say by a factor of at least four, and continues to improve appreciably until good graphic freedom obtains with a matrix of 20×28.

The economical question then becomes one of determining whether for a particular application it is more desirable to utilize N objectives (in N small projectors) each resolving L bits, or L equivalent sphericules each resolving N bits. We find that a numerical display will be slightly more economical when built with a lenticular than it would be built with a projector battery and that this advantage increases as the amount of information per channel increases.

An example of a large information display developed for a link in the SAGE system is illustrated in (Fig. 2). There are 20 channels in this display. The used screen area is six square inches and each channel carries 3600 bits per square inch. This particular display was developed to replace a battery of signal lights and represents, we believe, a tool which the human engineer can use to good advantage to satisfy what might be called the system requirements of a human operator. Interestingly, the human link in a system is the one least susceptible to redesign. With substantial training, an operator can learn to utilize unfamiliar information codes, but in the final analysis we will always find that, as an information-receiving center, the operator is a noisy device. It behooves us, therefore, to address such a device with signals which will activate the various functional aspects of the individual and also supply a sufficiently large amount of information so that these recognition and reaction functions can operate reliability. Thus, one might argue that the signaling of one out of 20 pre-established messages constitutes relaying information of no more than five bits for each message, whereas the fully flexible tool in this instance utilizes over 20,000 bits and that the device is thus extremely redundant. However, when these highly redundant patterns can be generated basically by one molding operation and one photographic operation for each message, the potential economy is self-evident.

Control complexity of the lenticular displays is naturally greater than that of coded displays. In the previous example some means must be provided to deliver more than five control lines to the display. One solution is to apply power to one out of N (in this case 20) leads. $N+1$ leads must then be brought out of the device. For maximum application freedom we prefer to bring out both ends of each filament. This may allow the user to simplify his decoder. Due consideration must be given to sneak paths. In general, the glow of a filament in a sneak path will be negligible if the voltage across the filament is no greater than one third of the operating voltage. The tolerable sneak path will vary depending upon the type of filament, the type of display and the application requirements. The individual application should be examined. Relay decoders have been used successfully to drive 10-channel digit displays where sneak paths included three filaments in series.

Conclusion

The lenticular medium lends itself to space-sharing display purposes in many applications. If the lenticular art is mastered, good manufacturability can be obtained. Power requirements are not negligible, the devices being best suited to low-voltage, high-current applications. Where electrical requirements can be met, excellent graphic freedom is obtained and this can materially assist the human engineer.

Devices for Reading Handwritten Characters

T. L. DIMOND†

In the last five years, much thought and effort have gone into the development of printed character-recognition devices. Varying degrees of success have been achieved. In some cases, ingeniously distorted type faces have been required. One might wonder why all this interest exists. The answer is simple. Character-recognition devices help reduce the substantial cost of getting information into forms that computers can understand.

However, in creating devices that read printed or even typed characters, we are not reaching back far enough toward the origin of the information in the majority of the cases. Only a little reflection will show that nearly all of the information used by business data processing computers originates in the minds of humans. What is needed are methods and devices which will allow these people to produce, by simple and inexpensive means, the *initial* expression of their information in a form suitable for machine reading. Without these, there will be many situations, especially where the volume of input information is large in comparison to the amount of processing, where computers cannot be proven even if they cost little or nothing.

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We have an example of this input problem in the Bell System, where toll switchboard operators are producing two billion toll tickets per year. These are the records of long-distance calls handled by operators. They are $2\frac{1}{2} \times 5$-inch pieces of paper, each containing 20 to 30 characters of information needed for processing. While there are plans for ultimately eliminating these tickets by improvements in switchboards, they will be with us for a long time. Some idea of the magnitude of this input can be given by stating that these two billion paper tickets produced each year would make a pile 200 miles high or, if laid end to end, a strip 150,000 miles long. What is more significant, it is estimated that it would cost about $32,000,000 per year to transcribe this information to cards by means of keypunching.

A broad look at possible methods by which humans can communicate with machines, including computers, reveals the following situation.

First, the human can communicate by physical actions (generally involving the fingers) on keys, levers, dials, etc. Of these, the telephone dial is undoubtedly the one used in the greatest number. On the other hand, the key is used on a greater variety of machines, including typewriters, teletypewriters, calculating machines, keypunches, and switchboard operator key sets. Second, the human can communicate through physical action which produces a document without the intervention of a machine (disregarding the pencil). This document, in turn, is used to control a machine. Mark-sense cards exemplify this method. Third, it seems probable that it will be possible some day to produce machines which can interpret the human voice reciting numerals and letters. Possibly we may half facetiously suggest that ultimately the human mind can directly control machines.

When one examines the methods just mentioned in comparison with handwriting, one must conclude, however reluctantly, that it is pretty hard to beat handwriting as a ready, economical, fast, and accurate means of expression. Consequently, this discussion deals with two different methods by which handwritten characters may be read. The first falls in the category, mentioned above, of control by physical action and involves a new device which permits real-time communication with machines as characters are written by a stylus. The second falls in the category of communication through documents, and consists of simple methods and devices by which handwritten characters can be automatically read.

Let us consider the problems encountered in automatic recognition of handwritten characters. To simplify the discussion, it will be confined first to numerals. Of course, the problem can be greatly simplified if it is permissible to adopt an entirely new set of characters created specifically for easy machine reading. For example, characters in the set of Fig. 1 could easily be recognized by a machine scanning vertically and horizontally. The patent literature discloses many such sets of symbols. They have the obvious and common disadvantages that writers must learn them and become proficient and accurate in their use, and that they cannot be understood by the uninitiated who occasionally come in contact with them. Personal experience indicates that it would be very difficult to persuade people to adopt them and that promoters of such systems are viewed as enthusiastic but misguided.

Mark-sense marks cannot be considered as special symbols because it is the mark position rather than the shape that carries the information. Mark sensing has the disadvantages of occupying considerably more space than ordinary numerals and of being slow for humans to read.

If the idea of special sets of symbols is rejected, nothing remains but regular Arabic numerals. The problems which are encountered in reading these will now be surveyed.

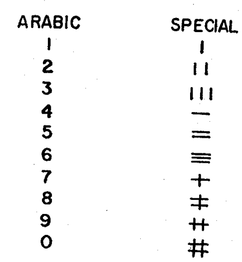


Fig. 1—Special handwritten symbols for machine reading.

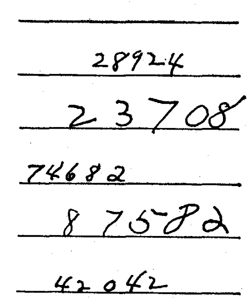


Fig. 2—Numerals written without constraint.

Fig. 2 shows a collection of Arabic numerals chosen from those produced by a random group of people. An examination of these forces the conclusion that some degree of control must be placed on their writing not only to enable machine reading but to reduce "sloppiness" which makes even human reading difficult. The variable factors which must be dealt with by an automatic reading device are location, size, orientation, and shape.

Location is important, if for no other reason, because it generally defines the meaning. For example, a given number appearing in one place on a form may indicate revenue and in another, expense. Also, of course, the machine's problem is greatly eased if it knows exactly where the numeral is located. It may be remarked that while the information content is in the shape rather than size or orientation, nevertheless the machine must be able to recognize shape in the presence of variation in size and orientation.

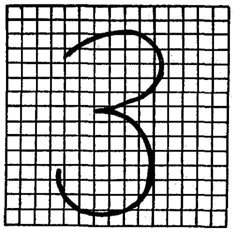


Fig. 3—Cartesian-coordinate grid for character recognition.

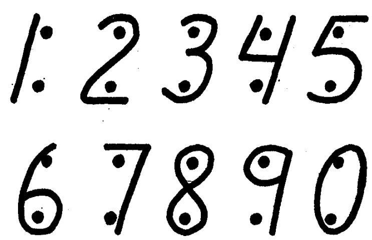


Fig. 4—Numerals with dot constraint.

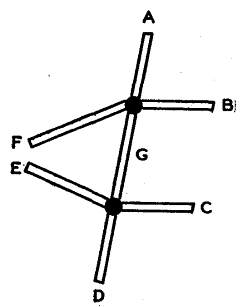


Fig. 5—Set of bipolar coordinates for character recognition.

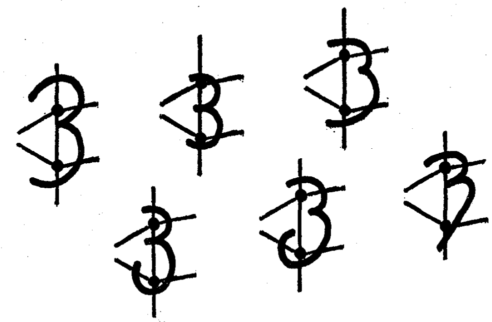
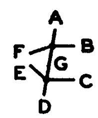


Fig. 6—Range of variation permissible.



ALLOWED CONFIGURATIONS	CRITERIAL AREA						
	A	B	C	D	E	F	G
1: 1:	0	0	0/1	0	0/1	1	0
:1 :1	0	1	0/1	0	0/1	0	0
2	1	1	0	1	0/1	0	1
3 3 3	1	1	1	1	0/1	0	0/1
4 4 4 4	0	0/1	0/1	0	0/1	1	1
5	1	0	0/1	0/1	0	1	0/1
6 6 6 6	0/1	0	0/1	1	1	1	0/1
7 7 7	1	1	0/1	0	0/1	0	0/1
8 8 8	0/1	1	1	1	0/1	1	1
9 9 9 9	1	1	0/1	0	0/1	1	0/1
0 0	0/1	1	1	1	0/1	1	0

Fig. 7—Truth table for numerals.

Any plan to control writing must take into account the methods by which the symbol is to be recognized. The method of recognition, generally proposed, is to examine the character in a field of Cartesian coordinates as in Fig. 3. The presence or absence of a mark in each rectangular cell is indicated by a television-scanning technique to a computer which can operate on the information with all its considerable resources. The cells may or may not be contiguous. Study of this plan indicates that unless very rigid writing controls are employed, this is a hard and expensive way to recognize characters.

At this point we may conclude that these things are needed to read handwritten numerals automatically and at reasonable cost: 1) a means of constraining writing which does not seriously affect writing habits, 2) a mode of machine examination of the symbols, under which the symbols appear invariant with reasonable changes in location, size, orientation, and shape, and 3) compatibility between 1) and 2).

A simple solution is now described which encompasses these three needs. First, the constraint is provided by means of two dots around which the numerals are written as shown in Fig. 4. The naturalness and ease of this method are obvious from the figure. Second, in order for the numerals to appear invariant, the machine examines them in two polar coordinate fields with the two dots as origins. The machine is able to recognize the numeral by sensing which of the radius vectors in the particular set of Fig. 5 are traversed by the lines making up the numerals. (The two left-hand vectors are moved out of their horizontal positions to avoid the ends of 3's and 5's.) The use of the same dots both for the origins of the polar coordinate sets and for controlling the writing makes it possible for simple machines to recognize numerals even though they vary quite widely in location, size, orientation and shape. In Fig. 6, the numeral 3 is shown to be invariant with a wide range of these four variables.

It remains to be shown that the set of radius vectors crossed by each numeral is unique. This is done in Fig. 7 in which a binary 1 indicates a necessary cross, a binary 0, a necessary noncross, and 0/1, indifference to a cross. A point to be noted in the left-hand column of this figure is the considerable tolerance of this method for the vagaries of humans. For example, 1 may be written either to the right or left of the dots since the associated transversals are each unique and can both be interpreted as 1. The nu-

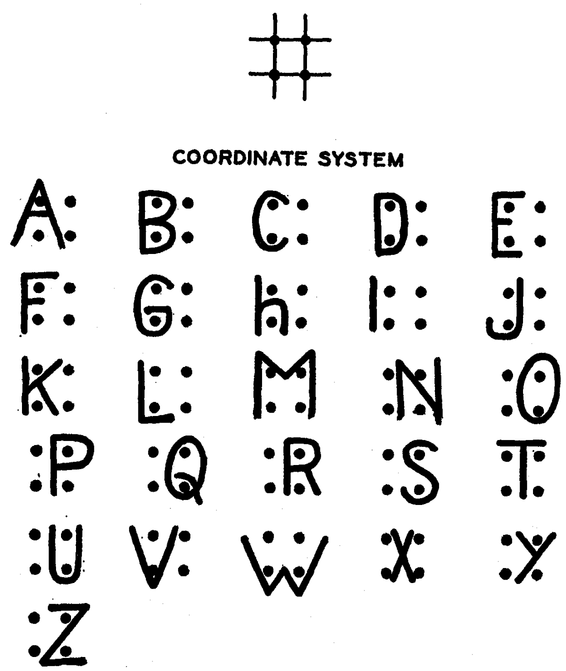


Fig. 8—Four-dot letter restraint—method 1.

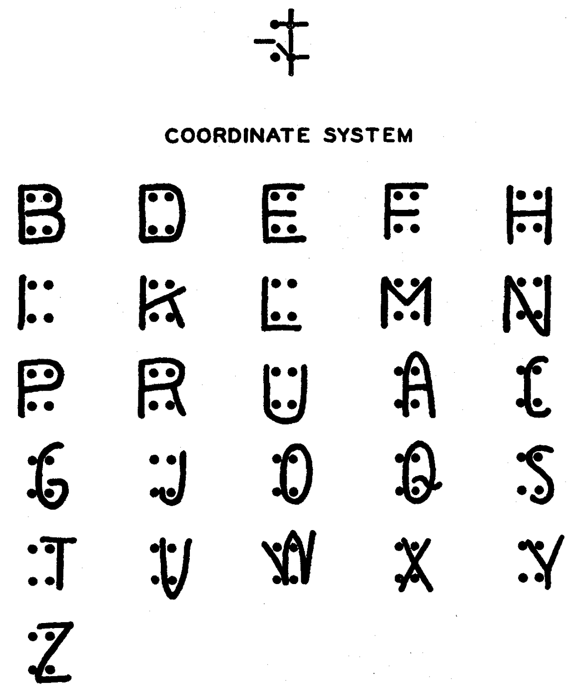


Fig. 9—Four-dot letter constraint—method 2.

meral 7 may be written with the vertical leg either between the dots or to the right. However, a closed top 4 cannot be permitted because it will appear the same as a 9. There are many different truth tables that could be devised following the philosophy indicated in Fig. 7 but trading among allowable variations in the formation of the different numerals. Still others could be designed by adding a "goof" detection feature which detects combinations not corresponding to any numeral. The logic for the latter would be quite extensive, however, because there are 2^7 or 128 possible combinations of which a minimum of 10 are legitimate.

So far only Arabic numeral recognition methods have been disclosed. The question naturally arises as to whether the basic methods of controlling writing by dots and invariance in polar coordinate fields can be extended to include letters.

There are several ways of accomplishing this result. Two will be discussed briefly. The first, involving four dots, is shown in Fig. 8. The basic idea here is that the first half of the alphabet is written about the left two dots, and the rest, with a few exceptions, about the right two dots. It will be noted that with a few exceptions which are necessary to attain uniqueness of each character, all the letters are regular upper-case block or drafting type. H is lower case to avoid confusion with K. G and Q are somewhat specially formed. In passing, it should be noted that block letters seem preferable to script because script writing is more likely to be undecipherable even by humans. Evidence of this is the statement, "please print," on the job applications which some of you have filled out.

Another set of characters is shown in Fig. 9. Here advantage is taken of the fact that 13 of the 26 letters begin with a vertical line, while 13 do not. In this embodiment the letters G, K, Q and W are slightly peculiar.[1]

To mechanize any of the logical methods described above, it is only necessary to devise a machine which can detect marks in the long, narrow areas (hereafter called criterial areas) corresponding in position to the radius vectors. An obvious way of doing this is with electro-optical scanning. Alternatively, a very simple reader can be made by providing a sensing head made with printed wiring as shown in Fig. 10. In this figure, each criterial area is made up of one long, narrow conductor connected to a source of potential, and another, parallel to it, used as a sensing element and connected to a translator. When the head is properly placed on a piece of paper on which a numeral has been written around dots with a conductive lead pencil, the mark on the paper closes circuits between the two parts of each of the criterial areas[2] which it crosses. Hence, certain of the seven leads from the seven criterial areas will be energized causing the translator to energize a different output lead for each different character.

A translator using transistor logic and based on the truth table of Fig. 7 is shown in Fig. 11. The input leads A to G connect to the seven criterial area conductors similarly designated at the top of Figure 7. The RS lead connects to a contact which is closed to reset the translator

[1] Proposed by Dr. L. A. Kamentsky of Bell Telephone Labs., Inc.

[2] Subsequent to the presentation of this paper, U. S. Patent 2,741,312 issued to R. B. Johnson was called to the author's attention. It discloses the use of the two dots and of the radial areas for sensing conduction through the mark constituting the numeral. Relays are operated to control a card punch.

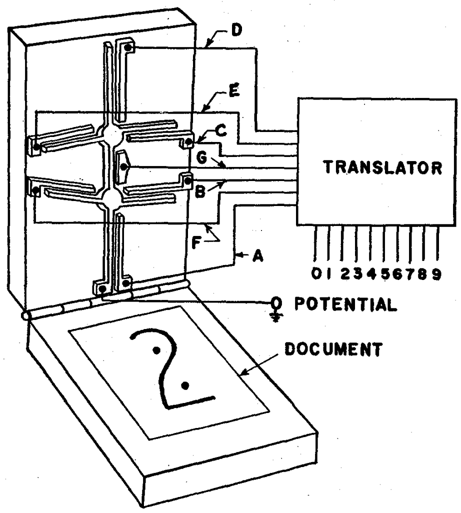


Fig. 10—Reader.

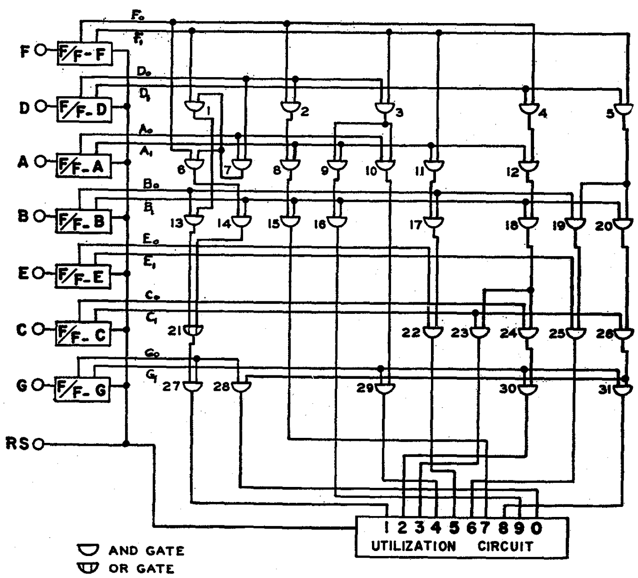


Fig. 11—Translator circuit.

by restoring flip-flops F/F-A to F/F-G to a normal condition in which they energize the leads designated with a zero subscript. The recognition of the numeral 2 will now be followed. Conductors A, B, D, E, and G will have been energized by conduction through the conducting pencil mark although the energization of E is immaterial to correct recognition of the numeral 2. Flip-flops of corresponding designation energize leads of subscript 1. The end result is that leads A_1, B_1, D_1, E_1 and G_1 are energized as well as leads C_0 and F_0. Leads D_1 and F_0 open gate 4. Gate 12 is opened by the output of gate 4 and lead A_1; gate 18 by gate 12 and lead B_1; gate 24 by gate 18 and lead C_0; gate 30 by gate 24 and lead G_1. Gate 30 energizes lead 2 to indicate recognition of that numeral. The flip-flops are not strictly necessary, but they aid by furnishing ample power to drive the logic circuitry.

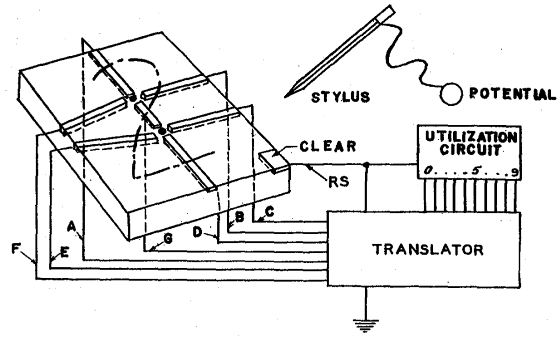


Fig. 12—*Stylator.*

As mentioned before, a method will be described which permits automatic recognition *as the characters are written.* A novel device for performing this function for numerals is shown in Fig. 12. A writing surface is provided on which there are two guide dots surrounded by a set of criterial areas consisting of seven conductors embedded in a plastic plate. As a numeral is written with a stylus connected to a source of potential, the stylus energizes, one at a time, the conductors in the criterial areas involved in the numeral. The combination of areas energized causes certain flip-flops in a translator such as that in Fig. 11 to operate and drive the rest of the translator to indicate the correct numeral. The flip-flops are necessary because the criterial areas are not all energized simultaneously. Alternatively, seven relays may be used to replace the electronic translator of Fig. 11. This device has been tentatively christened a *Stylator,* meaning stylus translator or interpreter.

The problem arises in connection with the *Stylator* of informing it when the writing of a character has been completed. This is necessary because in some cases the character changes from one to another during the writing process and because the translator must be returned to normal before a new character is written. A simple way of incorporating this feature is to provide another conductor in the writing plate which, when touched by the stylus, causes the memory and translator circuits to return to normal as soon as the character already written has been recorded. This conductor may extend around the whole perimeter of the plate so that it can be touched by a continued stroke of the stylus.

In the devices just described, no advantage is taken of the information residing in the sequence in which the criterial areas are crossed. Of course, this information cannot be recovered from a character already written but it is readily available in the case of the *Stylator.* This added information is so meaningful that the two-dot system can be used for letters as well as numerals.

Several uses have been suggested for the *Stylator.* It is a competitor for key sets in many applications. It has been successfully used to control a teletypewriter. It is attractive in this application because it is inexpensive and does not require a long period for learning to use a keyboard.

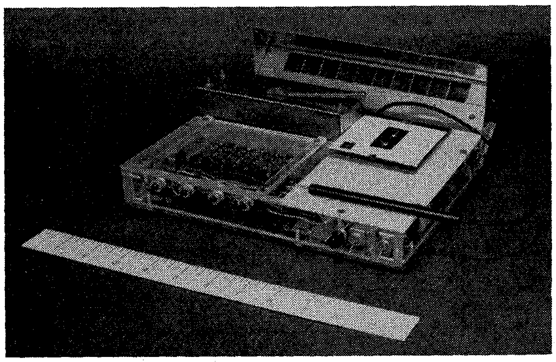


Fig. 13—Number reader and *Stylator*.

If the criterial areas are used to control the frequency of an oscillator, an inexpensive sending device is obtained which may be connected to a telephone set to send information to remote machines.

Fig. 13 shows a combined number reader and *Stylator* which can successively read four separate numerals from a sheet of paper as well as recognize numerals as they are written. The following set of rules will help in using the *Stylator*.

1) Clear by touching the stylus to the small area at the lower right.
2) Make open top 4's.
3) Keep ends of 3's and 5's out of area between segments E and F in Fig. 5.

Conclusion

Methods of constraining the writing of characters for machine reading and machines for reading such characters has been described. A new device called a *Stylator* has been disclosed which permits real-time recognition of characters as they are written on a platen.

Acknowledgment

The author wishes to mention that Dr. L. A. Kamentsky of the Bell Laboratories designed the first logic circuits, constructed the first model and furnished many valuable ideas as well, and that W. W. Gulden of the Cincinnati and Suburban Bell Telephone Company designed and constructed the small model shown in Fig. 13.

Discussion

E. A. Etling (RCA Service Co): What thought, if any, have you given to the development of a system which places no constraint on the handwriting of characters, other than broadly defined statistical bounds?

Mr. Dimond: The polar scanning technique can be extended to systems involving different methods and degrees of constraint. I think that some degree of restraint is desirable because it requires people to form their characters more carefully than they would if they followed their normal habits, which may be so sloppy that the characters are sometimes unrecognizable even by humans.

P. Hersh (General Ceramics): How does the Stylator distinguish between the "early" versions of a character and the final (correct) one?

Mr. Dimond: In these demonstration machines, a separate segment is touched by the tip of the stylus after writing is complete to cause the information stored in the translator circuitry and indicated by lamps to be wiped out. In a commercial machine, the touching of the segment would first cause the information stored in the translator to be transferred to some sort of memory and would then restore the translator to normal. To minimize the effort required, the segment could consist of a border surrounding the platen. It could then be touched with the stylus by continuing the last stroke in writing a character.

M. J. Stoughton (Sears Roebuck): What controls are you contemplating for reducing operator errors?

Mr. Dimond: Errors may result either because the operator writes a wrong number or because she forms it incorrectly. Errors of both sorts may be reduced by training. Nothing can be done in the design of the machine to prevent entirely the former. In this respect, the problem is the same as with a keyboard. In some cases the error can be detected by a system of control totals.

There are some things that can be done to minimize errors due to incorrect formation. More criterial areas and a more able translator would help. If the degree of accuracy required justifies it, mentally computed check numbers can be used. Suppose, for example, the number 13 is to be recorded. The operator also records 24 which is obtained by adding 1 to each digit of the number 13. At some later stage the two numbers are automatically subtracted to check that a difference of 11 is obtained.

L. C. Oesterich (U.S. Navy): You are apparently adapting this reading device to your toll ticket problem. Please outline the system.

Mr. Dimond: The proposed reading device is one of the contenders for solving the toll ticket problem. It would be used in the following manner. The tickets furnished to the operators would have dots preprinted on them around which the operators would write the characters, most of which are numerals. These tickets would be gathered up periodically and sent to a processing center where they would be fed automatically into a device which would read the information and record it on cards or magnetic tape for further processing.

E. Nassell (Electronic Associates): Wouldn't all cases where you consider transmission be much faster handled by a ten-key keyboard of some sort? And as cheaply? As I see it, the best use for reading characters handwritten is when the original recording must be made remote from accessibility to transmitting or recording equipment. Since a form is necessary in any case, doesn't it appear the conventional existing methods of electrographic sensing would remain superior?

Mr. Dimond: If we consider only the originating device, there is probably not much difference in speed or cost between a ten-key keyboard and a Stylator. Two other factors appear to tip the balance in favor of the Stylator. First, preliminary tests indicate that better accuracy is obtained in writing than in keying. Second, a written document can be made at the same time the Stylator is used as a sending device, if the Stylator is designed to use capacitive coupling through the paper rather than direct coupling between the stylus and the criterial areas. If it is necessary to transmit letters as well as numerals, the keyboard would undoubtedly cost more than a Stylator and would require more skill.

I assume that in using the term electrographic sensing, Mr. Nassell refers to what is more commonly known as mark sensing. The main difficulty with mark sensing is that 10 to 20 times more space per character is required than for written characters.