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OPTICAL FILTER TEXT READER STUDY

by

John A. Fitzmaurice, Edward N. Sabbagh
and William G. Elliott

Baird-Atomic, Inc.
33 University Road
Cambridge 38, Massachusetts

B-A Job No. 5166
B-A Document No. 3055

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for

The Intelligence Laboratory
Rome Air Development Center
Air Research and Development Command
United States Air Force
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DISCUSSION

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Approved by:

Walter C. Driscoll
for Walter C. Driscoll
Vice President for Research
and Engineering

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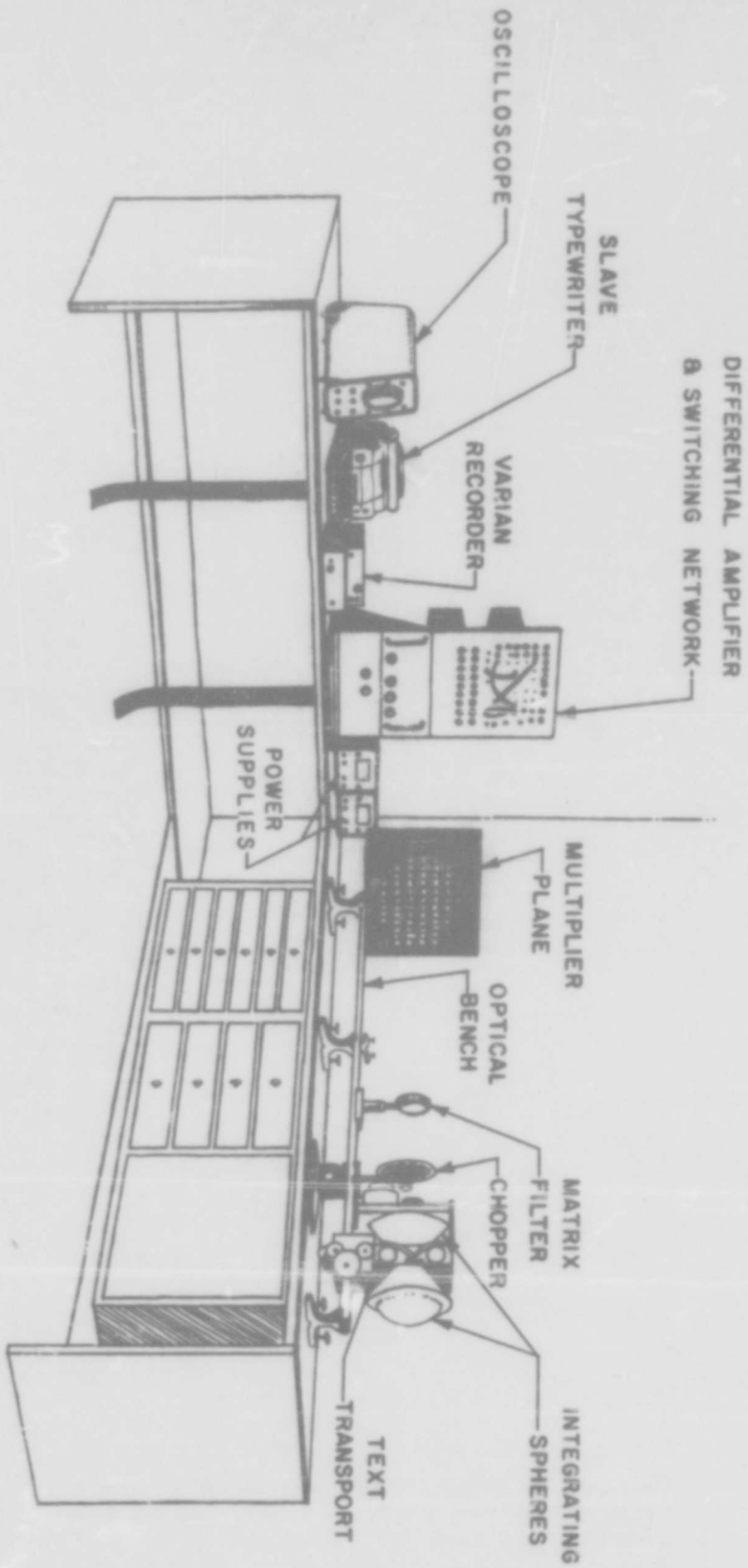
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EXPERIMENTAL MODEL OF PRINT READER

ABSTRACT

→ The use of aperture-stops to perform general ²~~two~~-dimensional, linear, filtering operations is described. This theory ~~has been~~ applied to the problem of building an automatic print reader. A breadboard model was built and used to demonstrate the feasibility of this method of print reading. ←

Part I

INTRODUCTION

Several years ago, a new method of automatic text reading was invented at Baird-Atomic, Inc.

The primary purpose of the present contract has been to demonstrate the feasibility of this method of obtaining an electrical input for a high speed Russian-English translating machine.

The research performed under the present contract was as follows:

a. Theoretical and experimental evaluation of optical aperture filtering techniques for automatic recognition of typewritten symbols on an 8 1/2 inch by 11-inch document. This evaluation was based on Pica style typewriter symbols consisting of the upper and lower cases of the English alphabet (52 characters), the Arabic numerals from 0 to 9 (10 characters), and 19 punctuation marks, i. e., a total of 81 different characters.

b. Preliminary considerations of the entire electro-mechanical-optical reader were provided. These considerations included experimental and laboratory tests to determine the affect of slant letters, letters of different sizes (not case difference), and overlapping of letters of a limited degree in both fields (vertical and horizontal). A breadboard system was set up to demonstrate the applicability of techniques investigated.

Part II

DISCUSSION

The many devices for text reading which have been investigated at one time or another may be divided roughly into two categories. These are: Scanning devices which detect intersections, line crossings, etc. and process this information (usually, by means of a digital computer) to obtain an identification of the character; and aperture-matching devices which effectively image the unknown character onto a mask having the same shape as some reference character. If the unknown character were brighter than its background then the total amount of light transmitted by the mask would be a maximum when the unknown character had exactly the same shape as the mask. If the unknown character were darker than its background then the total amount of light transmitted by the mask would be at a minimum when the unknown character had exactly the same shape as the mask. There have been many devices of this general type proposed in the past. In general they have had two defects. One was their slow speed due to the fact that the unknown character had to be compared successively with many different reference characters. The other was their inability to distinguish between closely similar characters. Recent work by Baird-Atomic, Inc., has succeeded in overcoming these two defects.

A. Negative Transmittance

The ability to distinguish characters with very similar shapes has been greatly increased by the use of an optical system which, in effect, has an aperture with a NEGATIVE transmittance. The nature of such a system is indicated in Fig. 1. When an aperture is being designed for the detection of the letter "A", it is desirable to have one region of the aperture (having the size and shape of the letter "A") have a positive transmittance while the background has a negative transmittance. When the letter "A" is imaged onto such an aperture,



Figure 1 - Apertures for a Two-Channel System

These apertures transmit in the clear region and are opaque in the shaded region. The typical matching system of the past has used a single aperture such as shown in (b). Better discrimination would be obtained with an aperture, such as (a), which has a background with a negative transmittance. An equivalent system which is physically realizable would utilize two apertures, (b) and (c). The output of (c) would be subtracted from the output of (b).

the negative region has no influence while the positive region would transmit all the light in the image (assuming that the character is brighter than its background). On the other hand, when a different character, such as a "B" is imaged on the aperture, not only is less total light transmitted by the positive portion of the aperture, but, since the "B" could not be exactly superimposed on the positive region, the negative region would "transmit a negative amount of light" thus further reducing the algebraic sum of all light transmitted and improving the discrimination between the "A" and the "B". This type of aperture is especially powerful in recognizing punctuation marks. In other methods of print reading, punctuation marks are the most difficult characters to recognize whereas they are very easily recognized by the Baird-Atomic system.

Of course, it is impossible to construct an aperture with a negative transmittance. However, exactly the same result may be obtained by the use of two separate optical systems identical in every respect except that they use different apertures as shown in Fig. 1. One aperture transmits in a region having the size and shape of the character to be recognized and is opaque elsewhere. The second aperture transmits in a region corresponding to the background of the character to be recognized and is opaque elsewhere. When the outputs of the two apertures are measured by photodetectors and the output of the second system is subtracted from the output of the first system, the net result is the same as if a single optical system with a single aperture having a region of positive transmittance and a region of negative transmittance were used.

Because of this use of a dual optical system, if a particular type font having N characters is used, then $2N$ apertures are needed to recognize all the characters. This total number of apertures needed may be reduced by a simple modification of the system: If the operation performed by the positive aperture used to detect the i th character is designed as P_i and the operation performed by the corresponding negative aperture system is designated as N_i , then the decision as to

whether a particular character to be recognized is the i th character is based on the magnitude of the voltage resulting from the operation $(P_i - N_i)$. However, it may be noted that

$$P_i - N_i = 2 P_i - (P_i + N_i).$$

The vital significance of this equation is that $(P_i + N_i)$ is independent of i . That is to say, a single aperture having the shape of the total field of view would perform the operation $(P_i + N_i)$ regardless of which character were represented by i . Hence, if a given type font contains N characters, the total number of apertures needed to distinguish these characters is $N + 1$.

B. Simultaneous Use of Reference Apertures

The very low operating speed of earlier aperture-matching type print readers was due to the relatively slow mechanical motion needed in the successive comparison of the character to be recognized with each of the reference apertures. Attempts at simultaneous comparison bogged down with the problem of obtaining a large number of identical lenses.

Baird-Atomic solved this problem with an optical system which does not require any lens at all unless the character to be recognized is very small. In that case, it is usually magnified before being recognized.

This system is shown schematically in Fig. 2. Here a photographic transparency containing an image of the unknown character is placed in plane A in front of a diffuse light source. A second photographic transparency containing an image of a reference aperture is placed in plane B parallel to plane A. However, the magnification of the transparency in plane A is greater than the magnification of the transparency in plane B. It may readily be seen that the illumination at point P in plane C is directly proportional to the total amount of light that would be obtained if the transparencies in plane A and B were made with the same magnification

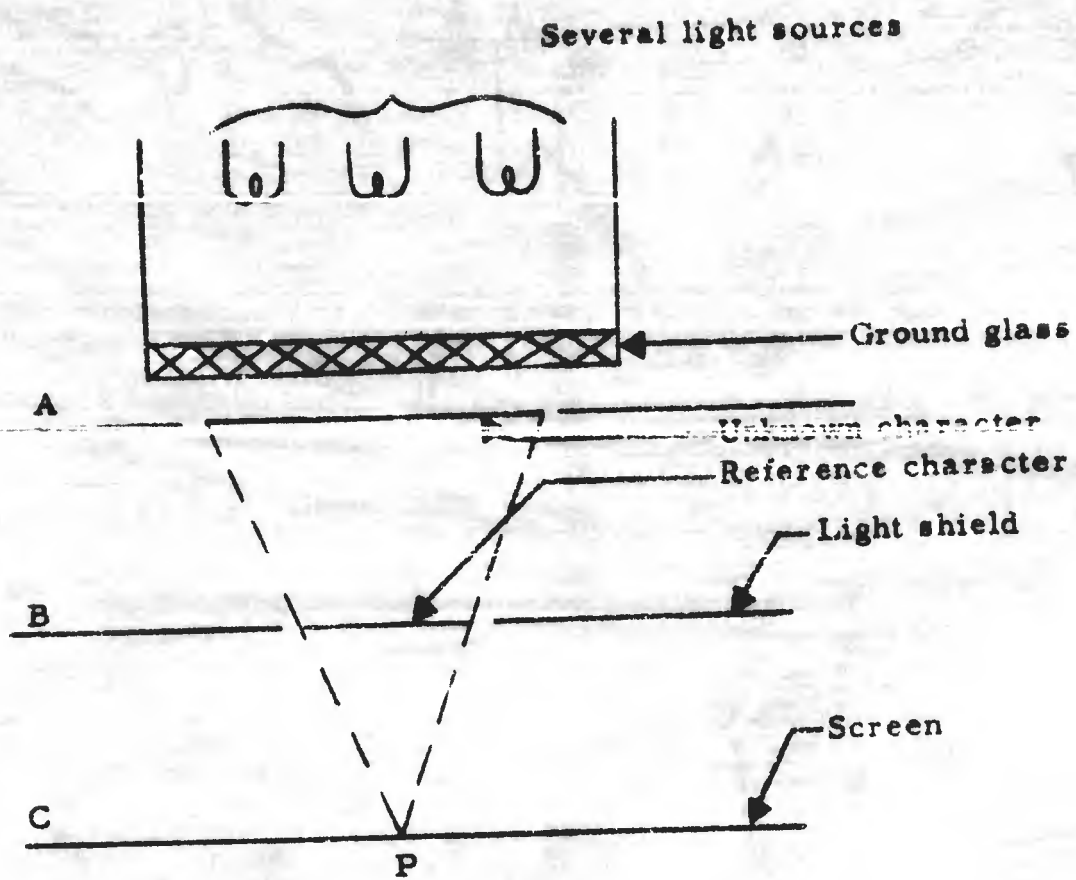


Figure 2 - Optical Device for Matching the Images on Two Photographic Transparencies.

and directly superimposed. Hence, the results obtained with the system shown in Fig. 2 are completely equivalent to the results obtained with other aperture-matching systems.

Although the system shown in Fig. 2 has both transparencies arranged so that a line passing through their centers is normal to plane C as well as to both transparencies, the same effect is achieved even when the transparencies are displaced considerably horizontally. Thus, several small reference transparencies may be placed side by side. A matrix of photodetectors is used to measure the illumination at each of the other points in plane C, analogous to point P. Where two separate apertures are used to detect a single character, the outputs of the corresponding photodetectors are subtracted. If the difference is greater than a certain predetermined amount, then the character corresponding to this pair of apertures is indicated.

Two additional features have been added to this basic system in order to make it more efficient optically. These are a better illuminating system and a lens in the plane of the reference characters. Rather than a diffuse light source directly behind the unknown character on the photographic transparency, a lens is used to image a diffuse source onto the transparency or other representation of the unknown character. This results in a much greater illumination of the unknown character than is achieved with an ordinary light box. The system as shown required that the reference characters each be smaller than the unknown character. When it is desired to read microfilm or Mini-cards, this restriction makes it awkward to align the system properly and results in a waste of much of the available light. If it is necessary to recognize letters at a great distance,

this system also implies that the image pattern in plane C be very small if the apparatus is not unreasonably large. Both of these situations may be corrected by inserting a lens in the plane of the reference aperture. The effect of the lens is merely to change the angles of the light rays and thereby change the rate at which they diverge or converge. This gives control of the spacing of the elements. The array of reference apertures may be as large as the lens itself regardless of the size of the unknown character.

In this discussion it has been assumed that the unknown character is displayed in the form of a photographic transparency. However, if the unknown character is displayed as printed text on opaque material, the optical system required remains very much the same. The unknown character is illuminated uniformly and diffusely on its front surface rather than from the rear.

Figure 3 shows a photograph of the reference matrix of apertures used for the recognition of the characters of one particular English type font. The "negative" aperture in the center was formed by simply superimposing all of the characters in the type font.

C. General Linear Two-Dimensional Optical Filters

The optical system described above was developed as a special case of a more general linear two-dimensional filter of images formed with non-coherent light. Before choosing this particular system, a thorough study was made of the characteristics of various kinds of linear two-dimensional filters. The results of this study are next described.

1. Coherent Filtering

Probably the most thoroughly investigated technique for two-dimensional filtering has been diffraction pattern filtering (Refs. 1, 2, 3, 4, 5, and 6). Since the end of the nineteenth century, it has been well known that the Fraunhofer diffraction pattern of any aperture (or photographic transparency) has an amplitude proportional to the Fourier transform of the transmittance of the aperture. Thus, the Fraunhofer diffraction pattern produced by a photographic transparency is a plot of the spatial frequencies present in the original image. The zero-frequency component is displayed in the center with the other frequency components at a position directly proportional to the components of the two-dimensional spatial frequency they represent.

If an optical system identical to the one used to form the diffraction pattern is used in reverse, the original object may be imaged.

Any object placed in the plane of the diffraction pattern acts as a two-dimensional linear filter. The transmittance of the object at any point determines the attenuation of the corresponding spatial frequency component; the optical path determines the spatial phase shift. For many years, the only kind of filter used was one which reduced the zero-frequency component to zero magnitude without having much effect on the other spatial frequency components. Such a system is known as a Schlieren system. It is especially useful for studying shock waves and convection in gases.

A very similar system is used in phase-contrast microscopy. Although there are many different variations (Ref. 6), the basic requirement is to attenuate the zero-frequency component and convert a variation in optical path

length to a variation in amplitude. Such systems are used for viewing transparent objects.

Several investigators have used diffraction plane filters to sharpen defocused or otherwise degraded photographic images but more general spatial filtering has not been reported. There are two reasons for this: Firstly, in order to get a diffraction pattern of sufficient diameter so that the prescribed filter is large enough to be conveniently built, the illumination of the final output image is necessarily very low. Secondly, in order to build an arbitrary general linear filter, it is necessary to be able to produce any arbitrary combination of transmittance and phase shift at any given point of the filter.

Recently (Ref. 5), a method was developed for obtaining a desired variation in transmittance with no phase shift at all; but, so far, no one has succeeded in achieving independent control of transmittance and phase shift.

2. Non-Coherent Lens Plane Filters

A non-coherent system has been developed with none of the difficulties described for coherent filtering. The filter is relatively large and easy to make. The amount of light is usually adequate.

The extraction of information from an optical image by two-dimensional filtering operations is subject to two conditions. First, since useful information may be located in any position in the image, any complete filtering operation must be spatially homogeneous; i. e., the operation must extract information in the same manner from every part of the image. Second, since physically obtainable images are necessarily finite in extent, every operation at a point ought to depend, at most, on a neighborhood of that point considerably smaller than the total image. Then the boundary of the original image affects only regions near the boundary of the filtered image. If the filter is linear in addition to satisfying the other two conditions, then its operation must be described by an equation of the form

$$I_2(x, y) = \int \int_{R(h, k)} \mu(h, k) I_1(x - h, y - k) dh dk \quad (2.1)$$

where I_1 is the intensity of the original image, I_2 is the intensity of the filtered

image, R is a neighborhood of (x, y) whose size, shape and orientation are independent of (x, y) , and μ is an arbitrary real function.

The significance of equation (2.1) is that, except for an almost constant factor, it is the equation of a defocussed lens with an aperture-stop in the lens plane having the shape and orientation of R and superimposed on a transmission filter (e. g. , a glass plate) with a transmittance proportional to μ . Such a filter is shown schematically in Fig. 4.

The relative positions of the lens and the screen are chosen so that if a diffusely illuminated object were placed in the plane of the broken line at the far left of Fig. 4, then its image would be in focus on the screen at the far right. The magnification would be s'/s . If the point (x_0, y_0) in the plane of the broken line is imaged at (x, y) on the screen, then the relationship between intensities is

$$I_2(x, y) = K_1 I_0(x_0, y_0) \quad (2.2)$$

If the intensities, I_0 and I_2 are interpreted as radiance and irradiance respectively, all image-forming rays form small angles with the optical axis, and there are no losses in the optical system, then

$$K_1 = \frac{A_L}{s'^2} \quad (2.3)$$

where A_L is the area of the lens. However, when an aperture-stop filter of non-uniform transmittance is placed in the lens plane,

$$I_2(x, y) = K_1 I_0(x_0, y_0) \int \int_{R_L(u, v)} \frac{W_L(u, v)}{A_L} du dv \quad (2.4)$$

where $W_L(u, v)$ is the transmittance of the filter at (u, v) and $R_L(u, v)$ is the region of the filter in which $W_L \neq 0$. The out-of-focus system shown in Fig. 4 is described by a similar equation. The significant difference is that the intensity at a point (x, y) in the image plane depends not only on the intensity of the corresponding point (x_1, y_1) in the object plane but also on the intensities at all points in a neighborhood around (x_1, y_1) . Specifically, let the object plane be moved in a distance, a , from its in-focus position toward the lens. (x_1, y_1) is the intersection

with the object plane of a straight line passing through (x_0, y_0) and (x, y) ; $(x_1 - h, y_1 - k)$ is the intersection with the object plane of a straight line passing through (x_0, y_0) and (u, v) in the filter plane. Then

$$I_2(x, y) = K_1 \iint_{R_p(h, k)} \frac{W_p(h, k)}{A_p} I_1(x_1 - h, y_1 - k) dh dk \quad (2.5)$$

where R_p is the locus of all points in the object plane through which a ray could pass from (x_0, y_0) and reach (x, y) , A_p is the area of the region R_p , and $W_p(h, k) = W_L(-u, -v)$.

In a sense, the neighborhood R_p is the projection or R_L on the object plane; and the weighting function, W_p , is the projection of the filter transmittance, W_L . For small angles with the optical axis,

$$\begin{aligned} u &= -h \frac{s}{a} & x &= -x_0 \frac{s'}{s} = -x_1 \frac{s'}{s-a} \\ v &= -k \frac{s}{a} & y &= -y_0 \frac{s'}{s} = -y_1 \frac{s'}{s-a}. \end{aligned} \quad (2.6)$$

Using (2.3) and (2.6), equation (2.5) may be put in the form

$$I_2(x, y) = \frac{A_L}{s'^2} \frac{1}{A_p} \left(\frac{a}{s}\right)^2 \iint_{R_L(u, v)} W_L(-u, -v) I_1\left(x_1 + u \frac{a}{s}, y_1 + v \frac{a}{s}\right) du dv,$$

or, since $\frac{A_L}{A_p} = \left(\frac{s}{a}\right)^2$, (2.7)

$$I_2(x, y) = \frac{1}{s'^2} \iint_{R_L(u, v)} W_L(-u, -v) I_1\left(x_1 + u \frac{a}{s}\right) du dv. \quad (2.8)$$

It may be noted that, for $a = 0$, equation (2.8) reduces to the in-focus case described by equation (2.4). Still another form of equation (2.5) is

$$I_2(x, y) = \frac{1}{s'^2} \left(\frac{s}{a}\right)^2 \iint_{R_p(h, k)} W_p(h, k) I_1(x_1 - h, y_1 - k) dh dk \quad (2.9)$$

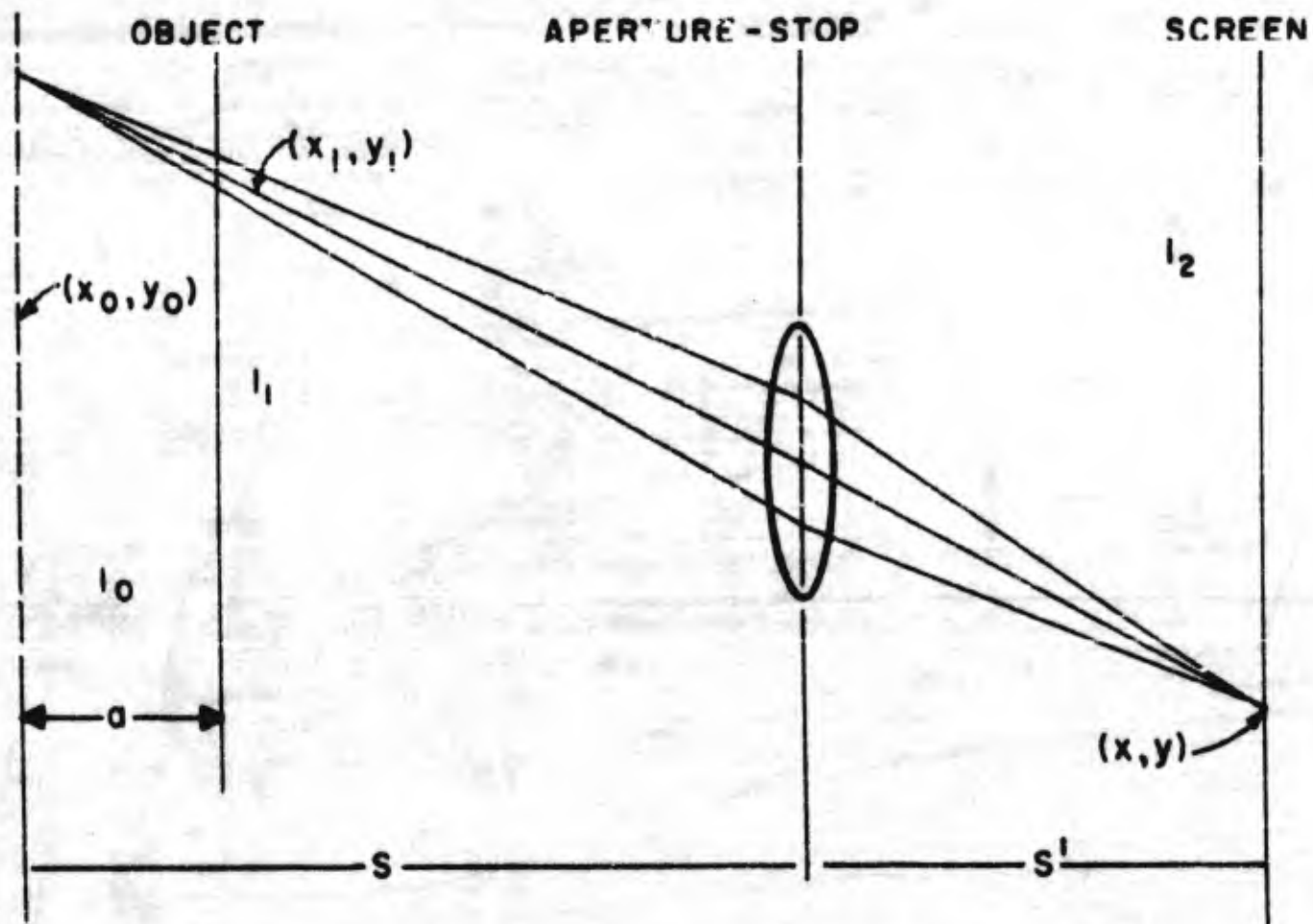


FIG. 4 - LENS - PLANE APERTURE - STOP FILTER

Since equation (2.9) clearly has the form of equation (2.1), it follows that the defocussed lens with an aperture-stop having non-uniform transmittance is a two-dimensional linear filter of the type sought, provided only that all rays imaged make small angles with the optical axis.

From the relationships

$$W_p(h, k) = W_L\left(h \frac{s}{a}, k \frac{s}{a}\right) \tag{2.10}$$

and

$$W_p\left(u \frac{a}{s}, v \frac{a}{s}\right) = W_L(u, v)$$

it follows that, except for a uniform attenuation, the filtering action of an aperture-stop is independent of size, depending only on shape. The size of the projection of the aperture in the I_1 - plane is important, but this can be adjusted at will by a proper choice of a .

There are only two basic differences between the general operations described by equation (2.1) and the aperture filtering described by equation (2.9).

First, while μ may have values such that

$$\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} I_2(x, y) dx dy > \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} I_1(x, y) dx dy,$$

aperture filtering necessarily implies an attenuation so that

$$\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} I_2(x, y) dx dy < \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} I_1(x, y) dx dy.$$

Second, μ may have both positive and negative values while W_L and W_p are always positive. Since the filtering action is the same except for a uniform attenuation, the first difference is not usually significant. The second difference is more important. It can be avoided by using two filters in combination. For example, if an aperture of transmittance W_L is desired where W_L assumes both positive

and negative values, then two separate apertures can be constructed with transmittances W_1 and W_2 where

$$W_1 = W_L \text{ for } W_L \geq 0$$

$$= 0 \text{ for } W_L \leq 0$$

$$W_2 = -W_L \text{ for } W_L \leq 0$$

$$= 0 \text{ for } W_L \geq 0.$$

The two apertures may be used in separate filters operating on the same original image. The output of the W_2 filter is then subtracted from the output of W_1 filter to give the desired result. This subtraction may be accomplished with point scanning and electric subtraction or it may be done photographically.

3. Recognition Filters

Many of the theorems pertaining to the design of optimum one-dimensional electrical filters may be readily extended to the two-dimensional optical filter. The principal change is that there is less restriction on physical realizability.

When accurate reproduction of the input signal is desired, the mean square difference between the input signal and the total output may be minimized. If the input signal is f , the input noise is g , and correlation functions are represented by ϕ , then the weighting function, h , of the optimum filter is given by the Wiener-Hopf equation (Ref. 5)

$$\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} h(r, s) \phi_{f+g, f+g}(x-r, y-s) dr ds - \phi_{f, f+g}(x, y) = 0 \quad (3.1)$$

$$\text{where } -\infty < x < \infty$$

$$-\infty < y < \infty$$

$$\phi_{f+g, f+g} = \phi_{ff} + \phi_{gg} + 2\phi_{fg} \quad (3.2)$$

$$\phi_{f+g, f} = \phi_{ff} + \phi_{fg} \quad (3.3)$$

A Fourier transformation of the Wiener-Hopf equation gives

$$H(\omega_x, \omega_y) = \phi_{f, f+g}(\omega_x, \omega_y) / \phi_{f+g, f+g}(\omega_x, \omega_y) \quad (3.4)$$

where H , $\phi_{f, f+g}$, and $\phi_{f+g, f+g}$ are Fourier transforms of h , $\phi_{f, f+g}$, and $\phi_{f+g, f+g}$ respectively. Thus, the frequency response, H , of the optimum filter is determined by the statistical structure of the signal f and the noise g .

If a simple yes-no type decision is to be made as in the case of detection of a two-dimensional pulse, then it is necessary to maximize the ratio of the peak output signal amplitude to the rms output noise amplitude (Refs. 7, 8) where the pulse to be detected is called signal and everything else in the image is called noise. If the complex conjugate of the Fourier transform of the input pulse is $F^*(\omega_x, \omega_y)$ and the power spectrum of the noise is $|\sigma(\omega_x, \omega_y)|^2$, then the optimum linear detection filter has a frequency response (Ref. 8)

$$H(\omega_x, \omega_y) = K \cdot \frac{F^*(\omega_x, \omega_y) \cdot \exp \{ -j(\omega_x x_0 + \omega_y y_0) \}}{|\sigma(\omega_x, \omega_y)|^2} \quad (3.5)$$

The constant factor, K , depends on the maximum gain of the system. The exponential factor has no influence on the signal-to-noise ratio; it merely shifts the output by a constant amount (x_0, y_0) .

Of course it is assumed in both cases that the statistical structure of the noise is such that it would be unaffected by a random phase shift filter.

In the case of aperture filtering in the presence of white noise, equation (3.5) has a very simple interpretation: the optimum aperture has the same shape as the object to be detected and a transmittance proportional to the corresponding brightness of the object.

Since the spatial structure would be completely disrupted by random phase shifts neither the Wiener filter nor the Dwork filter would necessarily be an optimum linear filter for the recognition problem.

Even though the optimum filter remains unknown, a sufficiently good filter may be constructed starting with the white noise filter as a first approximation. It has been found that when the characters to be recognized consist of the elements of a 12 point Pica type font commonly found on American typewriters, about one-third of the characters can be recognized solely on the basis of their response to white-noise type filters. The remainder of the characters may be identified when a two channel system is used. The positive channel uses an aperture which is transparent in a region having the shape of the character to be recognized and opaque elsewhere. The negatively weighted channel has an aperture which is opaque in a region having the shape of the character to be recognized and transparent in the remainder of the field of view. With such a system, if there are N different symbols to be recognized then $2N$ different apertures are required. The number of apertures required may be reduced from $2N$ down to $N + 1$ by the method discussed in section IIA.

Since the filtering action described here may be accomplished with a lens of any size, it is possible to operate with many different filters simultaneously simply by using small lenses and placing them side by side. An equivalent effect may be obtained using one large lens together with a matrix of small apertures contained effectively in the center of the lens.

If each reference aperture is smaller than the corresponding character in the scanned text, then lenses may be eliminated. This special case is the optical system described in section IIB.

D. Electrical System of the Breadboard Model of the Print Reader

Light from a tungsten filament source is collected by a condensing system and passed through a diffuser. A minified image of the diffuser is formed at the location of the unknown character. The unknown character is imaged by an objective lens onto an aperture which limits the field of view of the correlation system to the area occupied by one character. Near the plane of this aperture is a rotating segmented disc which chops the light at 450 cycles per second.

Light passing through the chopper and aperture travels through the correlation matrix to a bank of photomultipliers located in the critically defocused plane. These photomultipliers produce a 450 c. p. s. alternating voltage having an amplitude proportional to the total flux in that region of the defocused plane being sensed. An auxiliary photomultiplier and light source at the chopper produce a 450 c. p. s. reference that is in-phase with the signals produced by the multipliers in the defocused plane.

As explained in sections A and B, certain regions of the correlation matrix are given negative weight. The output of the multiplier corresponding to these regions is fed into the negative input of a differencing amplifier. The positive input comes from the corresponding positively weighted regions. Relative magnitude of positive and negative weighting is controlled by potentiometers at the differential amplifier input. The output is amplified and applied to the grid of a Schmidt trigger-type circuit which acts as an amplitude discriminator (see Fig. 5). Also applied to this grid is a signal derived from the chopper reference which clamps the grid at an adjustable d. c. voltage whenever light through the system is interrupted. Changing the d. c. level changes the amount of signal required to trigger the Schmidt circuit. When the grid clamp is released (i. e., light is passing through the system) a positive output from the differencing amplifier is added to the d. c. level; if the output is negative, it is clamped by a diode. Hence a positively weighted signal exceeding a given magnitude will trigger the Schmidt circuit.

However, the duration of the pulse from the Schmidt circuit is dependent upon the amount of time the signal exceeds the discrimination level. Therefore the Schmidt output is differentiated, amplified, clipped, and used to trigger a single shot multivibrator. This generates a 50 millisecond pulse which closes a relay operating the typewriter key connected to this unit.

The research reader included nine identical recognition channels which could be positioned so as to recognize any 9 of the 81 characters in the specified alphabet. A plug board permitted connecting the discrimination unit corresponding to a particular character to the appropriate typewriter key.

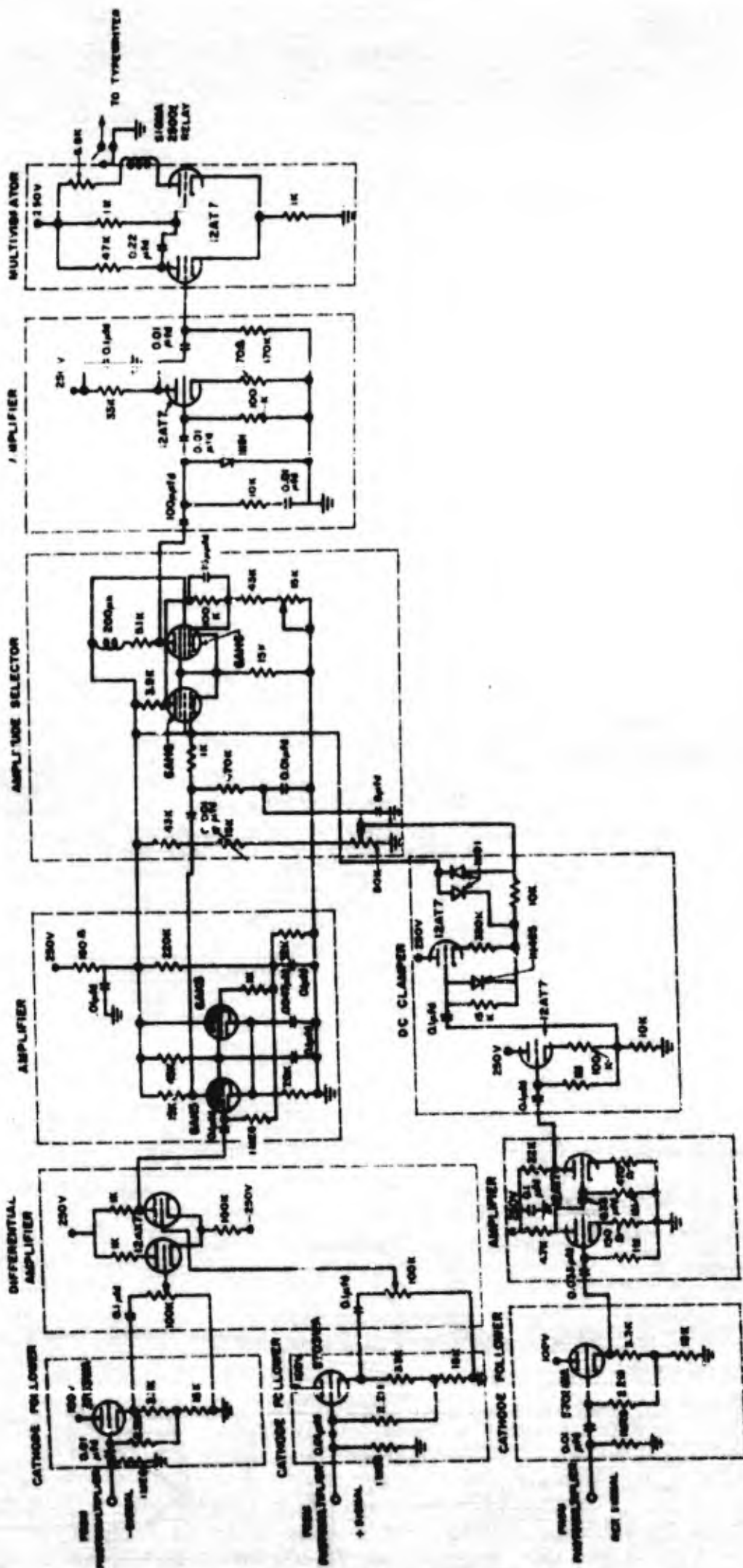


FIG. 5 - TRIGGERING CIRCUIT - TEXT READER

E. Test Results

In order to provide a quantitative measure of the ability of the experimental model of the print reader to distinguish various characters, a graphic recorder was used to plot the response of each filter to each of the 81 characters in the type font used. Figures 6 through 16 show the results. The matrix of reference apertures is shown in Fig. 3. In each case, the photomultiplier output corresponding to a measurement of the peak illumination produced by the negative aperture (having the shape of all the other apertures superimposed) is subtracted from twice the peak illumination produced by the given "positive" aperture. The positive filter used for each graph is indicated by the encircled character. The line was drawn from right to left as the characters passed through the field of view in the order:

1234567890ABCDEFGHIJKLMNPOQRSTUVWXYZabcdefghijklmnopqrstuvwxyz

*@#%&()'"':;_-,./

Only those characters which result in a strong response by the filter are separately marked.

It may be noted that the character corresponding to the filter being tested always produces a response at least 10% greater than the response caused by any other character.

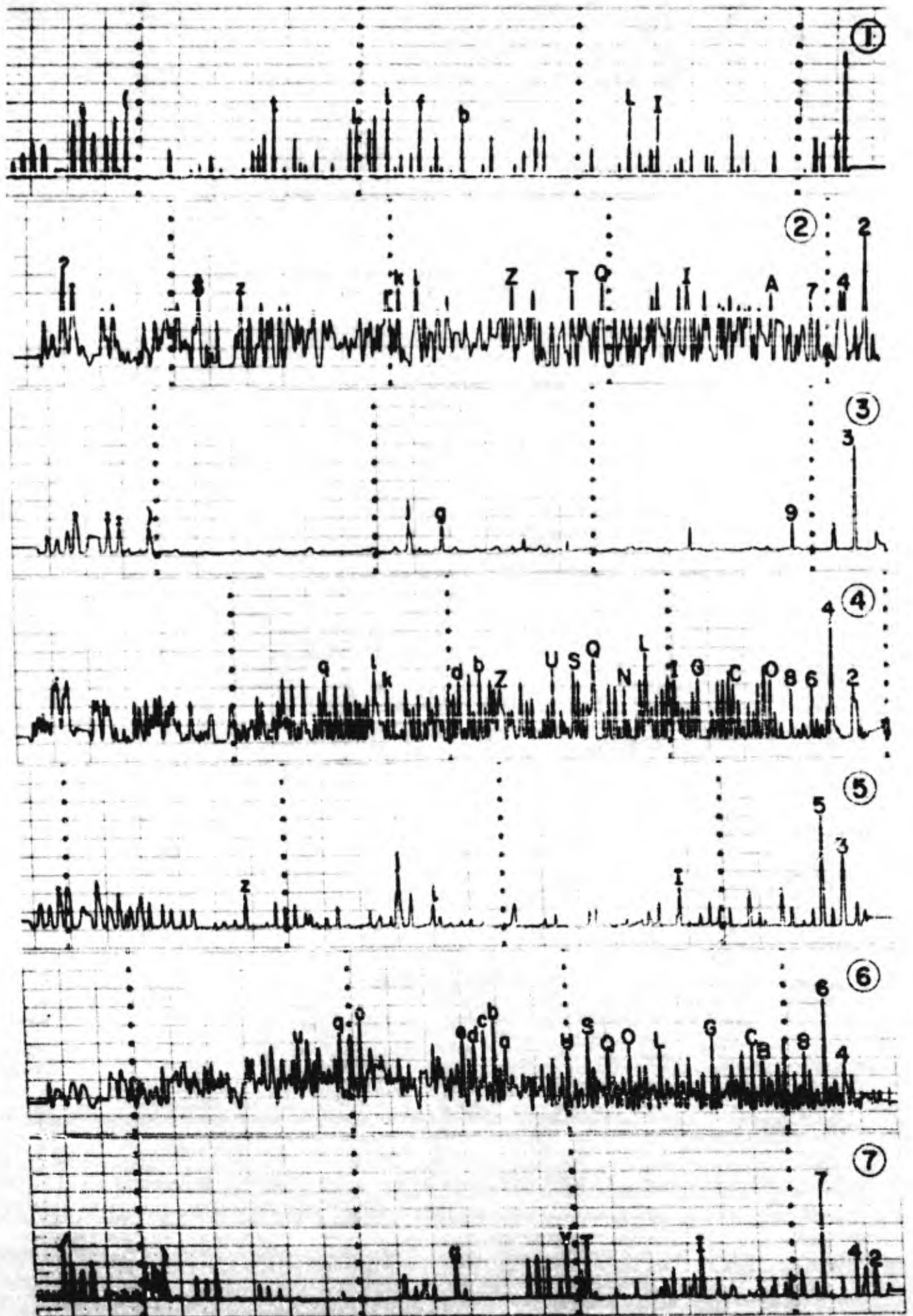


FIGURE 6

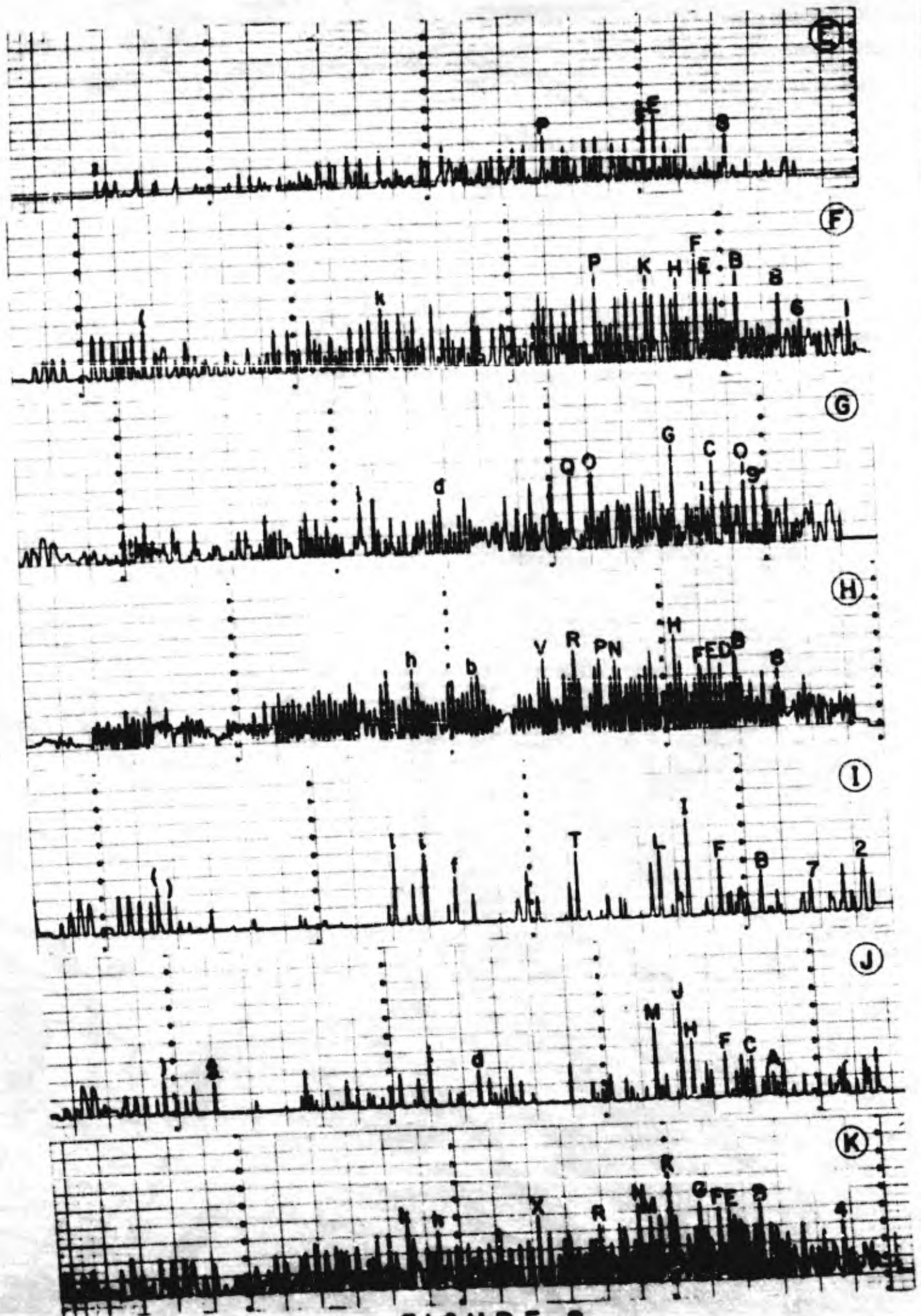


FIGURE 8

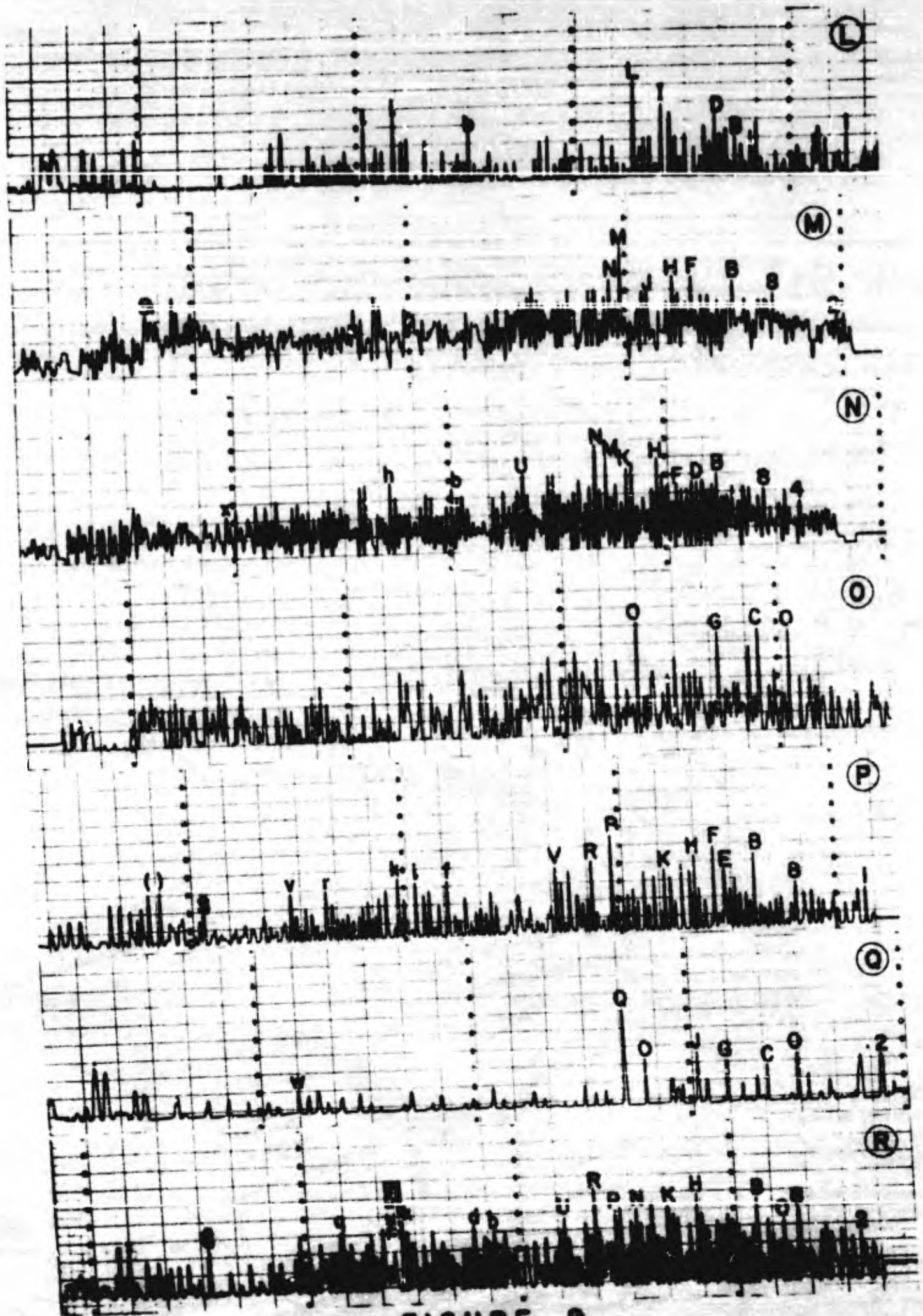


FIGURE 9

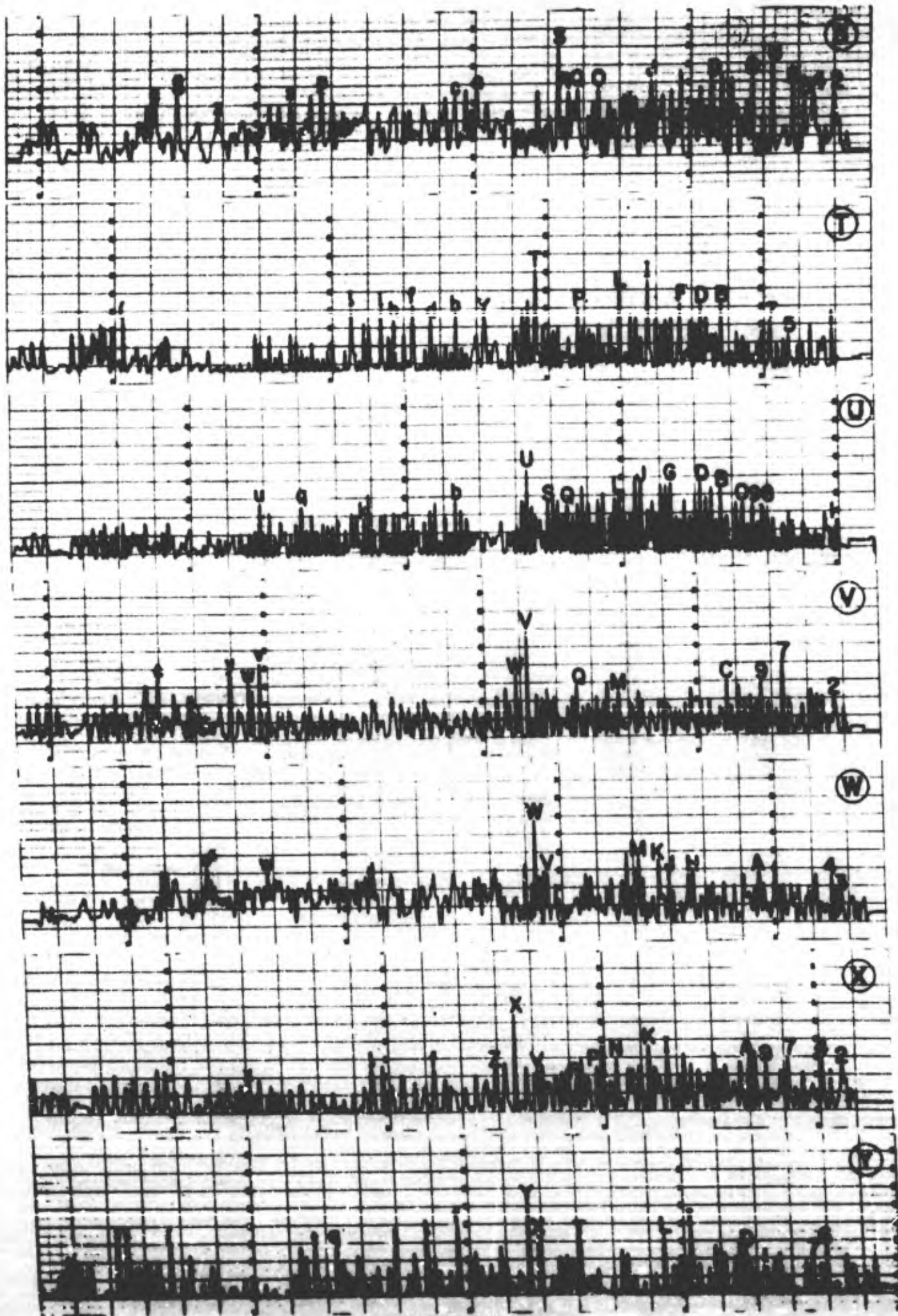


FIGURE 10

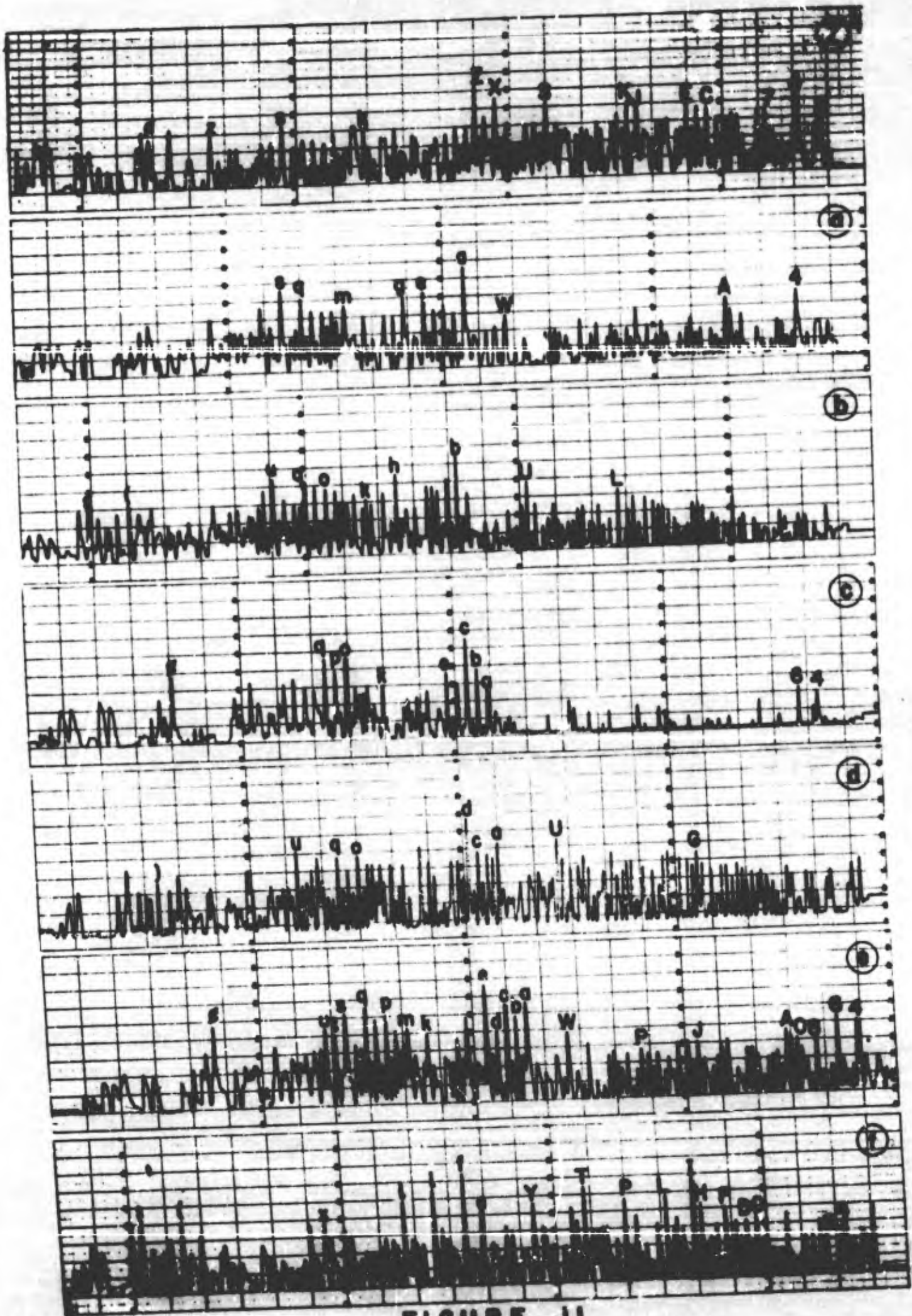


FIGURE II

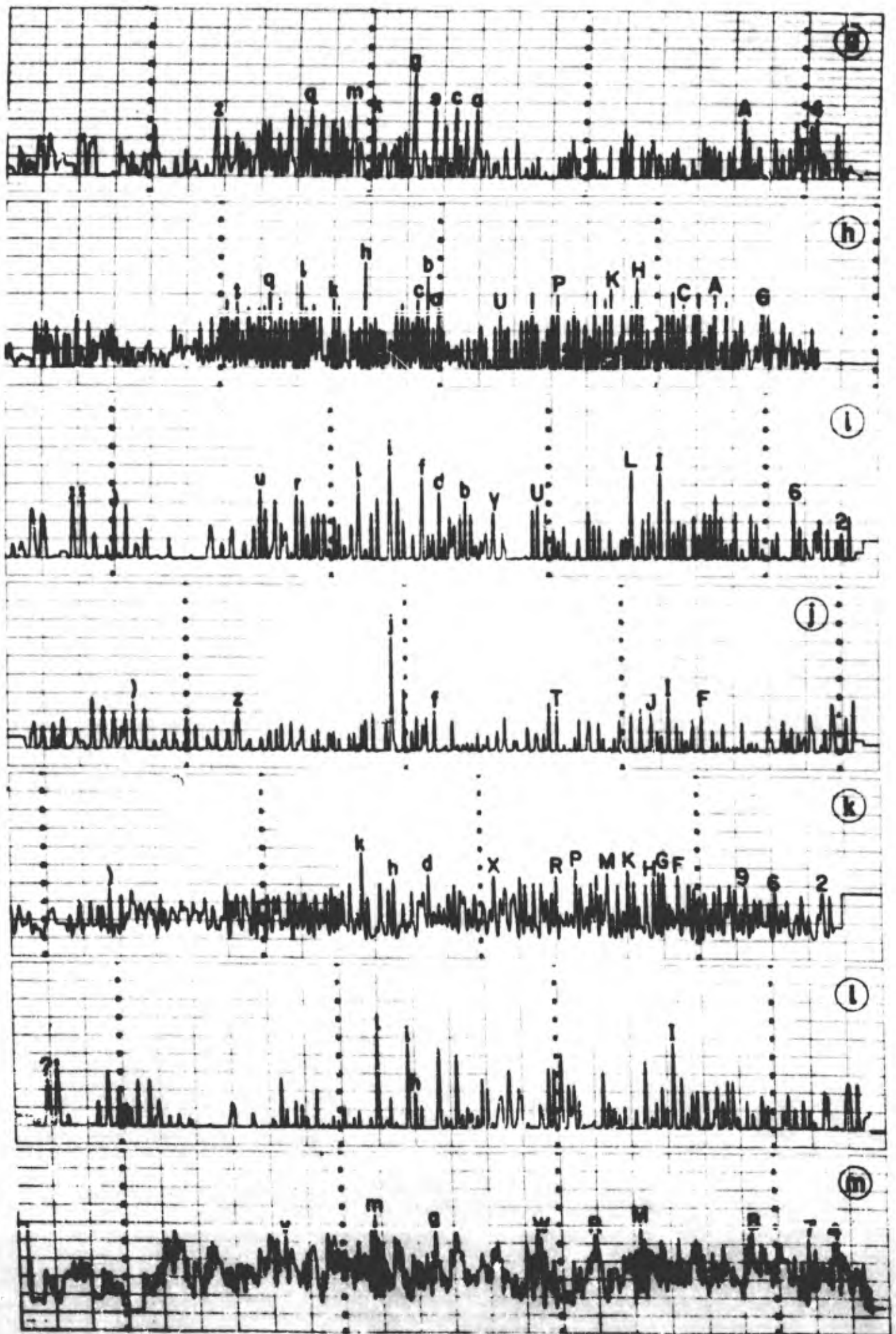


FIGURE 12

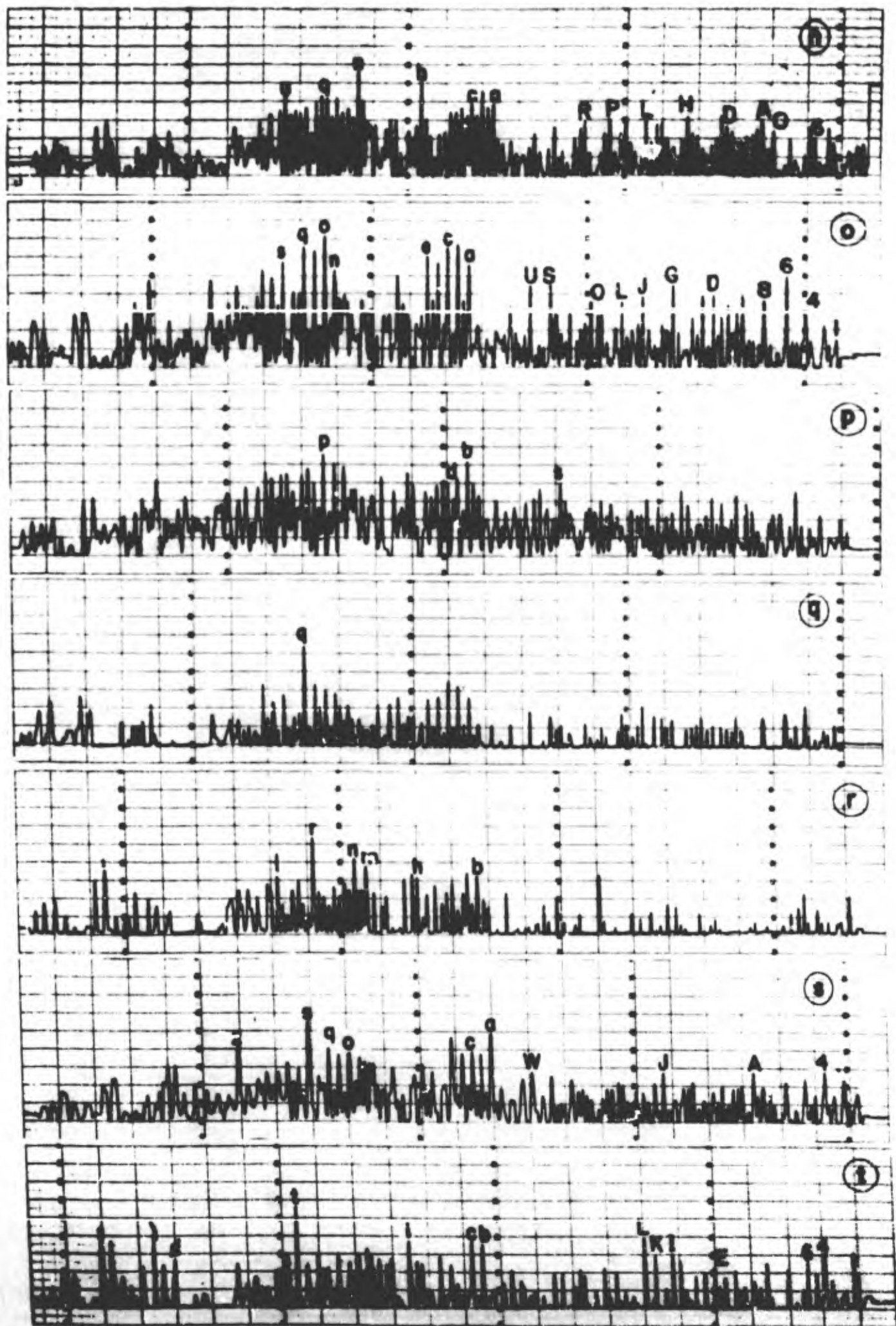


FIGURE 13

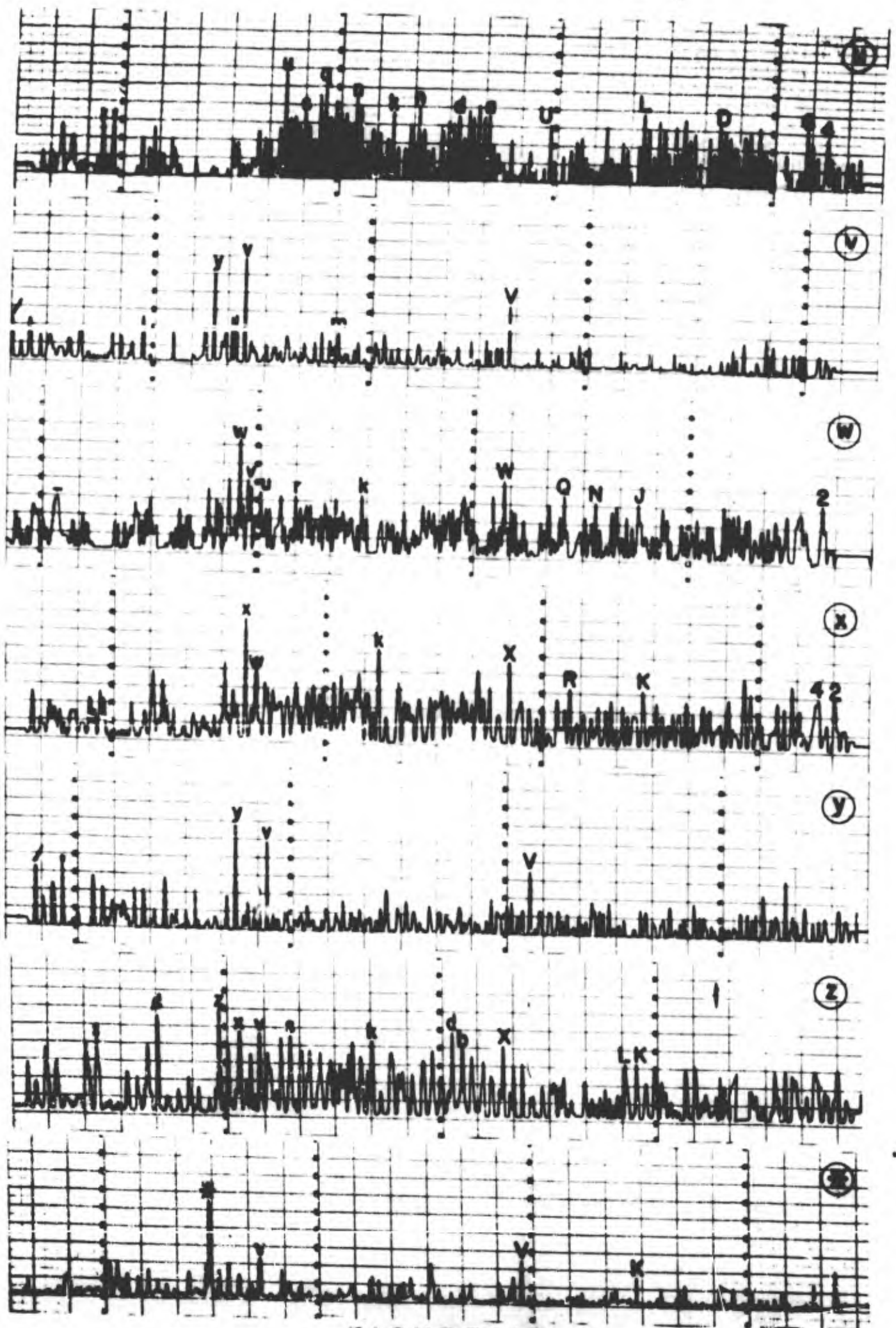


FIGURE 14

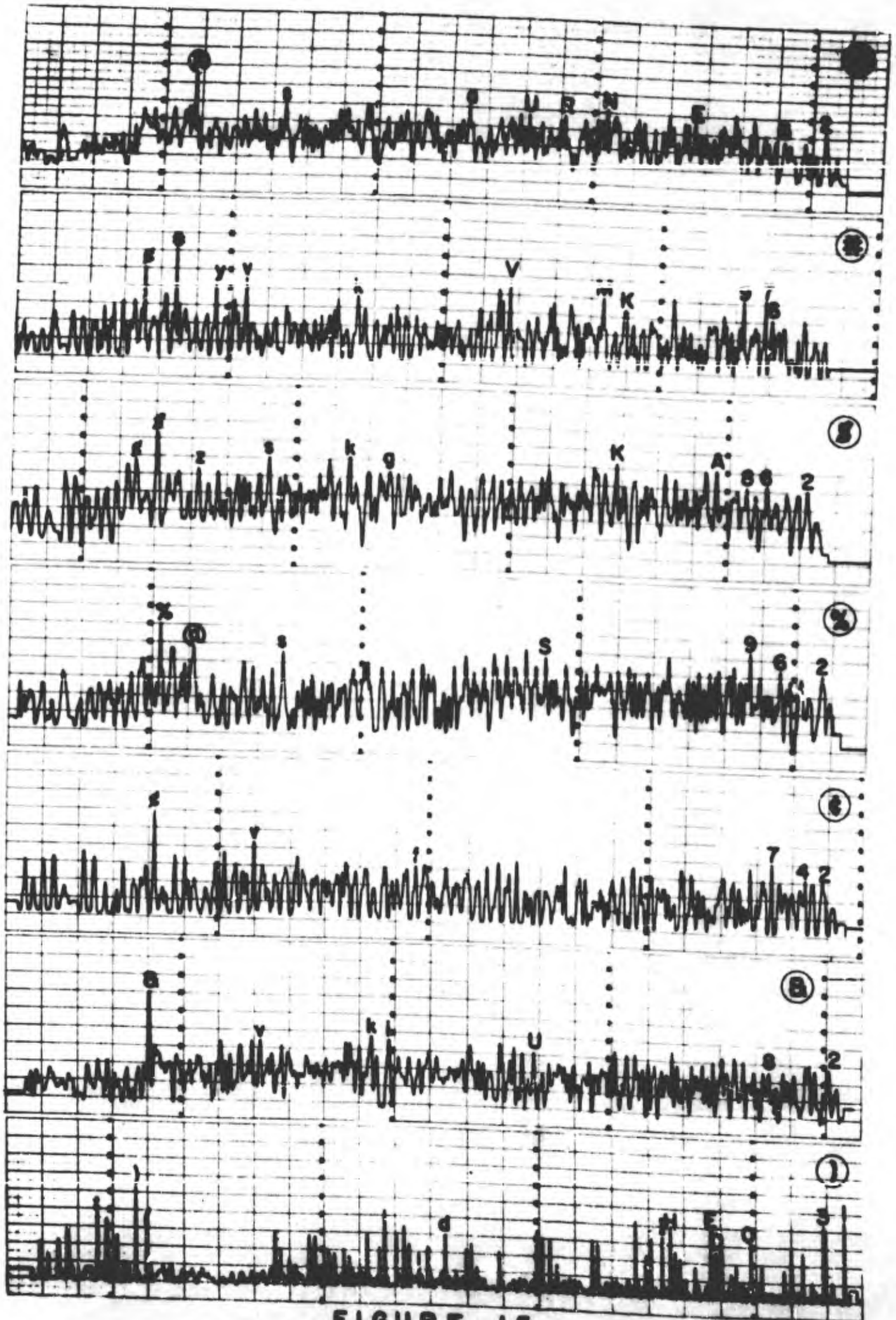


FIGURE 15

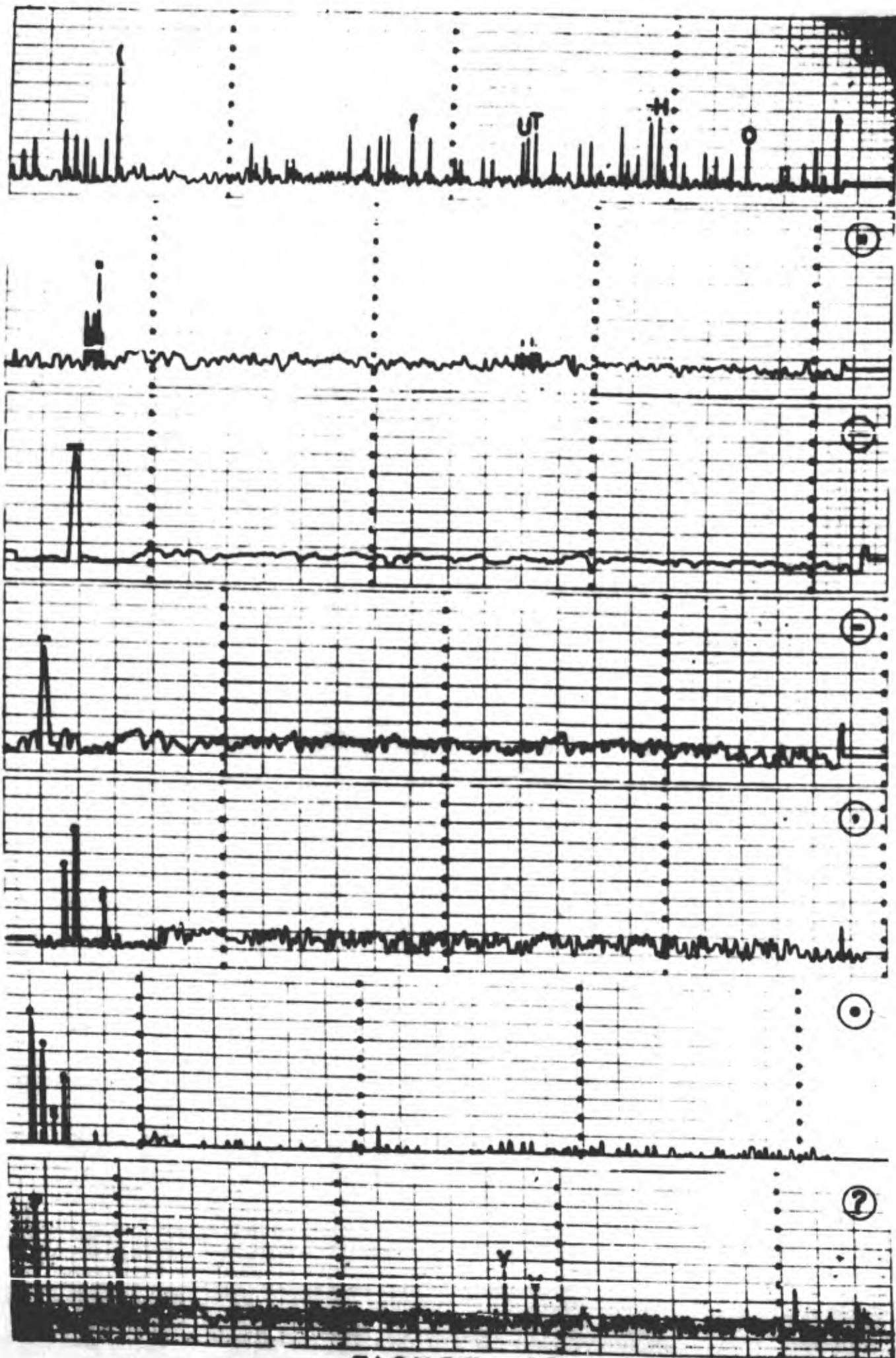


FIGURE 16

Part III
CONCLUSIONS

So long as only a single font is used, the recognition method discussed here is potentially fast and highly reliable. It may be extended most simply to a variety of type fonts by changing the matrix of aperture filters whenever the type font changes in the text.

Part IV
RECOMMENDATION

In view of the very successful results of this feasibility study, and the great need for a highly versatile print reader, it is recommended that an operational prototype print reader be built utilizing the methods discussed in this report.

Part V

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