a new display better adapted to the purpose. A system could be designed having a low force output but correspondingly less friction and mass, as it is force contrast rather than absolute force which is important. Modification of the damping circuit to permit more feedback in the critical frequency range, and less at lower frequencies, might facilitate the use of the line tracing mode. There is a danger inherent in this approach, however, an effective increase in inertia may result in failure to detect suddenly encountered edges. An improved monitor would be useful to those conducting experiments.

In the second category, means might be sought to eliminate the television channel for use with certain limited classes of material. The ideal form of the system would be a light-weight probe to which the desired forces might be applied by, for example, reaction through air jets, or friction on the surface containing the visual pattern.

APPENDIX A:
THE TELEVISION CAMERA

The television camera used in this system is a Model TC 110V manufactured by Allen B. DuMont Laboratories, Clifton, New Jersey. It is rated at 400 lines resolution. The horizontal scanning frequency is controlled by a crystal oscillator at approximately 15,750 lines/second. The frame rate is synchronized with the power frequency so that a semirandom interlace exists. One of the disadvantages of this system is that when the probe is located near a horizontal edge a beat frequency may occur due to the digital nature of the vertical scanning.

APPENDIX B:
THE *X-Y* PLOTTER

The *X-Y* plotter used as the display unit is a Model 1100E variplotter manufactured by Electronic Associates Inc., Long Branch, New Jersey. It has a 15-inch by 12-inch operating area. To modify it for use in this system, connections were made to the slide-wires and the chopper type servo amplifiers through connector P11. These connections are shown in Figure 22. Jumpers were connected across Pins 1 and 6 in each of the plug-in sensitivity networks to enable full amplification to be used for the velocity signal. The power supply for the system is shown in Figure 23.

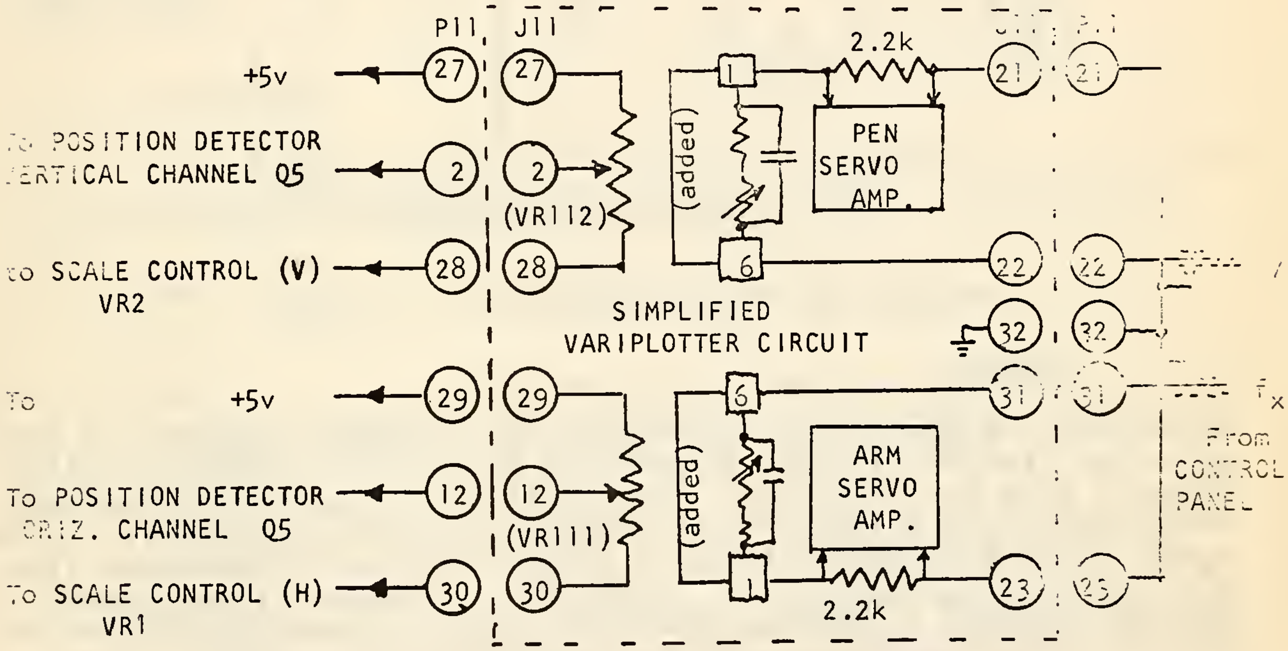

Figure 22. Connections to Variplotter model 1100E

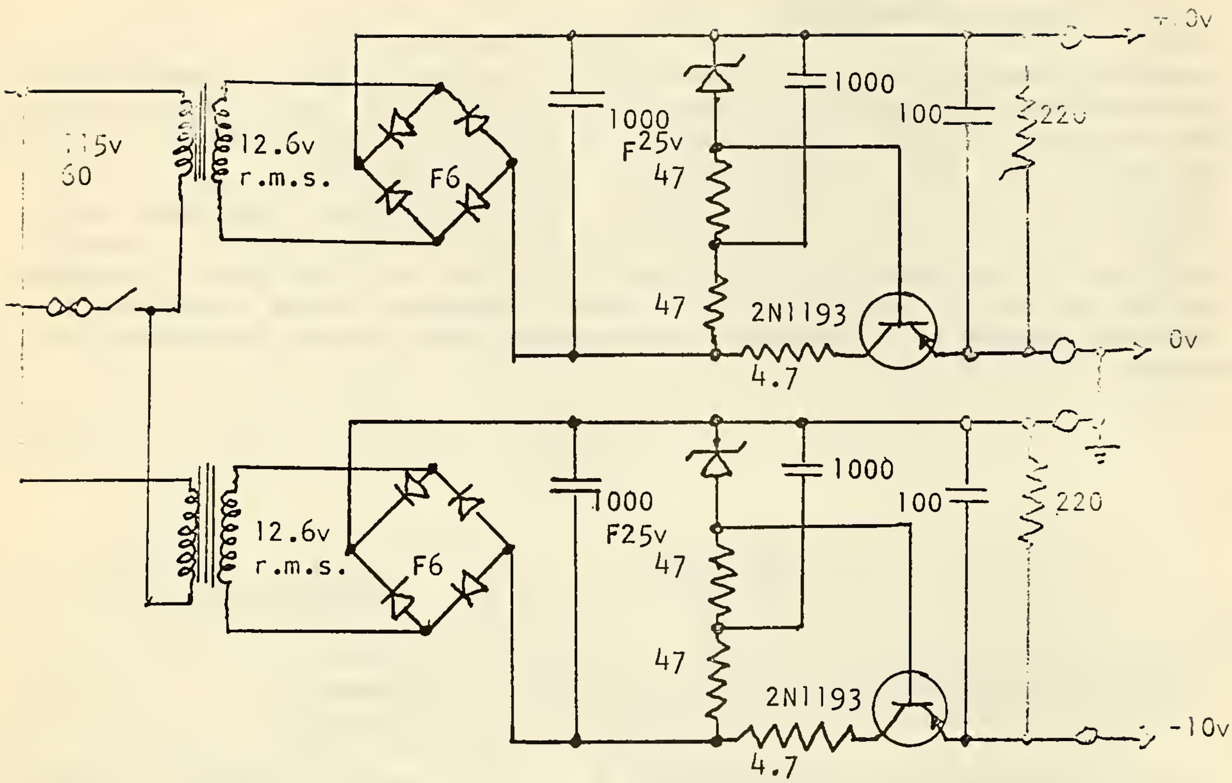

Figure 23. Schematic of power supply

SUMMARY

Perception of spatial relationships and patterns through the tactile and kinesthetic senses is being studied in connection with sensory aids for the blind. The ability to recognize characters by mechanically tracing their outlines might be applied in a slow speed reading device in which a visual pattern is converted into a suitable mechanical form. There is a fundamental difference between tracing an embossed pattern with a fingertip and tracing with a stylus constrained by forces to follow the edge of the pattern.

The subject of this thesis is a system to convert a two-dimensional visual pattern into a pattern of forces which is sensed when a 'stylus' is moved about in the display. The forces are produced by two motors acting at right angles on the stylus, in the plane of the display. The parameter used to control the force is the difference of brightness between adjacent areas of the image, one pair of areas for each motor direction. A television camera scans the image and samples of the video signal at appropriate times are compared to obtain the difference signals. Besides simulation of tracing on embossed pattern other effects can be produced by combining the signals in various ways.

Preliminary trials indicate that character recognition by tracing outlines with this system is possible. The system will permit psychophysical experiments to study this ability, and technological evaluation of systems for converting visual patterns into mechanical forms.

ACKNOWLEDGMENT

The author wishes to thank Professor S. J. Mason and Mr. John K. Dupress for their guidance and encouragement in the course of this thesis project. Credit is due to other members of the sensory aids group for many helpful discussions, to Mr. A. H. Molin for help in the construction of apparatus, and to Miss Rosina Petone for her assistance in typing this report.

The author is grateful to the Polaroid Corporation without whose support and understanding this work could not have been undertaken.

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TRANSLATION FROM MONOTYPE TAPE TO GRADE 2 BRAILLE*

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INTRODUCTION

In the 1820's Louis Braille, a blind Frenchman, devised a system of writing for the blind in which the basic character is a cell containing from 1 to 6 raised dots occurring in fixed positions allowing 63 possible characters. Most extensively used in English books for the blind is Grade 2 braille, in which 26 of these characters are used for the letters of the English alphabet and the rest for punctuation, for format notation, and for frequently encountered letter groups. The system also employs 1 or 2 cell abbreviations for many whole words. A rather complicated set of rules determines how abbreviations and contractions may be used (1, 5). The complexity of the system makes both the training of translators and the translating of material rather lengthy processes, with the result that many items of significant interest to the blind are unavailable in braille.

To alleviate this situation a number of people have become concerned with the possibility of using machines for fast and economical translation into the braille code. In 1956 Sidney Friedrich did research on translation into braille from teletype tape by mechanical means (6). A significant advance was made in 1961 when a program for translation from a specialized format of punched cards into an output suitable for mechanized braille publishing, using the IBM 704 computer, was prepared by Schack and Mertz of IBM (15). Abraham Nemeth of the University of Michigan is presently preparing an independent program for the IBM 650 computer (10). Gerald Staack of MIT has completed a thorough study of the braille code in which he has suggested revision which would make it more readily adaptable to fast and accurate machine translation (17).

The computer programs, especially that by Schack and Mertz which has already been used for translating several books, have opened the way for the possibility of direct input for translation of the original typesetting tapes. Many items of signifi-

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cant interest to the blind are originally prepared on teletype, monotype, or linotype paper tapes for standard ink printing. If these tapes could be adapted for use with a machine translation program the costly intermediate step of retyping the complete text could be eliminated. Previous studies by Kai Johanssen and Philip Siemens in the MIT Department of Mechanical Engineering indicated a very definite feasibility for doing this (8, 16). Robert Gammill of MIT has actually made translations of the news summary column of the *Wall Street Journal* from the teletype tape on which it is transmitted (7).

The existence and availability of these punched tapes in fields of interest is crucial to this scheme. Mr. Siemens indicates that between 40 and 65 percent of the elementary school texts published by major houses used the monotype, or a closely related, system (16). Above this level use of monotype dwindles except in the fields of science and mathematics, in which almost all texts and journals employ the system. These fields are just those in which braille material is scant but most needed. Dr. James Slagle of MIT (who is totally blind) has also pointed out the needs and possibilities in these areas (14). Siemens found a number of publishers willing and able to make tapes and proofs available and to cooperate concerning copyright restrictions.

The monotype system employs two separate machines (2, 3, 9, 13). The text is typed on a keyboard which produces the paper tape containing the character representations and information for line justification (12). The tape is about 4-1/4 inches wide, with feed holes on both sides and 31 positions in which holes may be punched. Usually two holes are punched on each line, indicating one position in a matrix of type characters which may be rearranged within certain broad limits. The tape is then used in a casting machine which forms the type by pouring metal in the appropriate matrix case positions (11). In general, the printer has no further use for the tape at this point.

There are two major obstacles to the proposed system. The first is the many differences between the final printed product and the text on the monotype tape. For example, most headings, titles, illustrations, and tables are set by hand and inserted into the galleys of text. The occurrence of errors on the tape and of special characters and symbols not included in the matrix may run also as high as 10 percent for technical material (9). In general, the illustrations and tables pose no special problem, since they must be specially prepared for the braille text anyway. However, there must be some means of correcting errors and inserting titles.

The second obstacle is that there is no equipment available for reading the tape other than the compressed air operated casting machine. For this reason it has been necessary to build a tape reader. A suggestion for using the TX-O computer display scope and light gun was adopted for this purpose (4).

The work done for this thesis is suggested as part of a system which will result in the production of books in both inkprint and braille almost simultaneously.

THE COMPLETE SYSTEM

The translation program described here is projected as a part of a complete system for the production of a work both in inkprint and in braille form. It involves the cooperation of publisher and printer with a computation center and a braille printer. A flow chart pictures the operation of the system (see Figure 1).

Initially the prepared text is typed at the monotype keyboard, producing the ribbon (paper tape) which contains the text as completely as possible within the limits of the monotype matrix case being used; dummy characters of the proper size are inserted for any symbols which are needed but unavailable. It also contains the information for line justification which is calculated during typing. The keyboard operator also prepares a ribbon ticket specifying the exact matrix characters used. The ticket is used in the casting room to set up the matrix case of type forms. Then the ribbon is run through the casting machine, actually producing the type. At this point in the present process dummy characters are replaced by the proper ones and titles or other information of different size type is inserted and a proof is printed. For the projected system it would be necessary to print a proof of the type exactly as it had been produced from the ribbon. A sequence of proof corrections, hand corrections of the type, and new proofs follows until the type is correct. The book is then printed. At this point the present process is concluded.

For translation into braille the publisher and printer must make available the ribbon, ribbon ticket, and sequence of corrected proofs. From the ribbon ticket IBM punched cards are prepared specifying the characters in the matrix case. Starting with the last proof, corrections are transferred sequentially to the prior proof, until all have been made on the original proof of the type as produced from the ribbon. The erroneous forms and the correction are then also punched on IBM cards sequentially from the beginning of text (see Input Specifications, below). The ribbon is placed in the tape reader and the matrix specification and correction punched cards are used as data for the program.

The translation program sets up an internal copy of the matrix (see Subroutine Matrix, below), then reads the tape, looking up items character by character. These are checked to see whether or not corrections are necessary, then are translated into a specialized format (see Main Program-Translate, below)

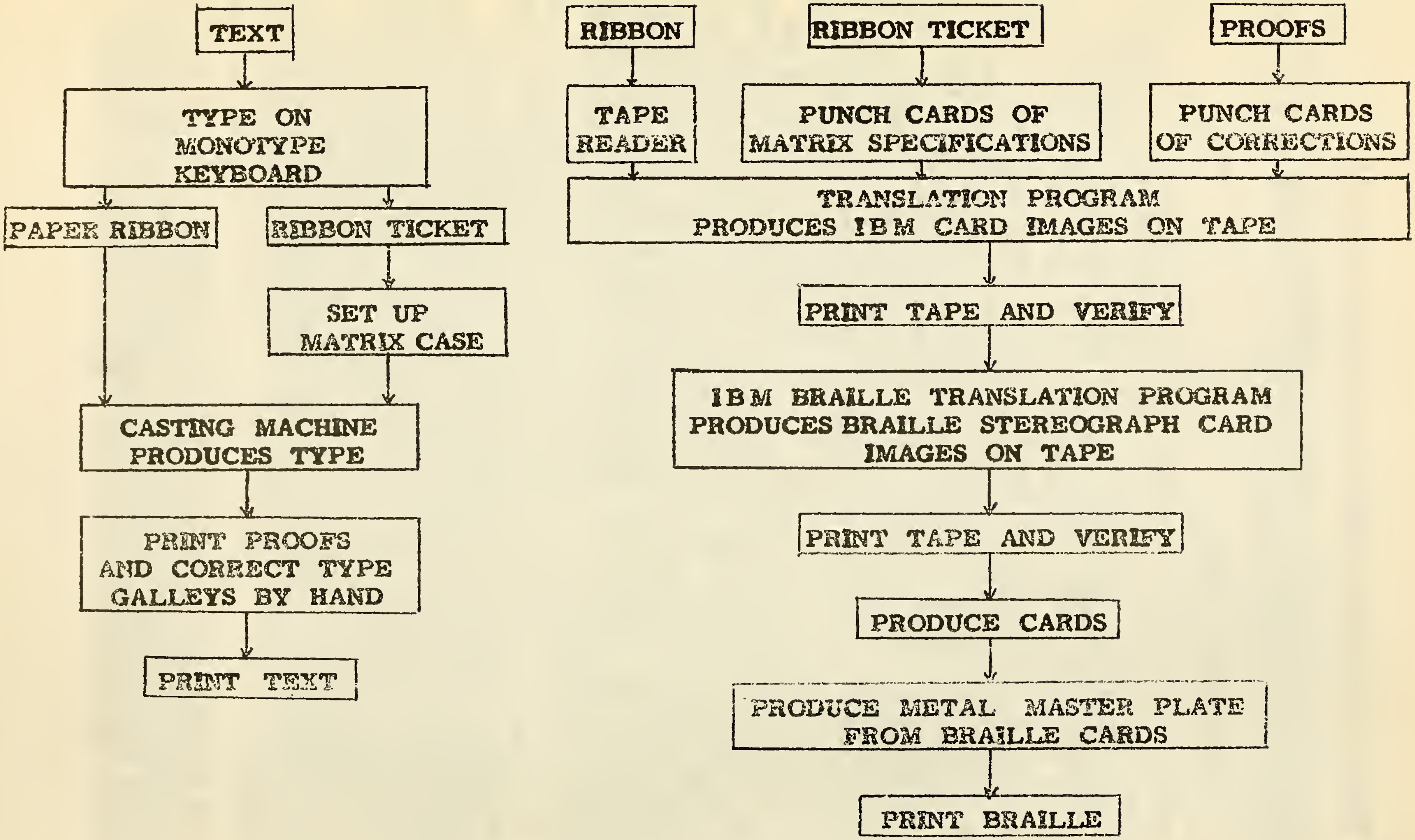

Figure 1. The complete system

and written on magnetic tape as IBM punched card images. This tape can be printed to check for correctness and, if necessary, punched cards can be produced and corrected.

The tape (or punched cards) are read into the IBM Braille Translation program (15) which produces an output tape with card images containing the Grade 2 braille for the text in a format corresponding to the paper tape currently used to control the stereograph machine. A proof of this tape is printed and its correctness checked. The tape is converted to cards from which the embossed metal master braille plate is produced. The plate is then used to print braille text.

INPUT SPECIFICATIONS

Of the many characters available in type, only 48 are available on the IBM card punch machine. It is therefore necessary to devise a scheme of representation of the extra characters through some combination of keypunches which will be unambiguous. The following scheme is patterned after the input requirements of the IBM Braille Translation program (15).

The matrix specification is given on 16 cards - 1 control card and 1 for each row of the matrix case. The control card has in columns 1 to 4 either *1515* or *1517* depending on which of the monotype matrix sizes is used. Each succeeding card is divided into 4-column blocks. The first has the letter *R* for row followed by a 2-digit row number, such as R04, or R13. Starting in column 5 the characters in the row are given in order, each filling a 4-column block. If the representation is less than 4 characters the rest of the block is blank. In this way the card is filled through column 72 for 1517 monotype (17 characters to a row) or through column 64 for 1515 (15 characters to a row).

Small letters are represented by the letters themselves. Multiple letters in type, such as *ffi*, are represented by the sequence of the letters which they combine. Capital letters are preceded by an equal sign, italics by a slash, and italic capitals by a slash and equals in that order. Italics are distinguished only on letters, numerals and punctuation having only one representation. Numerals are represented by the numbers themselves, and fractions or fraction denominators by writing out their parts sequentially. For example,

$\frac{1}{4}$ is written 1/4.

Fractions such as 63/64 cannot be represented in this scheme because they require five characters. There is a unique representation for each of many punctuation marks, signs, and symbols. For example, *?* is *$Q*, *:* is =., and *%* is *$PC*. Figure 2 presents a complete listing of input formats. Two sample sequences of matrix specification cards may be found in Figure 3.

CHARACTER		FOUR COLUMN FORMAT*
small letter	a	A___
capital letter	B	=B__
italic small letter	*c*	/C__
italic capital letter	*D*	/=D_
multiple letter	fi	FI__
italic multiple letter	*ffi*	/FFI
capital multiple letter	AE	=AE_
italic capital multiple letter	*OE*	/=OE
number	3	3___
fraction	$\frac{1}{4}$	1/4_
fraction denominator	/64	/64_

period	.	.___	colon	:	=.__
comma	,	,___	semicolon	;	=,__
question mark	?	$Q__	hyphen	-	-___
exclamation point	!	$X__	dash	—	--__
double quotes (left)	“	=(__	(right)	”	=)__
single quote (left)	‘	+(__	(right)	’	+)__
parenthesis (left)	(	(___	(right)	)	)___
bracket (left)	[	$(__	(right)	]	$)__
dollar sign	$	$$__	ampersand	&	AND_
number sign	#	$NUM	asterisk	*	*___
percent sign	%	$PC_	equal mark	=	$=__
degree symbol	°	$DG_	virgule	/	/___
paragraph symbol	¶	$P__	plus sign	+	+___
section symbol	§	$S__	leader	..	..__

* Underline (_) represents a blank column on an IBM card.

Figure 2. Keypunch symbols for matrix specification cards

```
1515     C       (BOOK)
R01         /L  /T  +(  +)  .   ,       L   I   $)  $(
R02 /J  /F  /I  $X  =.  =,  '   J   F   =I  $X  =.  =,
R03 /C  /R  /S  /E  )   (   +)  +(  R   S   T   =J  /V  $DG /Z
R04 $S  /Q  *   /B  /G  /O  $Q  =I  Z   C   E   =Z  S   $N  $Q
R05 /=I     9   7   5   3   1   0   .   9   7   5   3   1   0
R06 =C          8   6   4   2   $$  ''  $$  8   6   4   2
R07 /X  /K  /Y  /D  /H  /A  =X  =J  G   O   A   =P  =F  =L  =T
R08 =A  /FI /U  /N  °   =S  V   Y   P   U   N   =Q  =B  =O  =E
R09 =D      /FL /P  FL  FI  Q   K   B   H   D   =V  =Y  =G  =R
R10 =H  AND /=J /=S /OE /AE /FF     =Z      FF  =X  =U  =K  =N
R11 /=O /=L /=C /=F /W  LB  AE  =L  =P  =F  $PAR=M  /=Z /=Q /=G
R12 /=E AND =Q  =V  =C  =B  =T  =O  =E  =A  W   /=P /=T /=R /=B
R13 /=D /=A /=Y /FFL/FFI/M  OE  =Y  =U  =G  =R  =OE =AE =W  /=V
R14 /=K /=N /=H FFL FFI =X  =D  =N  =K  =H  M   AND LB  /=X /=U
R15 =OE =AE 3/4 /128/2  /=W /=M ''  ..  =M  =W  $PC /=OE/=AE


1517     7C1A    (JOB)
R01 +(  +)  L   I   /L  /T  +(  +)  .   ,   ,   L   I   $)  $(  .
R02 J   F   T   /I  /F  $X  =.  =,  '   J   F   =I  /J  =.  =,  $X
R03 $X  '   =,  =I  R   /C  )   (   /E  /R  R   S   T   =J  /S  /V  /Z
R04 $Q  =.  Z   C   S   /B  /O  /G  $Q  =I  Z   C   E   $Q  =S  .   /Q
R05 9   7   5   3   1   0   Q   /D  /A  /Y  .   9   7   5   3   1   0
R06 $$  8   =C  6   4   2   V   X   /X  /K  '   $$  8   6   4   2
R07 =J  O   Y   G   A   P   E   /H  X   =J  G   O   A   =P  =F  =L  =T
R08 B   U   =A  N   /P  /U  /N  =S  V   Y   P   U   N   /FL =B  =O  =E
R09 K   H   =D  D   /FI /=I FL  FI  Q   K   B   H   D   V   FI  =G  =R
R10 =Z  =F  =H  =L  =S  FF  /=J /=S /=Q /=C =Z  /FF FF  /=Z =U  FL  =N
R11 =X  =C  =E  =P  =T  =V  =B  =A  =Y  =L  =P  =F  /W  =M  /=F /=L /=O
R12 =R  =U  W   /=G =Q  =V  =C  =B  =T  =O  =E  =A  W   /=P /=B /=E /=T
R13 =K  =G  =D  =O  =N  =G  /=Y /=R /=V =Y  =U  =G  =R  /M  /FFI=W  /FFL
R14 FFL FFI =H  M   /=A FFL FFI =X  =D  =N  =K  =H  M   /=H /=U /=N /=D
R15 AND =W  =M  /   3/4 1/4 1/2 /=W /=M ''  °   =M  =W  $PC AT  AND
```

Figure 3. Matrix specification cards

The correction specifications cannot be so easily restricted to a certain number of columns, since this would be very wasteful of card space and would be very inconvenient for correctly making a number of corrections. Therefore, in corrections, characters follow each other without spaces except for the spaces between words.

The erroneous form, produced exactly as it appeared on the initial proof, is on the left side of the card, starting in any column from column 1 on. It is followed by at least two spaces, an asterisk (*), and at least two more spaces. The correct form follows on the right hand side of the card, with all columns up through 80 available. The error and correction texts use the same specification as the matrix input with the following exceptions.

1. No spaces are inserted except as they occur in the text.

2. A symbol whose representation requires more than one character, other than punctuation symbols, is enclosed within dollar marks. For example, *ffi* becomes *ffi*, *1/4* becomes *$1/4$*, *AE* becomes *$=AE$*.

3. The slash (/) is represented by *$/*.

Figure 4 lists the keypunch symbols for characters on error correction cards.

For ease in representing passages written other than in small letters, the following abbriviations are used:

= for a text of capital letters

/ for a text of italic letters

/= for a text of italic capital letters.

When one of these symbols is placed two spaces before the entire text it applies to the whole text, when placed one space before a word in the test it applies only to that word, and when placed immediately before a single letter only that letter is in the particular format. These forms may be within one another. A few examples are listed below.

error: accidental CAP word correct: accidental cap word
ACCIDENTAL = CAP WORD * ACCIDENTAL CAP WORD

error: ACCIDENTAL *ITALIC* WORD correct: ACCIDENTAL ITALIC WORD
ACCIDENTAL / ITALIC WORD + = ACCIDENTAL ITALIC WORD

error: accidental cap leTTer correct: accidental cap letter
= ACCIDENTAL CAP LE=T=TER * ACCIDENTAL CAP LETTER

CHARACTER		CORRECTION SYMBOL
small letter	a	A
capital letter	b	=B
italic small letter	*c*	/C
italic capital letter	*D*	/=D
multiple letter	fi	FI
italic multiple letter	*ffi*	/FFI
capital multiple letter	AE	$=AE$
italic capital multiple letter	*OE*	$/=OE$
number	3	3
fraction	$\frac{1}{4}$	$1/4$
fraction denominator	/64	$/64$

period	.	.	colon	:	=.
comma	,	,	semicolon	;	=,
question mark	?	$Q	hyphen	-	-
exclamation point	!	$X	dash	—	--
double quotes (left)	“	=(	(right)	”	=)
single quote (left)	‘	+(	(right)	’	+)
parenthesis (left)	(	(	(right)	)	)
bracket (left)	[	$(	(right)	]	$)
dollar sign	$	$$	ampersand	&	AND
number sign	#	$NUM	asterisk	*	*
percent sign	%	$PC	equal mark	=	$=
degree symbol	°	$DG	virgule	/	$/
paragraph symbol	¶	$P	plus sign	+	+
section symbol	§	$S	leader	..	..

Figure 4. Keypunch symbols for error correction cards

error: *a few CAPS inSide* (italic text) correct: *a few caps inside*

= / A FEW = CAPS IN=SIDE * / A FEW CAPS INSIDE

The correction cards are sequentially ordered and placed after the matrix specification cards at the end of the input deck.

The correction scheme can easily be extended to provide for handling longer corrections or insertions than can be punched on one 80-column card by requiring an asterisk in column 1 of the first card and as asterisk in column 80 of the last card of the correction.

THE TAPE READER

To test the translation program it was decided to use a temporary tape reader rather than to construct a photoelectric tape reader. It was assumed after brief investigation that the oscilloscope display and light gun facility of the TX-O computer would provide a reasonably easily constructed and programmed tape reader. The gun sets an indicator whenever it "sees" a point displayed on the scope face. If the tape intervenes the gun should only see those points which lie behind holes in the tape.

Several difficulties were encountered. When the gain on the light gun was adjusted sufficiently high for it to see all the points it should see, it also reported seeing points which should have been concealed. This is because the thin white monotype tape was reasonably translucent. There were other spurious signals due to noise in the gun system. Another problem was determining the proper spacing of points on the oscilloscope to correspond best with the tape hole spacing since there was no exact match possible. Since no one could be found who knew the correspondences between the TX-O tape recording and the 7090 tape reading, several experiments had to be run to determine them.

The operation of the tape reading program combines both manual and programmed operations. The tape is placed through a guide on the oscilloscope frame and run through the rollers of a motor which moves it at a constant speed. The program scans the scope face, locating the left edge of the tape and the feed hole positions, and sets up indicators for the feed hole and information hole positions. The tape is then put in motion and the program started. A point is displayed at the feed hole positions to determine when a character position has been reached. Points are displayed sequentially at each of the hole positions, the gun indicator being checked after each display to determine whether or not the point was seen. When a hole is seen, the bit which represents it is looked up in a table and set to 1. Each hole position is checked three times and each line rechecked three times. Because the tape has 31 hole positions and the TX-O word only 18 bits, the left 13 holes are checked first and their results stored;

then the right 18 holes are checked. The results of the scan are stored character by character until a buffer has been filled, then are written on the magnetic tape along with the control words required for the 7090 Fortran Read Tape Binary subroutine. A flow chart of the program is shown in Figure 5.

The speed at which the tape was read was about 2 lines per second, the fixed speed of the motor. The program itself was capable of reading over 50 lines per second.

Although this method of tape reading was projected to be a quick and simple expedient for getting reasonably reliable results, the difficulties encountered expanded it to a large part of the total effort expended on the project. It would have been simpler and better to have designed a photoelectric tape reader from the start.

SUBROUTINE MATRIX

The subroutine matrix uses the 16 data cards to form an internal representation of the monotype matrix employed.

The matrix specification characters are converted to the following format before being stored. The 36 bits of the IBM 7090 word are divided into three parts. The first of 24 bits store a 4-BCD character representation of the symbol which, with a few exceptions, is the 4-character input from the card. (In the case of italics, for instance, the initial slash has been removed.) The second part of 6 bits stores a count of the number of spaces that will be required on the output cards for the character. The last section of 6 bits has an octal number which is a code for the type of character. The codes are

01	small letter(s)
02	capital letter(s)
03	italic small letter(s)
04	italic capital letter(s)
05	number
06	fraction
07	fraction denominator
10	space
11	initial punctuation

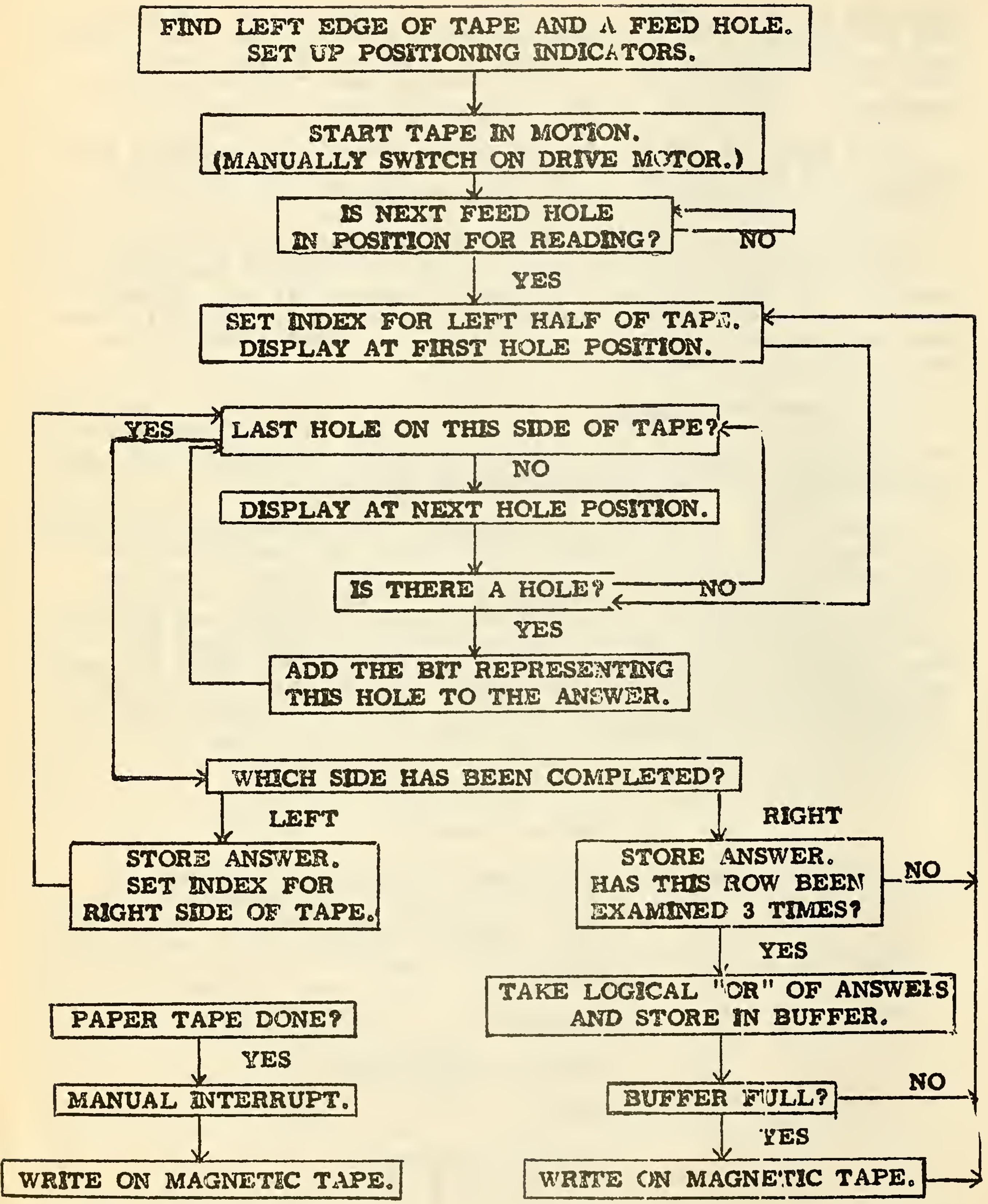

Figure 5. Monotape Read

12	medial punctuation
13	final punctuation
14	period
15	hyphen
16	carriage return
20	a word (such as *at* or *and*)
23	left single quotation mark
24	right single quotation mark

Some of these categories are necessary because of special usages: a period may be a period or a decimal point; a hyphen may signify the division of a word because of end of line or may be used in some other way; single quotation marks may be used as such, combined to form double quotation marks, or the right mark may be used as an apostrophe. These cases may present some problems.

After counting the number of nonspace characters in the four-character group, the program looks up the first one in a table and branches accordingly, checking each of the possibilities for the remaining three characters when necessary. The type code number is added and the character, count, and code number are stored. (A chart of these internal representations is included in the Appendix.) This procedure continues row by row until the complete matrix is stored. The operation for this subroutine is shown on the flow chart in Figure 6.

MAIN PROGRAM-TRANSLATE

After calling subroutine matrix for setup of the internal representation of the monotype matrix, the main program calls subroutine *GET* which gets one character from the paper ribbon. The character here is a 31-digit binary number with 1's representing the positions where holes were punched. Subroutine *ORDER* converts this to two 2-digit octal numbers giving the column and row numbers in the right end of the accumulator. These are used to locate the appropriate character in the matrix. (When the correction subroutine is programmed, it will accumulate a group of characters at this point, then check for errors.) The identifying code is checked and the program branches according to what type the character is. (See list of types of characters in Subroutine Matrix, above, and the flow chart in Figure 7.)

The program then puts the characters sequentially into the format required by the IBM Braille Translation program (15). A

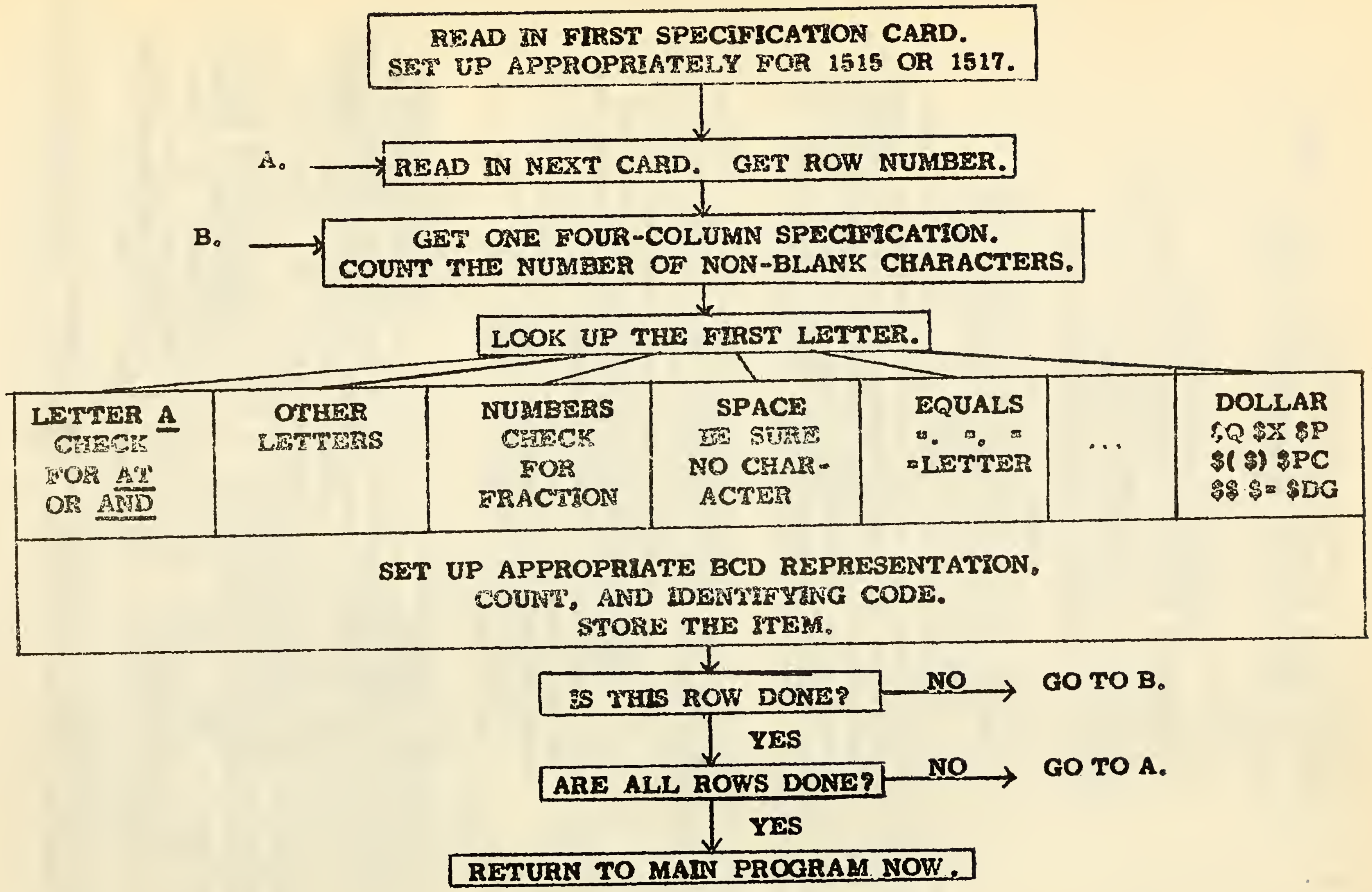

Figure 6. Subroutine Matrix

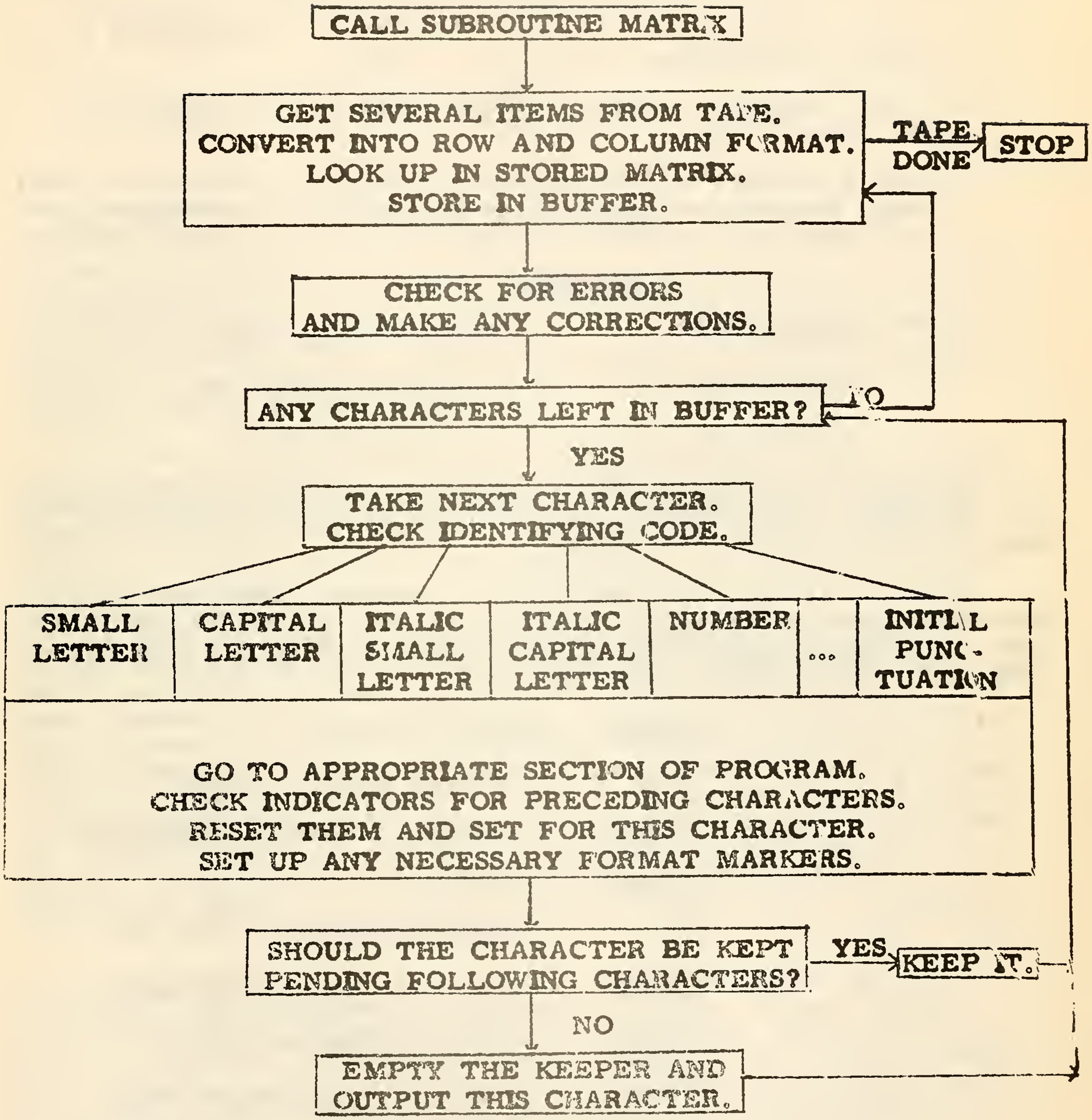

Figure 7. Translate (Main Program)

few examples of these specifications are as follows.

1) A word beginning with a capital letter is preceded by a single equal mark.

2) A word which is entirely capital letters is preceded by two equal marks.

3) When a portion of the word is capitalized, the double equal marks precede the capitalized portion and a terminate capitals mark ($TC) denotes the end of the capitalized section.

Example

DIStinguish	==DIS$TCTINGUISH
disTINguish	DIS-==TIN$TCGUISH
distinGUISH	DISTIN-==GUISH

A similar representation is used for italicized words or portion of words, and a special mark denotes an italic passage of more than three words in length.

Since it is of prime importance to remember what type of characters have preceded the present one, the sense indicators are used for this purpose. Twelve are used to specify the possibilities of the last single character.

ISMALL	a small letter
ICAP	a single capital letter
INUMBER	a number, including fractions
ISPACE	a space
ICR	a carriage return
IPUNCI	an initial puncutation mark
IPUNCM	a medial punctuation mark
IPUNCF	a terminal punctuation mark
IRQUOT	a single right quotation mark
ILQUOT	a single left quotation mark
IHYPHN	a hyphen
IPER	a period

These indicators are used so as mutually to exclude each other.

Four other special purpose indicators are used.

ICAPWD	a capitalized word
IITALW	italic word
IITALQ	italic question
IITALM	italic mode

ICAPWD is on whenever a word, or the current portion of a word, is capitalized. It may be on simultaneously with any of the above except ISMALL, ICAP, ISPACE, or ICR, and probably should never be on concurrently with IPUNCI. It is on along with the others because a capital word is not terminated because of an internal number or punctuation mark.

The italic indicators mutually exclude each other, but may be on concurrently with any of the others. IITALW is used whenever the italic section has started in the middle of the word. ITALQ is used while there is a question whether or not this is an italic passage of more than three words. IITALM is used for italic passages.

Within the main program, for each category of characters, checks are made for each of the important possibilities for preceding characters and appropriate formats set up. The program, because of this, has to allow a number of possible character sequences which are very unlikely and may never occur. Several assumptions have been made which occasionally will produce incorrect results. A period is considered to be a period unless it occurs immediately before a number, in which case it is taken as a decimal point. A single right closing quotation mark is assumed to be an apostrophe if it occurs before a letter, otherwise it is taken as a quotation mark. Other similar assumptions have been made for ambiguous characters.

When the character is a letter, the first check determines whether it was preceded by italics or regular letters; then, whether by capitals or small letters, or by any of the other possible marks. For other characters an appropriate similar procedure is used. When the proper format has been determined insofar as possible, the character and any special signs necessary are either held in the keeper pending information from succeeding characters or subroutine QUE is called to queue the letter onto the current IBM output card format. The output to QUE is from five BCD characters followed by a count number in the right hand end of the register. (These internal formats are summarized in the Appendix.)

Several utility routines are used in the main program. A brief description of each is listed below.

GET has an internal buffer which it periodically fills with tape characters. These characters are supplied one at a time when GET is called.

ORDER converts the bit pattern supplied by GET to the row and column number of the matrix position represented.

KEEP places the word in the accumulator at the end of the keeper which holds characters whose final format depends on succeeding characters. Italic words are held in the keeper until it is determined whether the italic passage is greater than three words long. Italic words within a passage are held in the keeper until completed. Punctuation and numbers are temporarily stored there.

UNKEEP sends the entire contents of the keeper, item by item, to the subroutine QUE.

UNKP1 returns the last item put in the keeper to the main program for elimination or revision.

ITQSET inserts the italic symbol *($1)* before each word in the keeper when it is determined that there are less than four italic words in sequence. ITQST1 inserts the italic symbol before all except the last word in the keeper.

QUE places the character in the accumulator into the next position(s) on the current output card.

CLEAR fills the current output card with blanks and starts a new one.

CONCLUSIONS AND RECOMMENDATIONS

Several specific changes and areas of study are planned for continuing this project.

Because of the clear inadequacy of the method of reading the monotype tape with the TX-O oscilloscope and light gun, work should be begun as soon as possible on a photoelectric tape reader (PETR). When it is incorporated into the system, the whole TX-O program, MONOTAPE READ, and the 7090 subroutine GET are replaced by 7090 data channel command to read the tape. Depending on the speed of the PETR it may be possible to process characters as they are read. If not the tape must be started and stopped for reading each block of characters, then the manipulations performed on each block. Perhaps an in-between situation of correcting errors as the tape is read in, and processing after a certain number of characters have been read, could be employed.

The next step in programming is to write the correction subroutine. In addition to the features already mentioned it should have the ability to insert the titles, headings, and other information inserted by hand in the monotype galley. There should be added a provision for inserting format notations and the poetry or foreign language markers required by the Schack translation program. The scheme for inserting longer descriptive passages which would replace figures or tables in the text must also be included.

It is very possible that program efficiency could be improved by entering into a middle point in the Schack program, since some of the information it needs has already been determined. It is rather time wasting to code such information into a special format, them have to decode it again. This would also eliminate the intermediate step of arranging tape records in IBM card format. This suggestion has the potential of being a significant factor in reducing the computer time required.

Once these suggestions are effected the system should be ready to make actual translations. It is not unreasonable to assume that, with such an operation, plates for producing the braille text could be ready for printing within only one or two weeks of the completion of the galleys for regular printing, the only typing required having been essentially that of errors and corrections rather than of the whole text.

APPENDIX:
SUMMARY OF INPUT AND INTERNAL CHARACTER REPRESENTATIONS

Character		matrix* input form	correction form	storage* form in matrix		output* to QUE
a	(small letter)	A____	A	A____1	01	A____01
B	(capital letter)	=B___	=B	=B___2	02	=B___02
c	(italic)	/C___	/C	C____1	03	C____01
D	(italic)	/=D__	/=D	=D___2	04	=D___02
fi	(single type)	FI___	FI	FI___2	01	FI___02
ffl	(single type)	FFL__	FFL	FFL__3	01	FFL__03
fi	(single italic)	/FL__	$/FL$	FL___2	03	FL___02
ffi	(single italic)	/FFI	$/FFI$	FFI__3	03	FFI__03
AE	(single type)	=AE__	$=AE$	=AE__3	02	=AE__03

Character		matrix* input form	correction form	storage* form in matrix		output* to QUE
OE	(single italic)	/=OE	$/=OE$	=OE__3	04	=OE__04
2	(number)	2____	2	2____1	05	2____01
$\frac{1}{4}$	(fraction)	1/4__	$1/4$	1/4__4	06	__1/404
3/16	(fraction)	3/16	$3/16$	3/16 5	06	__3/165
/64	(denominator)	/64__	$/64$	/64__3	07	/64__03
__	(space)	_____	__	_____1	10	______1
(	(open parenthesis)	(___	(	(____1	11	(____01
[	(bracket)	$(___	$(	$(___2	11	$(___02
"	(opening quotes)	=(___	=(	=(___2	11	=(___02
#	(number sign)	$N___	$N	$N___2	11	$N___02
¶	(paragraph symbol)	$P__	$P	$P___2	11	$P___02
§	(section symbol)	$S___	$S	$S___2	11	$S___02
$	(dollar sign)	$$___	$$	$DOL 4	11	$DOL 04
*	(asterisk)	*____	*	*____1	12	*____01
/	(virgule)	/____	$/	/____1	12	/____01
..	(leader)	..___	..	..___2	12	..___02
)	(close parenthesis)	)__	)	)____1	13	)____01
]	(close bracket)	$)___	$)	$)___2	13	$)___02
"	(close quotes)	=)___	=)	=)___2	13	=)___02
,	(comma)	,____	,	,____1	13	,____01
;	(semicolon)	=,___	=,	=,___2	13	=,___02
:	(colon)	=.___	=.	=.___2	13	=.___02
=	(equal sign)	$=___	$=	$=___2	13	$=___02
—	(dash)**	--___	--	--___2	13	--___02

Character		matrix* input form	correction form	storage* form in matrix		output* to QUE
?	(question mark)	$Q___	$Q	$Q___2	13	$Q____02
!	(exclamation point)	$X___	$X	$X___2	13	$X____02
%	(percent sign)	$PC__	$PC	$PC__3	13	$PC___03
°	(degree symbol)	$DG__	$DG	$DG__3	13	$DG___03
.	(period)	.____	.	.____1	14	._____01
-	(hyphen)**	-____	-	-____1	15	-_____01
£	(pound sign)	LB___	LB	LB___4	20	_LB____4
@	("at" sign)	AT___	AT	AT___4	20	_AT____4
&	(ampersand)	AND__	AND	AND__5	20	_AND___5
+	(plus sign)	PLUS	+	PLUS_5	20	__PLUS 5
‘	(open single quote)	+(___	+(	+(___2	23	+(____02
’	(close single quote)	+)___	+)	+)___2	24	+)____02

SUMMARY

A computer system has been developed for producing Grade 2 braille directly from the printer's monotype tape. A computer program for preparing from the tape the required input format for an IBM Braille Translation program is presented. It employs the TX-0 computer oscilloscope display and light gun for reading the paper tape, and the IBM 7090 computer for converting the punched tape pattern into the format required for the Grade 2 braille translation program. Provision is made for inserting additional material and correcting errors which have been previously detected on the tape. Specific suggestions for completing the system and instructions for its operation are given.

* Underline (_) represents the blank column on an IBM card, or the Hollerith code for a blank.

**Dash and hyphen are IBM cardpunch 8-4 punches.

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