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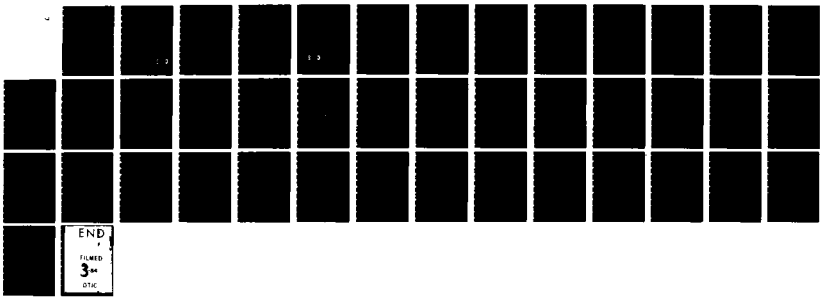

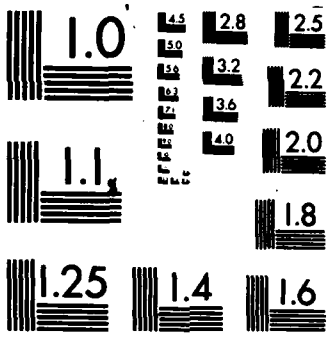

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APPLICATION OF METHODS OF NUMERICAL AND SOFTWARE ENGINEERING ANALYSIS TO PHYSICAL & ENGINEERING DATA COLLECTED IN A VARIETY OF LABORATORY AND FIELD MEASUREMENT PROGRAMS

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September 1980 - September 1983

28 October 1983

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This report presents a summary of analyses and mathematical modelling done in support of some AFGL atmospheric research projects. In particular, work on the problems of linear filtering on intensity data, broadening of peaks in the photoelectron energy spectrum, and interactive OPAQUE file editing are discussed.

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EFFECTS OF LINEAR FILTERING ON INTENSITY DATA

1. INTRODUCTION AND SUMMARY

In this paper we consider a complex random signal which can be thought of as representing the in-phase and quadrature components of a demodulated signal. The complex signal is modelled as a sum of two statistically independent random processes which lie in disjoint frequency bands. The purpose of this paper is to determine the efficiency of linearly filtering the intensity of the complex data in an attempt to isolate the intensities of the two statistically independent components. We do this by first defining a mathematical model to describe the complex signal and the two components of the signal, then we determine the power spectral density of the intensity of the complex signal in terms of the power spectral densities of the two statistically independent components. Finally, we address the issue of isolating the two processes by filtering the intensity data.

The results show that the frequency regions defined by the two statistically independent processes are not mapped into the same regions in the intensity signal. This occurs because the intensity is a non-linear function of the complex waveform. Although the energy in the two statistically independent processes is assumed to be in disjoint frequency regions, the energy in the intensity is spread throughout the spectrum and, at any frequency, it depends on both input processes. The implication of this result is that, given intensity information alone, one cannot isolate the intensities of the two components by linearly filtering the intensity even if the two components lie in disjoint frequency regions.

2. ANALYSIS

2.1 Signal Model

Let us assume that the signal to be considered is the output of an in-phase and quadrature demodulation system. We model these components as the real and imaginary parts of a complex signal $\tilde{w}(t)$[1]:

$$\tilde{w}(t) = \mathrm{Re}[\tilde{w}(t)] + j\mathrm{Im}[\tilde{w}(t)]. \tag{1}$$

We now assume that the signal $\tilde{w}(t)$ consists of a sum of two statistically independent band-limited complex Gaussian random processes, each lying in disjoint frequency regions. (Although the assumption that the processes lie in disjoint frequency regions is unnecessary, this assumption simplifies the graphical interpretation of the power spectral density of the intensity of $\tilde{w}(t)$.) Thus,

$$\tilde{w}(t) = \tilde{n}_1(t) + \tilde{n}_2(t), \tag{2}$$

where $\tilde{n}_1(t)$ and $\tilde{n}_2(t)$ are the two statistically independent random processes. For simplicity we assume that $\tilde{n}_1(t)$ is a zero-mean low-pass complex Gaussian random process with spectral height N_1 over a two-sided bandwidth B_1. Similarly, we assume $\tilde{n}_2(t)$ is a zero-mean band-pass complex Gaussian random process with spectral height N_2 over a bandwidth B_2 centered at $-f_c$.

---

[1]In this paper all complex quantities are denoted by the tilde ($\sim$) overbar. Also, the notation x^* indicates the complex conjugate of x.

The (complex) auto-correlation functions for these processes can be written as

$$\tilde{R}_{\tilde{n}_1}(\tau) = E[\tilde{n}_1(t)\tilde{n}_1^*(t-\tau)] = N_1B_1 \frac{\sin \pi B_1\tau}{\pi B_1\tau}$$

$$\tilde{R}_{\tilde{n}_2}(\tau) = N_2B_2 \frac{\sin \pi B_2\tau}{\pi B_2\tau} \exp[-j2\pi f_c\tau]. \tag{3}$$

The power spectral densities $S_{\tilde{n}_1}(f)$ and $S_{\tilde{n}_2}(f)$ associated with these auto-correlation functions are shown in Fig. 2-1 (a) and (b).

Since the processes $\tilde{n}_1(t)$ and $\tilde{n}_2(t)$ are assumed to be statistically independent, the power spectral density of $\tilde{w}(t)$ is simply the sum of the power spectral densities of $\tilde{n}_1(t)$ and $\tilde{n}_2(t)$:

$$S_{\tilde{w}}(f) = S_{\tilde{n}_1}(f) + S_{\tilde{n}_2}(f). \tag{4}$$

This spectrum is shown in Fig. 2-1(c).

2.2 Power Spectrum of Intensity

The intensity of the complex signal w(t) is defined as

$$I(t) = \left|\tilde{w}(t)\right|^2$$

$$= \left|\tilde{n}_1(t)\right|^2 + \left|\tilde{n}_2(t)\right|^2 + 2\mathrm{Re}[\tilde{n}_1(t)\tilde{n}_2^*(t)]. \tag{5}$$

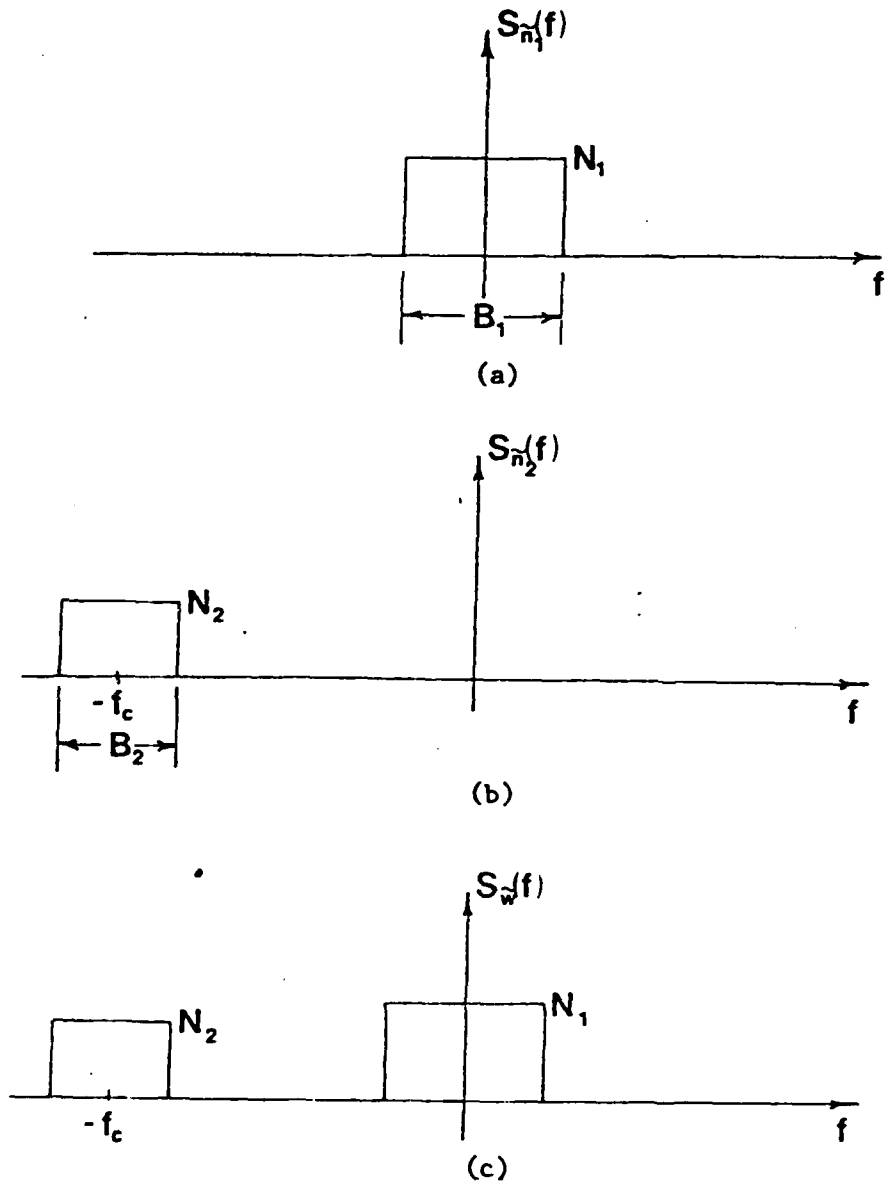


Fig. 2-1: Power Spectral Density Functions
(a) for $\tilde{n}_1(t)$, (b) for $\tilde{n}_2(t)$, (c) for $\tilde{w}(t)$

The power spectral density of I(t) can be found by first determining the autocorrelation function of I(t) (defined by $R_I(\tau)$) and then Fourier transforming the result.

$$R_I(\tau) = E[I(t)I(t-\tau)], \tag{6}$$

which, after multiplying (5) out and using Gaussian moment factoring, becomes

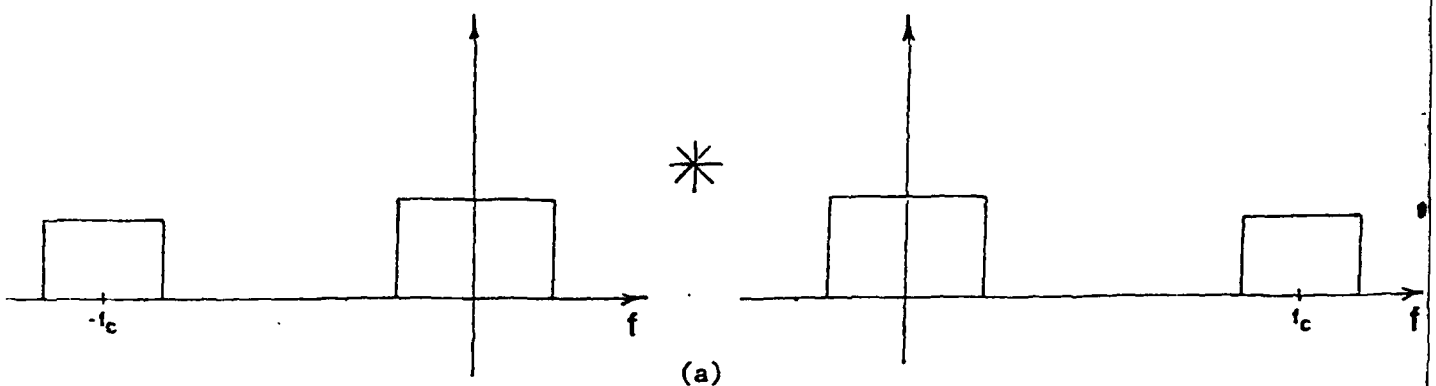
$$R_I(\tau) = \left|\tilde{R}_{\tilde{n}_1}(0) + \tilde{R}_{\tilde{n}_2}(0)\right|^2 + \left|\tilde{R}_{\tilde{n}_1}(\tau) + \tilde{R}_{\tilde{n}_2}(\tau)\right|^2. \tag{7}$$

To find the power spectral density of I(t) we Fourier transform both sides of (7). Since the first term is a constant, we know it will transform to an impulse in the frequency domain. The second term is a product of the sum of the two autocorrelation functions with the sum of their complex conjugates. Therefore, the Fourier transform of this term is a convolution of the sum of the two power spectral densities with the sum of a frequency reversed version of the two power spectral densities:

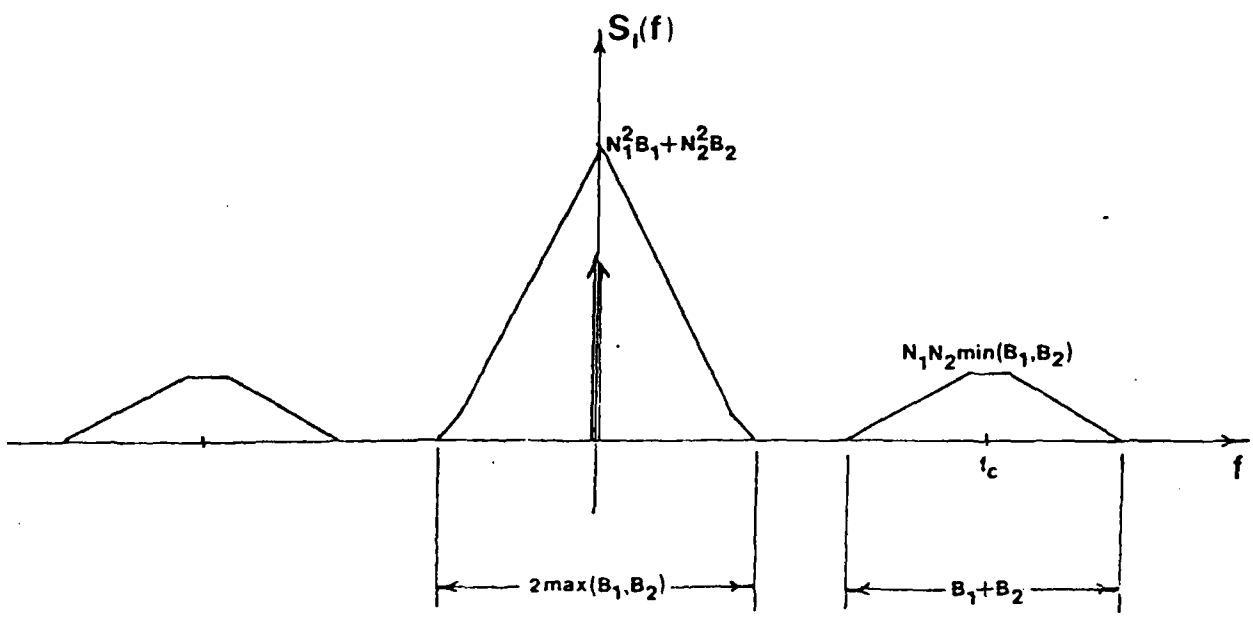
$$S_I(f) = \left|\tilde{R}_{\tilde{n}_1}(0) + \tilde{R}_{\tilde{n}_2}(0)\right|^2 \delta(f) + [S_{\tilde{n}_1}(f) + S_{\tilde{n}_2}(f)]*[S_{\tilde{n}_1}(-f) + S_{\tilde{n}_2}(-f)]. \tag{8}$$

All this is much easier shown graphically in Fig. 2-2. In Fig. 2-2(a) we show the convolution that is performed in the frequency domain, and in Fig. 2-2(b) we show the final result, $S_I(f)$.

It is clear from (8) and from Fig. 2-2(b) that, because of the cross terms in the convolution, the spectrum of I(t) is very different from the spectrum of the complex signal $\tilde{w}(t)$ seen in (4) and Fig. 2-1(c). Even though there are still two distinct frequency bands (for this example), we see that the low-pass portion depends on parameters of both $\tilde{n}_1(t)$ and $\tilde{n}_2(t)$. In other words, the low frequency portion I(t) depends not only on



(a)



(b)

Fig. 2-2: Power Spectral Density for the Intensity of $\tilde{w}(t)$
(a) Convolution in the Frequency Domain Required by (8)
(b) Resulting Power Spectral Density for Intensity

the low frequency part of the signal $\tilde{w}(t)$, but also on the high frequency part of $\tilde{w}(t)$ because of the non-linear operation on $w(t)$ to produce $I(t)$. The same argument is true for the high frequency region of $S_I(f)$: it is determined by both $\tilde{n}_1(t)$ and $\tilde{n}_2(t)$.

In the following section we shall see that we can filter out the high frequency portion of $I(t)$, but we cannot successfully isolate the intensity of $\tilde{n}_1(t)$ or $\tilde{n}_2(t)$ from the intensity data alone.

2.3 Effects of Filtering the Intensity Time Series

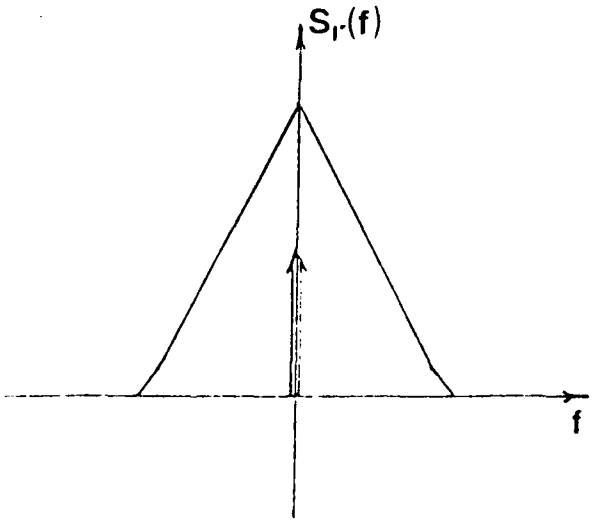
We now assume that we are given the signal $I(t)$ only, and we wish to isolate the intensities of the two components $\tilde{n}_1(t)$ and $\tilde{n}_2(t)$ by [illegible]early filtering $I(t)$. If we simply low-pass filter $I(t)$ as seen in Fig [illegible]-3(a) we can eliminate the high frequency portion of $I(t)$. The r[illegible]lting spectrum $S_{I'}(f)$ seen in Fig. 2-3(b) can be written as:

$$S_{I'}(f) = \tilde{R}_{\tilde{n}_1}(0) + \tilde{R}_{\tilde{n}_2}(0)^2\,\delta(f) + S_{\tilde{n}_1}(f)*S_{\tilde{n}_1}(f) + S_{\tilde{n}_2}(f)*S_{\tilde{n}_2}(-f). \qquad (9)$$

We see from (9) and Fig. 2-3(b) that low-pass filtering $I(t)$ cannot successfully isolate the intensity of $\tilde{n}_1(t)$ or $\tilde{n}_2(t)$ even though $I(t)$ is a low-pass signal. Once again we see that the non-linear operation on $\tilde{w}(t)$ causes the low-pass portion of the intensity to depend on both the low frequency portions of $\tilde{w}(t)$ and the high frequency portions of $\tilde{w}(t)$.

It may be possible, though, to use non-linear filtering in the frequency (or autocorrelation) domain to isolate either $S_{\tilde{n}_1}(f)$ or $S_{\tilde{n}_2}(f)$. However, we are interested in isolating the intensities of the processes $\tilde{n}_1(t)$ and $\tilde{n}_2(t)$ — not their spectra, and to do this we would have to determine what the non-linear filtering operations in the frequency domain correspond to in the time (intensity) domain. This is a very difficult, if not impossible, task. In other words, it may be possible to isolate the $S_{\tilde{n}_1}(f)$ or $S_{\tilde{n}_2}(f)$ by non linear filtering, but it would be impossible to isolate the intensities of the processes $\tilde{n}_1(t)$ and $\tilde{n}_2(t)$.

(a)



(b)

Fig. 2-3: Effects of Low-pass Filtering the Intensity
(a) Low-pass Filtering Operation
(b) Resulting Power Spectral Density

BROADENING OF PEAKS IN THE PHOTOELECTRON ENERGY SPECTRUM

1. INTRODUCTION

The main source of electrons in the ionosphere of the Earth is the ionization of the neutral species in the atmosphere by photons from the sun. [Fig. 1] The photon spectrum has structure which includes lines, energies at which there are more photons than at neighboring energies. The most prominent of these is the line radiated by ionized Helium at 304A or 40.8 eV.

When these photons ionize the species in the Earth's atmosphere, their energy spectrum creates an electron energy spectrum for each possible ionization process. The sum of these is the initial photoelectron spectrum. This distribution of electron energies is then modified by collisions. A nonlinear calculation by the program mentioned in the previous talk produces this electron distribution. [Fig. 2] the most structure occurs above 20 eV. This can be compared with satellite measurements by smoothing it to simulate the instrumental response function. [Fig. 3]

A more detailed set of measurements should yield something closer to the original calculation. [Fig. 4] This talk focuses on the origins of the lines in the electron energy spectrum.

2. BACKGROUND

We assume that the local approximation is good, since we are interested in the lower part of the ionosphere. This is the same as that of the last speaker and is described by the same equation. [Fig. 5] The photoelectrons are the main source. Since the cross-sections are relatively smooth, except near threshold, the main structures are caused by lines in the solar spectrum. The solar lines have widths caused

primarily by the kinetic motion of the atoms and ions while they are emitting.

3. LINE BROADENING

The structure of the photon spectrum is repeated in the electron energy spectrum for each possible state of the resulting ion. The atmosphere is cool enough not to introduce further thermal broadening into the lines. Other broadening mechanisms found when studying laboratory plasmas are also very small.

The lines can be widened by multiple nearby levels, such as those of vibration. [Fig. 6] In this case, the ion may be left in any of a number of final states, yielding a number of close lying lines. In the case of dissociative photoionization, where the molecule is broken up, the electron may be left with any energy from zero up to some maximum. In this case, no line appears in the electron energy spectrum.

The rotational levels are very close lying, but they rarely change by more than 2. For this reason, they do not cause the type of spreading mentioned above. The energy differences between the rotational levels is sufficiently small that they are well populated in the lower ionosphere. [Fig. 7] Due to the normally small change in rotation during ionization, each rotational level in the neutral state can give rise to only a few levels in the resulting ion. If the energy spacings between rotational states are different for the neutral specie and its ion, the neutral rotational population distribution generates an electron energy distribution; i.e., the line is widened.

The relative sizes of these effects are shown in Fig. 8.

4. ELECTRON LINE COLLISIONAL BROADENING

So far we have discussed only the photoelectron source term in the equation. [Fig.5] The photoelectrons produced are scattered and change their energies by large or small amounts. Relatively large energy losses to the electron occur when a neutral specie is excited or ionized by the collision. These large energy losses reduce the number of electrons in the energy region of interest but do not alter the shape of the structures there.

Collisions which are elastic in the center-of-mass frame of reference, such as momentum transfer and Coulomb collisions, result in relatively small changes in the electron energy. These also have a larger probability of giving energy to the electron. The most effective of these is that between electrons. These collisions cause a frictional spreading of a line on the lower energy side and a broadening of the line toward lower and higher energies due to a diffusion term. The relative sizes of the two effects varies with temperature and density.

At lower altitudes, e.g., 130 km, the neutral density is high, so that the main collisional effect is neutral excitation. The electron energy spectrum is not changed much from the initial photoelectron energy spectrum. [Figs. 9, 10] This can be seen most clearly if a solar spectrum having only one line is used. The structure arising from the vibrational states of the ion can be seen.

At higher altitudes, the neutral density is lower, so that more electron-electron collisions can occur before the electron is removed from a particular energy range. Consequently, at higher altitudes the widening is more evident. [Figs. 11, 12]

We have not mentioned additional structures caused by excitation of atmospheric species. A strong and relatively constant excitation cross section will copy a structure that exists at one energy in the electron spectrum to a lower energy. The lines resulting from this are relatively weak, but their mixture with the other lines must be considered for a detailed analysis of the electron energy spectrum structures.

5. CONCLUSION

We have shown that the solar line width is the main width for structure in the photoelectron energy spectrum, augmented by fine structure considerations. Structures in the photoelectron energy spectrum arising from the ionization of molecules are broader than the photon lines due to effects caused by the vibrational levels of the ion and by the population of the rotational states of the neutral. Thus, the cleanest electron lines are those due only to the ionization of atoms.

The broadening due to elastic collisions can be used to estimate the temperature and density. This broadening becomes pronounced at higher altitudes.

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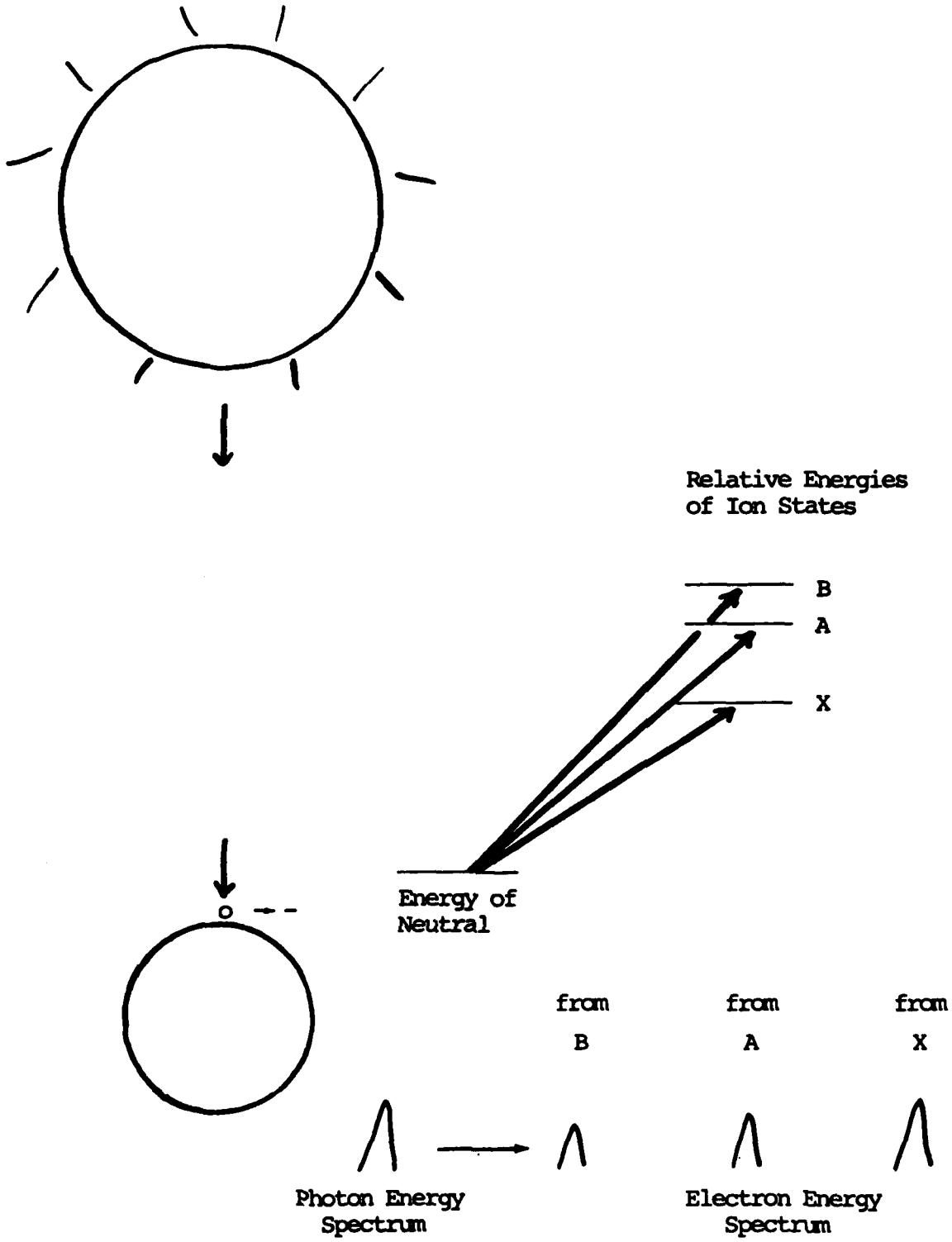


Fig. 1: Photoionization Process

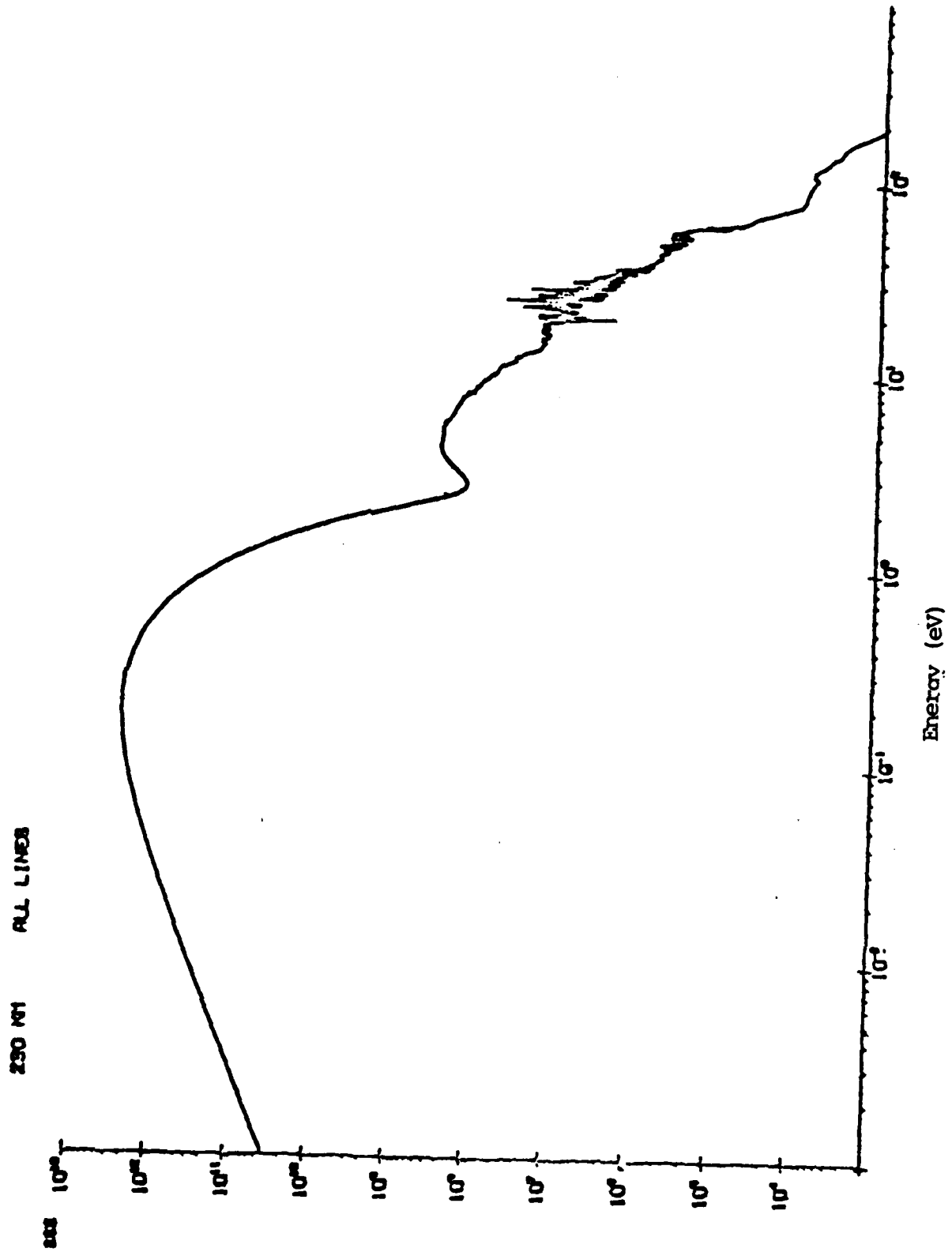


Fig. 2: Electron Flux

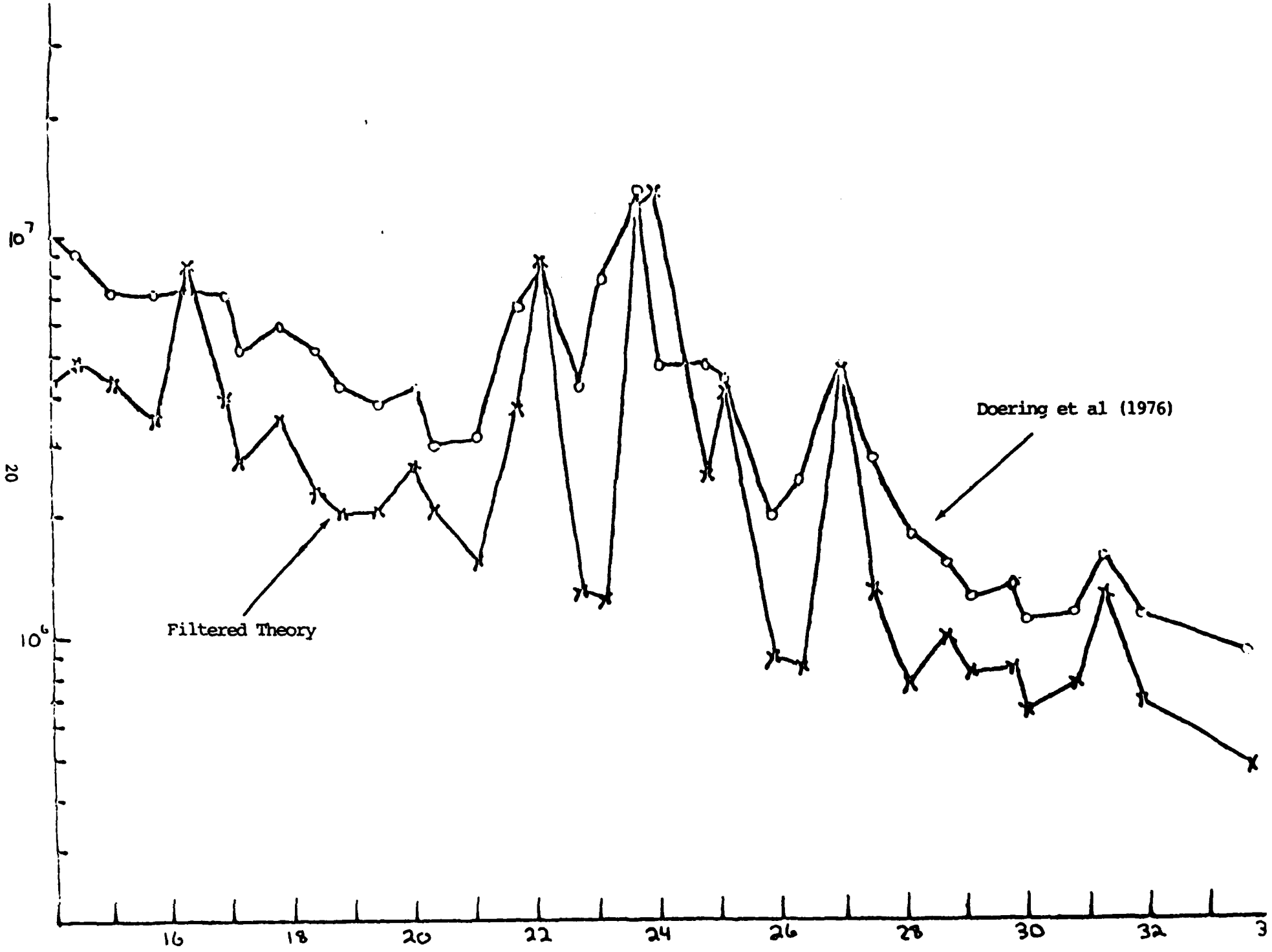


Fig. 3: Energy (Ev)

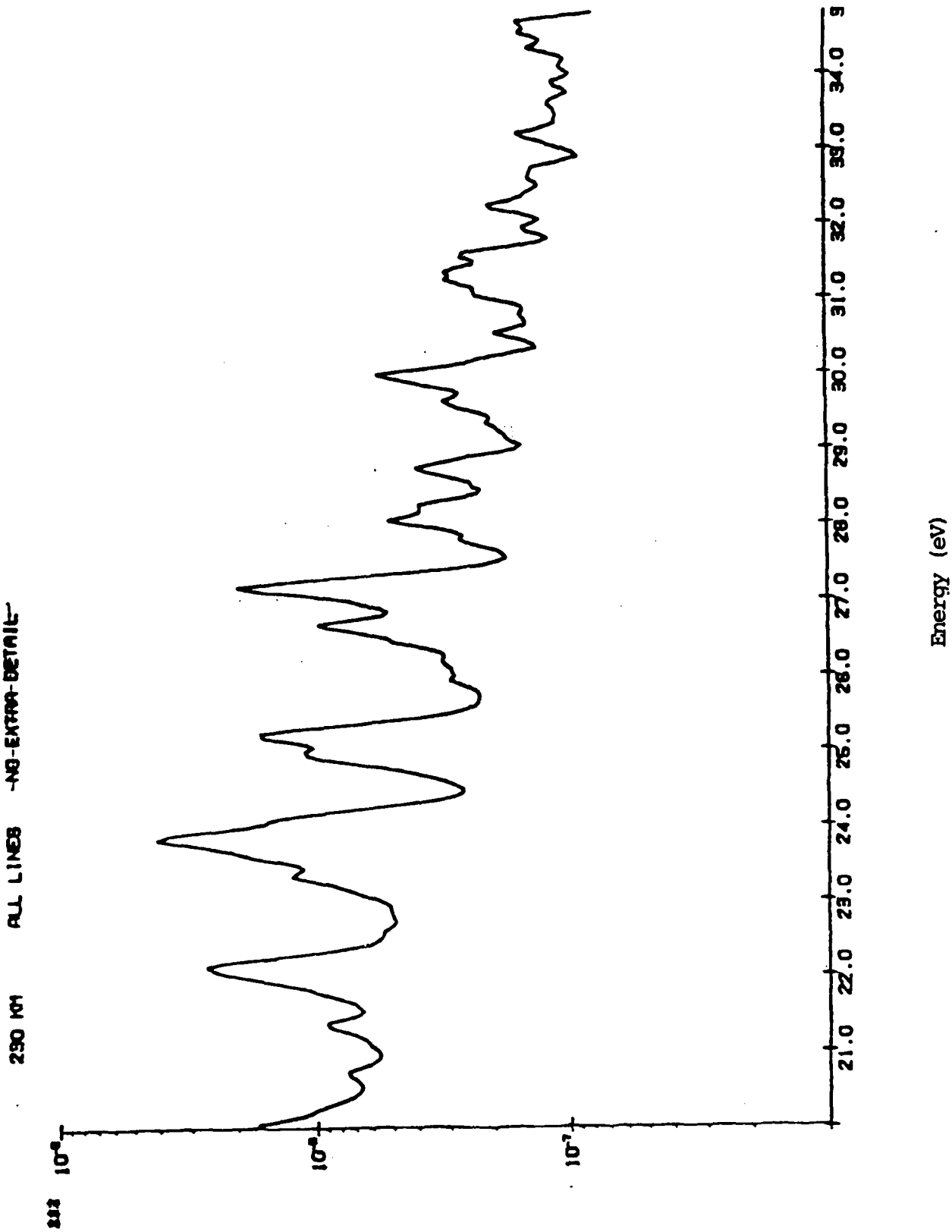


Fig. 4 : Relative Number of Electrons

THE STEADY STATE LOCAL KINETIC EQUATION

$$0 = \frac{\delta F_o(E)}{\delta t} + \frac{\delta F_o(E)}{\delta t} + \frac{\delta F_o(E)}{\delta t}$$

Photoionization E-N Ionization Recombination

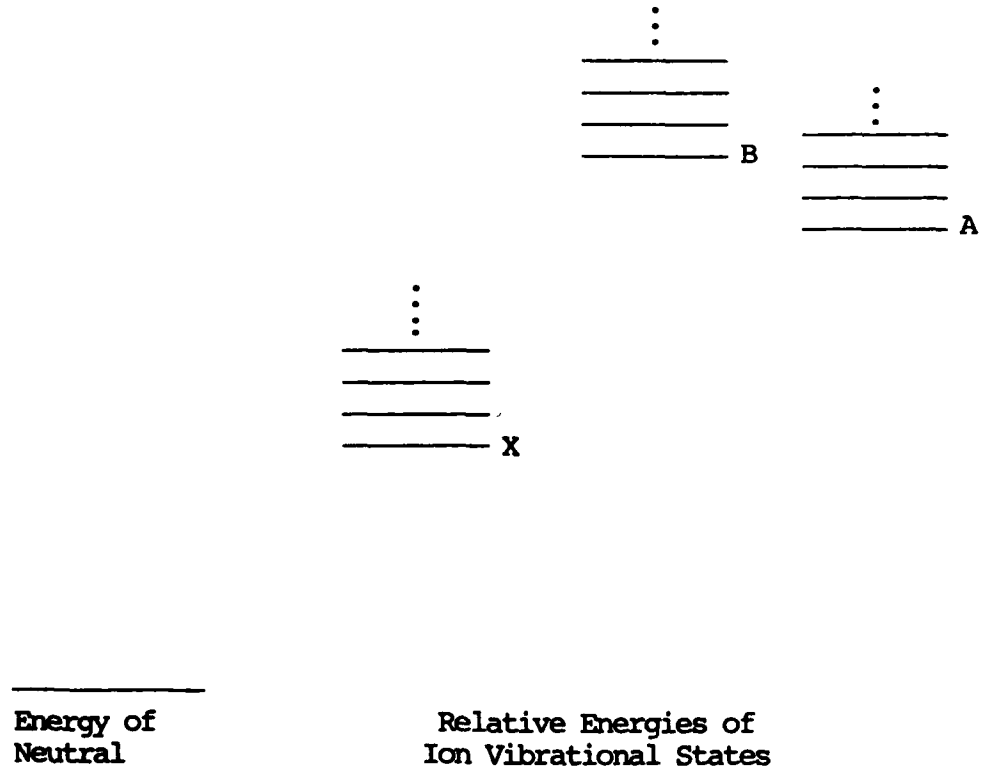
$$+ \frac{\delta F_o(E)}{\delta t} + \frac{\delta F_o(E)}{\delta t}$$

E-N Excitation E-N De excitation

$$+ \frac{\delta F_o(E)}{\delta t} + \frac{\delta F_o(E)}{\delta t} + \frac{\delta F_o(E)}{\delta t}$$

E-N Elastic Electron-Ion Electron-Electron

Fig. 5: Local Equation for Steady State



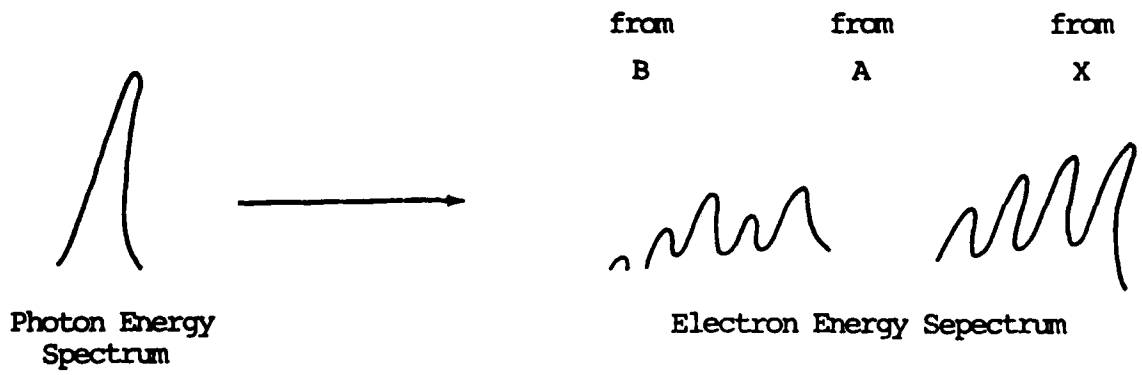


Fig. 6: Effects of Vibrational States

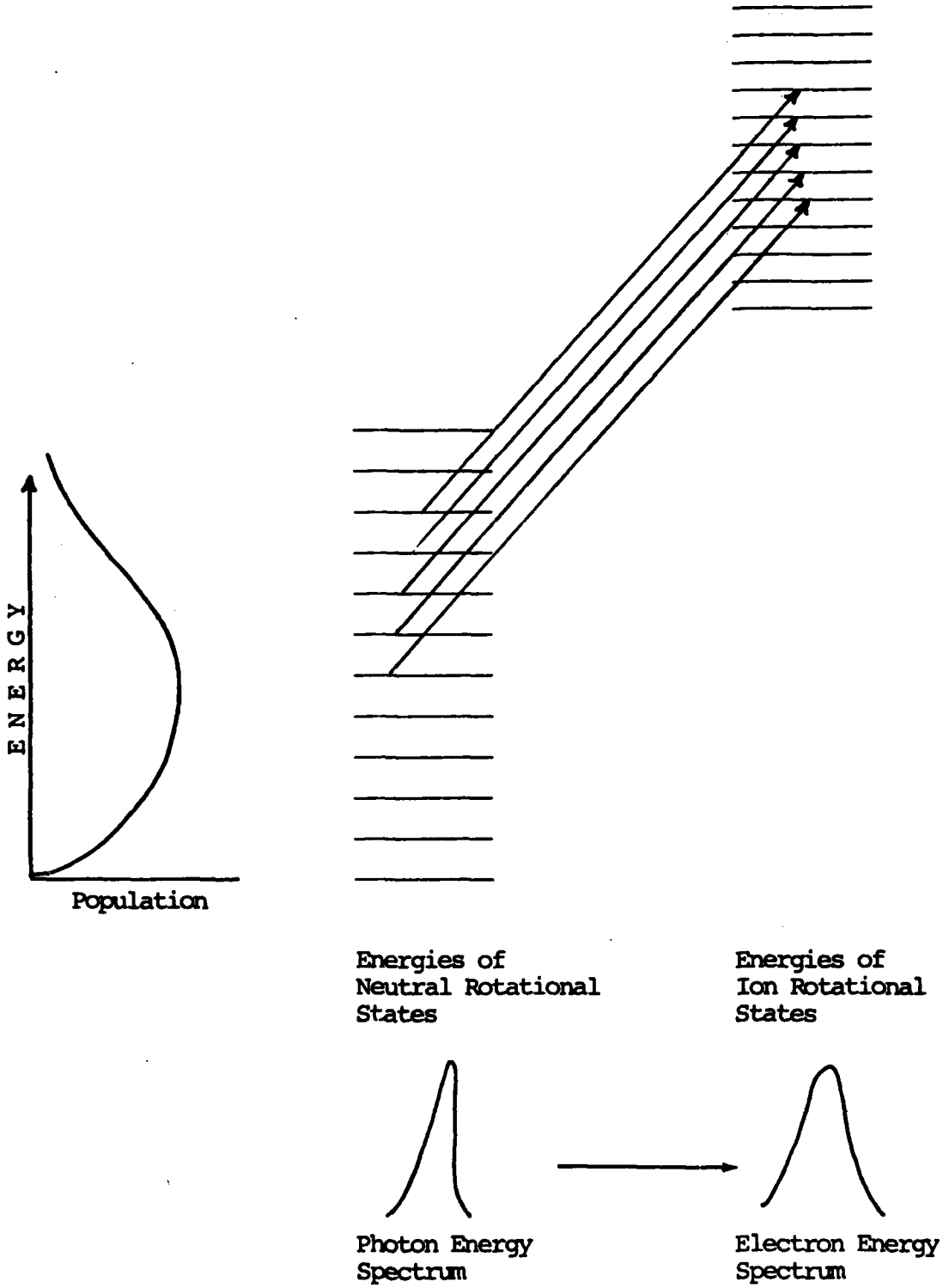


Fig. 7: Effect Of Rotational States

Solar Photon Emission	
THERMAL WIDTH (Observed)	.013 eV
Terrestrial Photon Absorption	
Thermal Width	.00004 eV
Close Lying Ion States (Energy Differences)	
VIBRATIONAL (O_2, N_2, $\Delta v = \pm 1$)	.2 - .3 eV
FINE STRUCTURE (O)	.03 eV
Rotational (O_2, N_2, $\Delta L = \pm 2$)	.0006 eV
Thermal Population of Neutral States	
ROTATIONAL (O_2, N_2)	.02- .03 eV

Fig. 8 : Ionospheric Electron Line Widths

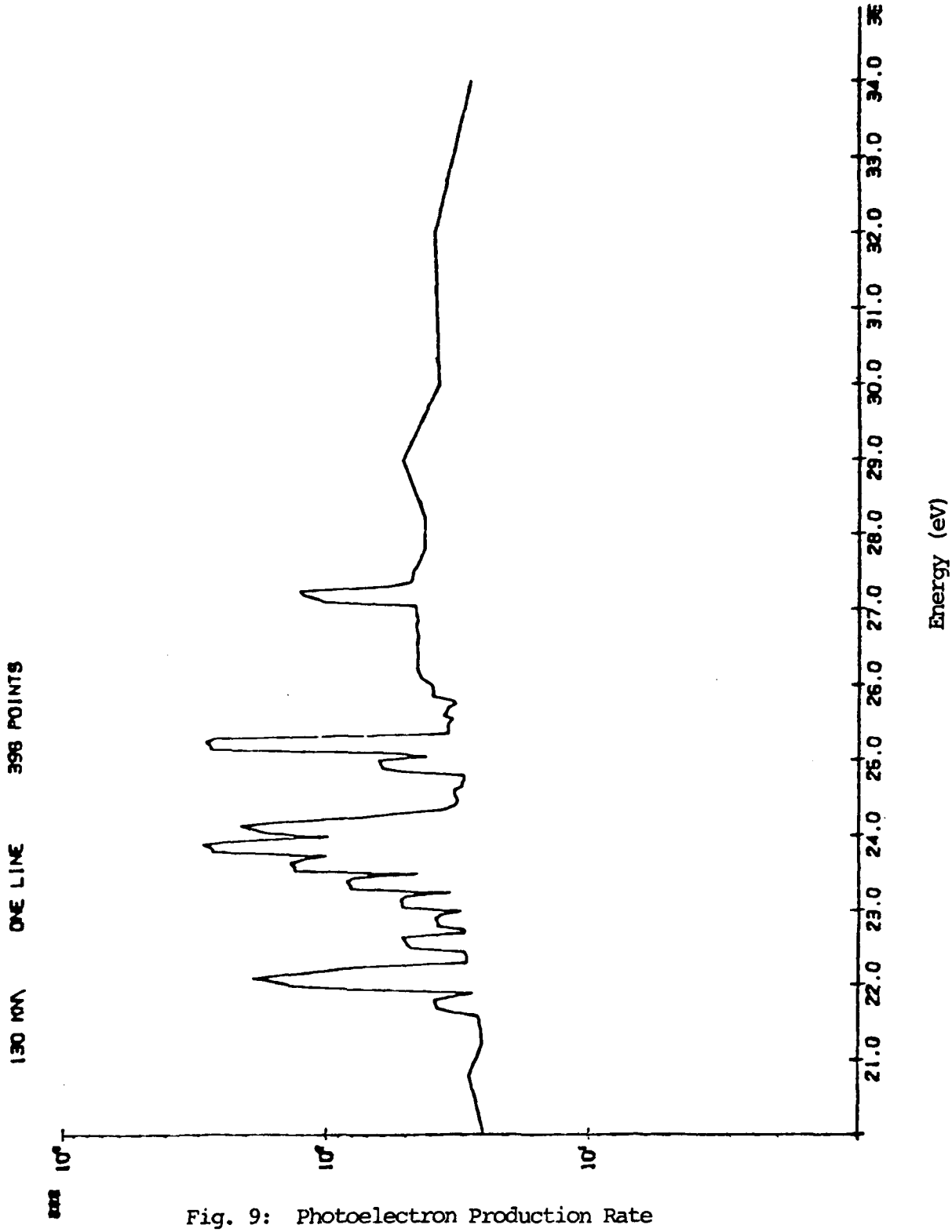


Fig. 9: Photoelectron Production Rate

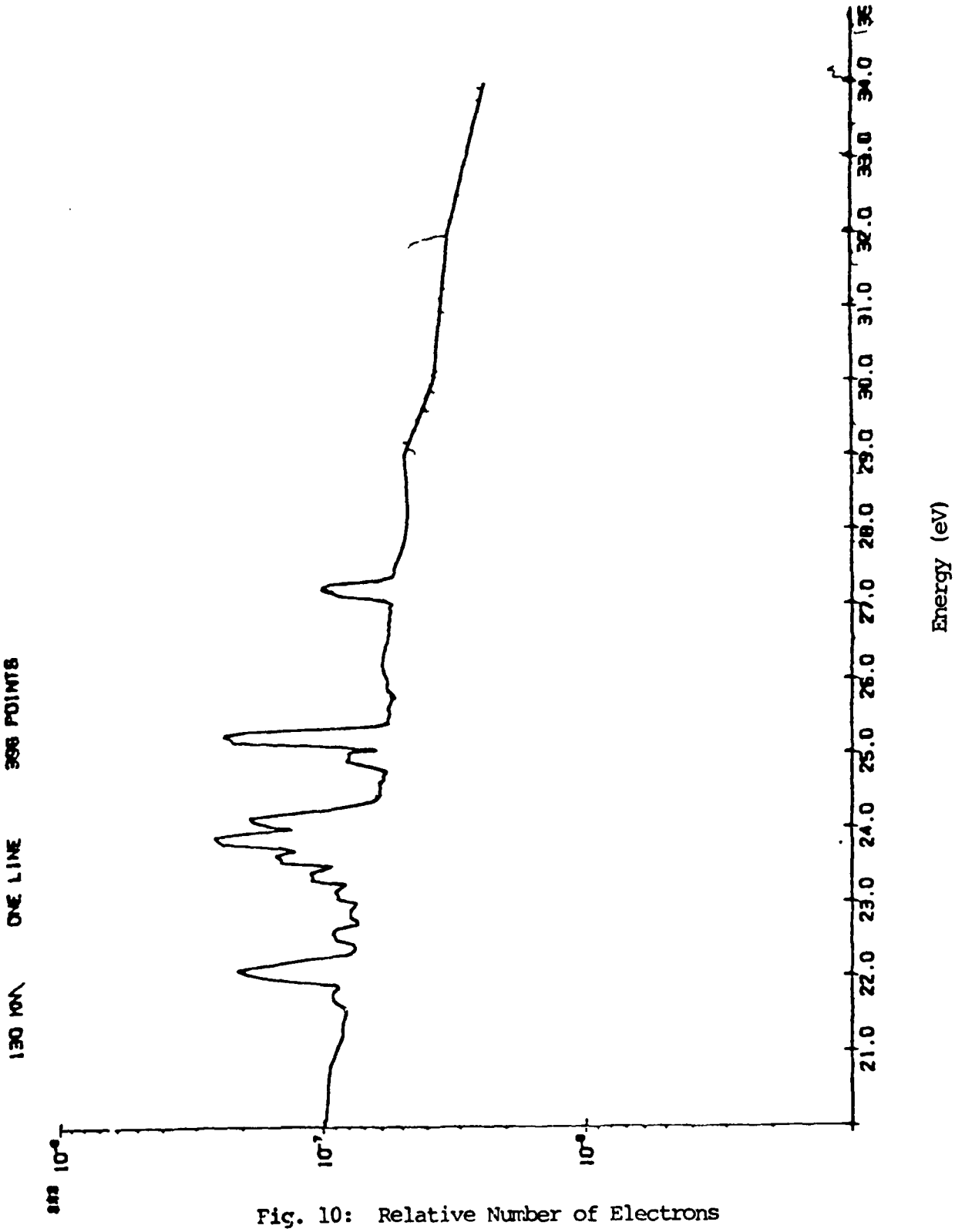


Fig. 10: Relative Number of Electrons

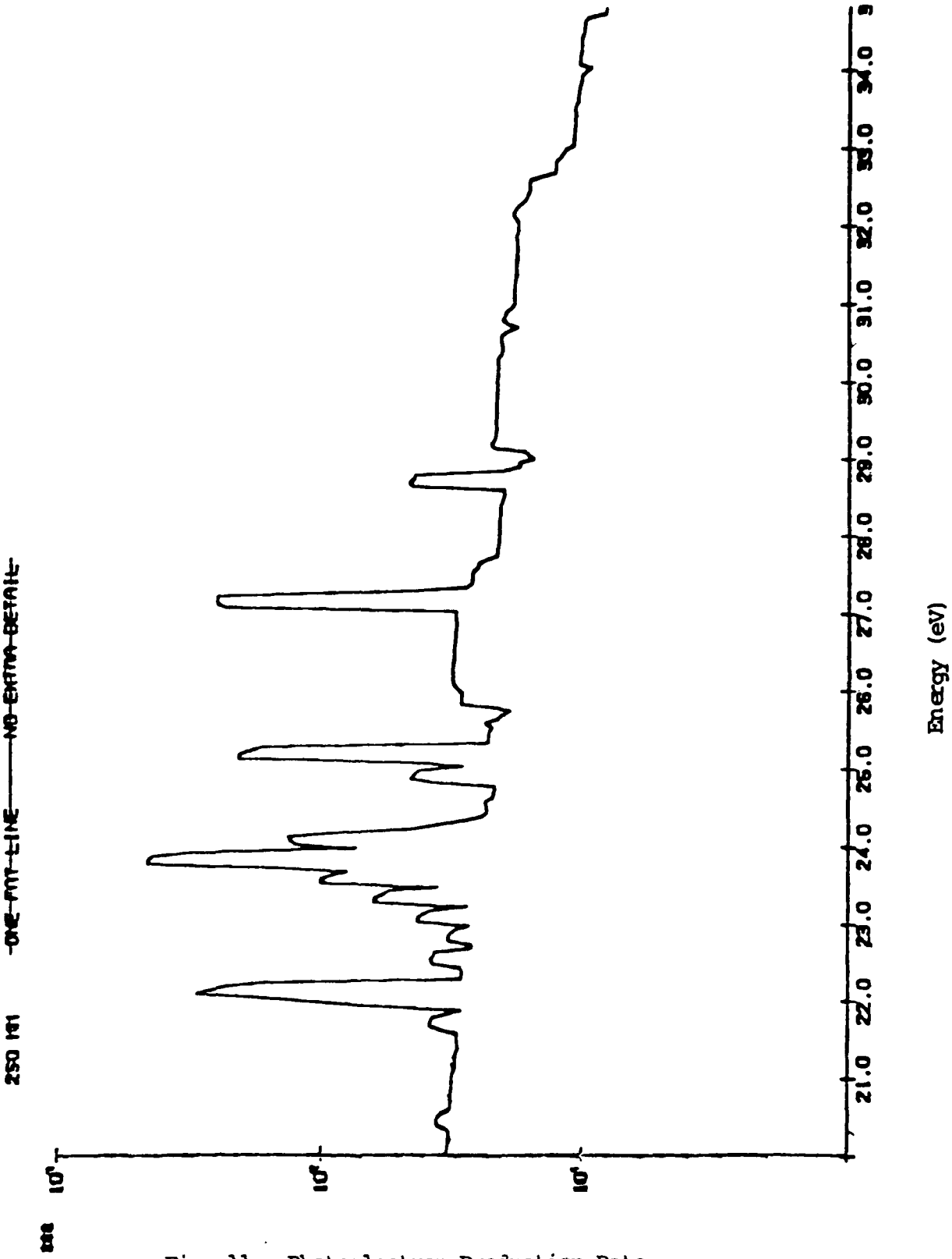


Fig. 11: Photoelectron Production Rate

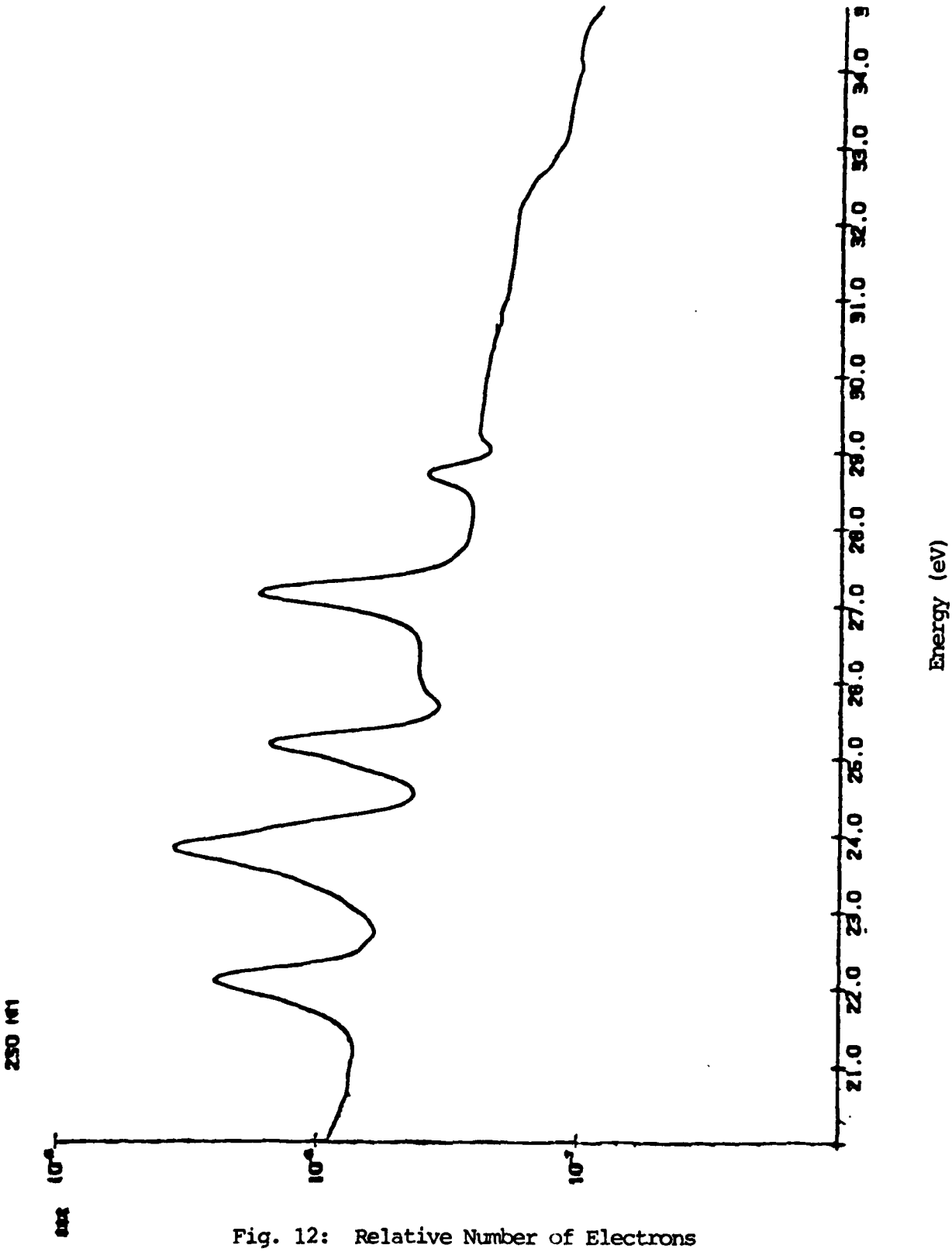


Fig. 12: Relative Number of Electrons

USER GUIDE FOR INTERACTIVE OPAQUE FILE EDITING PROGRAMS

1. INTRODUCTION

This guide is to instruct the user in running the package which updates an OPAQUE file. This package consists of five programs: QUALITY, UPDATES, ABSTOL, CHANGES, and LIST, stored in a file called SHETTLE LIBRARY, with an I.D. of FLAHIVE. These programs can be run singly or in combination using the procedure EDIT stored in a file called OPAQUEPROCEDURE with an I.D. of FLAHIVE. A listing of the procedure can be found in Appendix A.

2. PRELIMINARY CONSIDERATIONS

Due to the amount of processing time required by the programs CHANGES and LIST, the INTERCOM command ETL 100 should be input before running this package.

The only file that has to be explicitly attached is OPAQUEPROCEDURE, I.D. = FLAHIVE. This file contains the procedure EDIT that takes care of attaching all the necessary files and entering the needed system commands. Five parameters are needed when using this procedure. The first two are the permanent file name and I.D. of the OPAQUE file to be edited, hereafter called TAPE1. The next two are the permanent file name and I.D. under which the edited OPAQUE file will be catalogued. Hereafter, this edited OPAQUE file shall be called TAPE2. The fifth parameter is the site at which the output produced by the editing run is to be printed. This output is in TAPE3. If many changes have been applied, or if a listing of the edited file is being produced, the output will be routed to the central site, due to its volume. Comments from the User Dayfile are randomly printed out during the running of this package. Unfortunately, this is an idiosyncrasy of the CDC computer and cannot be avoided. This doesn't interfere with the user's inputting answers to the various prompts.

Simple terminal output from a run is in Appendix B, with user inputs underlined. This can be used as a guide when running this package. If any problems are encountered while executing the programs, please contact Bedford Research Associates.

3. PROGRAMS

This section contains brief descriptions of the programs which comprise this package.

3.1 Quality

The user has the option of executing this program or not, depending on the response to the first prompt.

This program compares the values of the collected data to pre-determined tolerance levels and constructs words 79, 80, 82 and 83, based on the results of the comparisons.

If any of the values of words 35 through 39 fall ouside the range 0.1 to 0.795, a message is printed to the terminal and TAPE3 giving the hour and the data of this unphysically high value.

TAPE2 is over-written, using the new values for words 79, 80, 82 and 83.

3.2 Updates

This is the next program to be executed in the sequence. The user has the option of either running this program or not, depending on the response to the first prompt.

There are two types of updates performed by this program: either substituting a new value for a measurement, or changing an existing measurement through dividing by a factor. Checks are built in to ensure that the value of a word is between 1 and 85, the value of a day is between 1 and 31, and the value of an hour is between 0 and 23. If an illegitimate value is input for any of these three variables, an error message is printed and the values input during the current sequence are ignored. Control returns to the beginning of the input sequence, with a prompt for the word to be changed. These checks are useful if an incorrect value is input for one of these prompts. If this is discovered before the new value/correction is input, inputting an illegitimate value to a prompt will cancel the whole sequence. If the new value/correction factor has already been input before the error is detected, inputting a sequence with the corrected values might not correct the error, since the changes are sorted before being applied, so the order in which changes are applied is not necessarily the order in which they were input. Depending on how many changes have already been input, the program should either be aborted and the procedure EDIT restarted, taking care to return all attached files, or the program should be allowed to continue and the procedure EDIT re-run with the desired change input then.

First, the words to be changed should be entered. When all the words to be changed have been entered, the user should input a zero when prompted for the word to be changed. This will transfer control to the section which prompts for the words that are to have correction factors applied. When all the words to have correction factors applied have been input, a zero should again be inputted when the prompt appears for the word to which a correction factor should be applied. This will transfer control to the section which does the actual updating of the file.

A listing of all the changes which were applied as well as the time period of their application is written to TAPE3. TAPE2 is over-written with the changes.

3.3 Abstol

The user has the option of executing this program or not, depending on the response to the first prompt.

This program compares the values of all the OPAQUE measurements to an absolute tolerance of $\pm 10 \times 10^{20}$. If the value of any word falls outside this range, the corresponding digit of the "packed quality" word is changed to 1. TAPE2 is over-written with the changes.

3.4 Changes

This program is always run whenever EDIT is used.

This program compares the original OPAQUE file TAPE1 with the updated OPAQUE file TAPE2. Whenever a difference is found between corresponding words, the date, time, word that is different and the two values are written to TAPE3. When the comparison is complete, a list of the words that are different is printed at the terminal and also written to TAPE3. Neither OPAQUE file is changed by the running of this program.

3.5 List

The user has the option of executing this program or not, depending on the response to the first prompt.

This program prints a formatted listing of TAPE2. This listing is written to TAPE3.

PROGRESS BRIEF OF SOFTWARE PROJECT MASK

ABSTRACT

An interactive graphics system of software allows an engineer to design monolithic microwave integrated circuits (MMIC's) by specifying the MMIC topology in geometric form. It also encodes on physical tape the instructions for fabricating the mask.

1. INTRODUCTION

A system for the graphic design of MMIC's now exists on the cyber computer system at AFGL. The entire cycle of design, tape generation, and tape checking will be completed prior to expanding the system.

The structure library is sparse, but complete in the sense that all manipulations can be performed on a single layer structure (MICROS) and on a multi-level structure (SCHOTT). The command set is complete but extensible. Available operations on structures nearly satisfy the original specifications of the Initiator.

The generation of output describing MMIC's is complete, but needs enhancement. Caltech Intermediate Form (CIF) proves a useful tool for representing MMIC's. Conversion into CIF has provided insight into the quality of data structures chosen by the programmer.

A program provided by the Initiator produces blowback drawings to verify the tape encoding of Electromask command language. This program, however, is being rewritten in FORTRAN77 to handle general MMIC's.

2. LAYOUT DESIGN

This section discusses the design of MMIC's by specifying the mask geometry.

2.1 General Outline

Here are mentioned several features of the system. The user selects I.C. structures from the library and places them at X,Y locations on any mask level, of which there are fourteen. After such placement of a structure, the user may connect a series of structures to the first without giving X,Y locations for each. Structures may be oriented vertically, horizontally or at any angle. The user may edit the dimensions or location of a structure; interconnections are preserved. The user may also delete structures from the layout. A series of interconnected structures (one or more) is reproducible in one step. A previously created mask layout may be merged with the one currently displayed. A magnified view of any portion of the layout is brought up by redefining the graphic window.

2.2 Structures

A set of three subroutines implements each structure in the library. These subroutines are well-structured to facilitate additions to the library. One subroutine performs all manipulations of a structure such as scaling, moving, or creating. Another displays the structure using the Plot-10 graphics package. The third generates the CIF of that structure.

Structures in the layout are identified by a six-character mnemonic and a sequence number. Geometric nodes on each structure are defined and may be referenced as points of connection. Many structures occupy multiple mask levels. Some typical structures are the microstrip (MICROS), the Schottky diode (SCHOTT), and gallium arsenide field effect transistors (GASFET).

2.3 Commands

The system has a command line interpreter. As each line is entered by the user, specified actions are performed immediately. Several commands exist in the system, and it is easy to add to this set by writing the FORTRAN subroutines for each new task. The subroutine which parses command lines is set up to be expandable, allowing for more commands to be added. All commands are six-character mnemonics. Show below are some typical commands.

HELPME	puts the user into a menu of all help facilities.
HELPME XXX	would bring up help facility XXX.
ESCAPE	allows user to terminate the session.
EXPAND Xn	redefines the window onto the layout with a magnification factor of n, prompting the user for lower X,Y coordinate.
CIFGEN	generates Caltech Intermediate Form description of the layout, storing it in a local sequential file.
LISTEM	prints all structures in the layout on the screen, showing the internal representation.
DELETE	will delete a series of connected structures.
LAYERS	allows user to view any combination of individual mask levels.

2.4 Operations

Various operations interconnect structures or alter their sizes and locations in the layout. Operations consist of two-character mnemonics. An operation works directly on a structure in the layout. Structures are

identified by the name and sequence number in the command line. This is followed by the operation. For example,

SCHOTT #02 UP

moves schottky diode number two up, after prompting the user for the distance. Interconnections are maintained as any structure is moved or changed.

Following is a description of some common operations.

++ connects the preceding structure to the following.

— deletes the preceding structure.

RT moves the preceding structure and all those connected to the right.

SC allows scaling of an identified structure.

XY places a structure horizontally at an X,Y position.

3. CONVERSION TO TAPE

3.1 General Outline

The circuit is designed by the engineer who manipulates the layout displayed on the graphics screen. The internal representation of the mask translates to several media, to the screen, to Caltech Intermediate Form (CIF), and to Electromask command language. A user-issued command causes the system to generate a CIF description of the mask layout. It is this form which then converts to all other output descriptions such as Electromask.

The tape format, Emask command language, consists of X,Y and angular coordinates necessary to expose single rectangular areas on the mask. Depending on the size of an area, more than one exposure (flash) may be needed. Large structures are decomposed into smaller rectangles by the module which converts CIF to Emask. The output of this conversion is finally written onto magnetic tape via a batch job generated by the program.

3.2 Caltech Intermediate Form

The idea of CIF is to describe every mask feature as a geometric item in a readable text format. CIF is produced by the computer program. However, it is easy for the user to modify the CIF files as a symbolic layout language.

The syntax of CIF is well-defined (see references). The role of CIF in this project is also clear. All output forms such as Electromask or ion beam pattern generators are constructed from the CIF of the mask layout.

The system converts an internal representation of a mask directly to CIF. Then the CIF file is organized and sorted, so that mask making occurs in a sensible fashion. The order in which structures are flashed greatly affects the speed of fabrication.

3.3 Electromask

This command language is much more restrictive than CIF, but it is nonetheless complete. The emphasis is on controlling the machine rather than on describing the mask geometry. One is concerned with the aperture settings and location. To fabricate a mask efficiently, optimizations must be made in the CIF prior to converting CIF to Emask. Reticle travel time is one consideration taken when optimizing CIF.

Emask commands are written onto tape in 800-character blocks. This tape is read by the machine which constructs the mask. Before the tape is sent to the pattern generators, the contents are checked by reading the tape and drawing the intended mask layout.

3.4 Blowback Drawings

The system verifies the Electromask commands on tape by creating a hard drawing of the mask layout. The segment of FORTRAN77 code to achieve this is now in development.

4. PROGRAM STRUCTURE

The design approach for this system has been to produce modules with well-defined understandable interfaces. For the most part, a top-down method has been applied. However, starting with the FORTRAN encoding of ideas often produces more efficient code. Also, unanticipated problems reveal themselves earlier.

4.1 Data Structures

With FORTRAN77, a powerful set of programming constructs are available. This software system makes extensive use of strings, substrings, and direct-access files. The internal layout representation is stored in such a file. Most text to display on the graphics screen is stored in sequential disk files. Thereby, the amount of core memory required for execution is lessened.

4.2 Programming Notes

This section is devoted to explaining what to expect from this programmer's work. The system should be easy to use and provide assistance

to the user who is unfamiliar with the system. Code must be well-structured, readable, and capable of checking extensively for errors in user input. Each subroutine has block comments as well as on-line documentation.

5. NOTES

The computer system used for this project is quite suitable. Although the graphics hardware is outdated by fifteen years, the capabilities of the program do not warrant a greater sophistication. Provisions are made for possible updating to a color graphics system.

REFERENCES

1. Mead, Carver A., and L. Conway, Introduction to VLSI Systems. U.S.A.: Addison-Wesley Publishing Co., Inc., 1980.

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