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CLOSED-LOOP IONOGRAM PROCESSOR FOR THE ANALYSIS OF TOPSIDE SOUNDER IONOGRAM FILMS (FILMCLIP)

by

Lawrence Colin and K. L. Chan

Ames Research Center

and

R. Glen Madsen

Astrodata, Inc.

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16. Abstract

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Lawrence Colin and K. L. Chan
Ames Research Center

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R. Glen Madsen
Astrodata, Inc.
Anaheim, Calif., 92803

SUMMARY

An on-line, computer processing system for reducing topside ionograms to electron density profiles is described. This operational system permits the operator to utilize all available redundant information for data selection, comparison, correction, and verification. When discrepancies occur, reinterpretation and recomputation may be iterated until a self-consistent result is obtained. Examples of this closed-loop processing technique, essential for the analysis of ionograms collected at high altitudes, are shown. Development of a more sophisticated, accurate, and rapid system also is outlined.

INTRODUCTION

This paper summarizes the operational features of an on-line, computer processing system for the analysis of satellite-borne ionospheric sounder data. The primary purpose of the topside sounding experiment, and the raison d'être of FILMCLIP, is the accurate, reliable, and systematic determination of height profiles of electron density (ref. 1). Although the system is designed only for this particular application, the concept, involving human interaction with a computer for data selection, manipulation, correction, reinterpretation, verification, etc., is valid for other experimental data analyses; the hardware and software are general enough for many other man-machine applications.

Background

The swept-frequency radar sounder historically has been the principal instrument for investigating the variations of electron density in the earth's ionosphere. Ground-based (bottomside) sounders, in use for more than 40 years, are able to explore the D-, E-, and F-regions below the F-layer maximum. Satellite-borne (topside) sounders, in orbit since 1962, explore the topside ionosphere above the F-layer maximum up to the satellite height.

The experimental data obtained from sounders consist of recordings of virtual range of radar echoes h' as functions of frequency f. An entire record over some finite band of swept frequencies is called an ionogram. Consecutive ionograms are produced by periodically repeating the sweep cycle. The virtual range is one-half the round-trip delay time of the echo multiplied by the free-space velocity of light. The true range of penetration is less than the virtual range at all frequencies because the group velocity of propagation is reduced by the ionized medium through which it travels. The conversion of $h'(f)$ data to reliable and accurate electron density height profiles $N(h)$ is a nontrivial problem (refs. 2-9). The conversion for topside ionograms is the underlying topic of this paper.

The topside sounding program is a cooperative international venture, organized and coordinated by the ISIS (International Satellites for Ionospheric Studies) Working Group (ref. 1). To date, three satellites (Alouette I, Alouette II, and ISIS–1) have been launched into earth orbits with swept-frequency sounder experiments aboard.[1] The salient features of these sounders, all of which are still operating, are summarized in table 1 (ref. 10). One new topside sounder experiment, ISIS–B, will be launched in 1971. This and the existing topside sounders are similar in principle. Their individual characteristics differ (power, antenna size, sweep range, sweep rate, pulse repetition frequency) because they probe varied environments as a result of differences in satellite orbit and phases of the sunspot cycle. The discussion herein is pertinent to the analysis of sounder data obtained from all the scheduled Alouette and ISIS satellites.

Data Acquisition and Processing

The primary operational sounding mode may be described as follows: A given command and telemetry recording station, of which there are about 20 irregularly located around the globe, commands the sounder to turn on as the satellite enters the station coverage. The sounder transmitter emits a train of RF pulses wherein the frequencies increase continuously from pulse to pulse. During the interpulse periods, the sounder receiver records reflected echoes and background noise. The ionogram data are telemetered to the ground station where they are recorded on magnetic tape together with frequency calibration markers, a coded timing signal, and a reference frequency. A complete ionogram requires some 10 to 30 sec (table 1) to produce. This cycle is repeated as long as the satellite remains within the station coverage. Some 15 individual ionograms are recorded for Alouette I and between 10 and 60 for Alouette II and ISIS–1 for each station. The tape-recorded data are later transcribed to a standardized visual format and stored on 35-mm photographic film.

An excellent Alouette II ionogram film (annotated) is shown in figure 1. Range and frequency markers, reflection traces, resonances, and cutoff frequencies are identified. Universal time 1-sec markers (single dots) and 5-sec markers (double dots) produced during the filming are shown immediately below the ionogram. An identification (ID) code for the ionogram is shown below the time markers (see figure caption). The useful sounder data consist of reflection traces (extraordinary, ordinary, and Z-traces and their local cutoff values: fxS, fNS, fzS, fzI) and "resonances" (fNs, fT, fHS, 2fHS, . . .).

[1] Complementary experiments flown aboard these satellites (ref. 1) are not discussed here.

TABLE 1.– TOPSIDE SOUNDER ORBITAL AND SYSTEM PARAMETERS

	Alouette I	Alouette II	ISIS–1
Launch date	Sept. 29, 1962	Nov. 29, 1965	Jan. 30, 1969
Orbit period	105 min	121 min	128 min
Apogee	1031 km	2982 km	3522 km
Perigee	996 km	502 km	574 km
Inclination	80.5°	79.8°	88.4°
Velocity			
Apogee	7.36 km/sec (av)	6.02 km/sec	5.76 km/sec
Perigee		8.16 km/sec	8.21 km/sec
Antennas			
Crossed	75′	75′	61.5′
Dipoles	150′	240′	240′
Transmitter power	100 W	300 W	400 W
Pulse width	100 μsec	100 μsec	97.7 μsec
Pulse repetition frequency	62 pps	30, 60 pps*	30, 60 pps
Sweep time	11 sec	27 sec	16.6 sec (nor)** 26.6 sec (ext)***
Flyback time	7 sec	3.6 sec	4 sec
Time between ionograms	18 sec	30.6 sec	20.6 sec (nor) 30.6 sec (ext)
Sweep range	0.5–11.5 MHz	0.2–14.5 MHz	0.1–10 MHz (nor) 0.1–20 MHz (ext)
Sweep rate	1 MHz/sec	0.15 MHz/sec for f < 2 MHz 1 MHz/sec for f > 2 MHz	0.25 MHz/sec for 0.1–2 MHz 0.75 MHz/sec for 2–5 MHz 1 MHz/sec for 5–10 or 20 MHz

*In practice, usually 30 pps
**(nor) = normal
***(ext) = extended

Open-Loop Analysis

The extraordinary (X) and ordinary (O) trace data provide redundant information; that is, it is possible to compute the complete N(h) profile from either the X-trace or the O-trace. A truncated portion of the profile can also be calculated from the Z-trace (ref. 7). On topside ionograms in general and on Alouette I ionograms in particular, only the X-trace is "complete" and available for analysis. The standard open-loop (ref. 3) analysis approach (fig. 2(a)) is to: (1) project the film image on a suitable working surface; "calibrate" the vertical (virtual range) and horizontal (frequency) scales; "scale" the X-trace by selecting a small set (typically 15-30) of suitably spaced $h_X'(f)$ pairs, either by hand or with a digitizer; and (2) enter the scaled data via punched cards, digital magnetic tape, or perforated paper tape into a computer wherein the N(h) "profile" (a set of electron-density/true-height pairs corresponding to the scaled $h_X'(f)$ pairs) is computed. The theory and technique (refs. 2, 3) involved in this latter computation, as well as certain simplifying assumptions, have been throroughly developed and tested and are *not* the source of significant errors or ambiguities in the computed N(h) profiles.[2] The major error source arises from the inability to choose reliably and accurately (ref. 11) the scaled $h_X'(f)$ pairs that result from vertical propagation. The ionogram shown in figure 1 does not exhibit this difficulty inasmuch as the reflection traces are relatively thin and clearly identifiable. The large majority of ionograms is not in this category because of:

1. Discrete or overlapping reflection traces (for one or more modes) resulting from nonvertical propagation

2. "Spread" echoes resulting from overlapping reflections from electron density inhomogeneities

3. "Resonances" obscuring accurate reading of the reflection traces

4. Invisibility of significant portions of the X-trace (more often for the O- and Z-traces)

Thus, simple inspection of the X-trace (or any other single reflection trace) by itself does not always provide sufficient information for an unambiguous scaling.

Despite these limitations, the open-loop approach $[h_X'(f) \rightarrow N(h)]$ has been used widely and successfully for analyzing Alouette I data (refs. 12-16). Soon after the launch of Alouette II, it became apparent that the complexities listed above were even more important for high altitude (1500-3000 km) data than for the Alouette I (1000 km) data. In fact, the great majority of the high altitude Alouette II ionograms cannot be accurately processed with the open-loop approach. However, because of improved sounder design at low frequencies, Alouette II ionograms usually contain significant portions of all three reflection traces. Thus, the available redundant information may be used as a check on an N(h) profile computed from a single trace. Because of the implied sophistication of this suggestion, a quick reliable way to accomplish the redundancy check is highly desirable. New data handling methods (refs. 6, 17-20) are required.

[2]Errors resulting from satellite position determination or magnetic vector computation inaccuracies are also negligible. These data are computed from published orbit element data and ionogram ID data. In the conversion of h′(f) data to N(h) profiles, knowledge of the earth's magnetic field strength and dip angle along the propagation paths is required.

Clearly, an on-line, closed-loop, data processing system is necessary wherein the computed results are immediately and conveniently displayed to the data scaler, and correction, recomputation, etc., are accomplished quickly.

Closed-Loop Analysis

Conceptually, a simple closed-loop flow procedure might be configured as shown in figure 2(b) and proceed as follows:

1. The operator "scales" the visible portion of all vertical reflection traces $[h_X'(f), h_O'(f), h_Z'(f)]$.

2. The X-trace data $h_X'(f)$ are used to compute an electron-density profile N(h), as before. O- and Z-traces $[\overline{h_O'(f)}, \overline{h_Z'(f)}]$ are computed from the N(h) profile.

3. Scaled and computed O- and Z-trace data are compared by the operator on a suitable display. If these disagree, the X-trace data are modified, and a new N(h) profile and O- and Z-traces are recomputed. This process is repeated until the scaled and computed traces agree.

In principle, it is desirable to automate as much of the data processing task as possible. Our studies have shown, however, that the human operator is an indispensable part of the total data processing operation because of complexity of the data. A trained operator has a pattern-recognition capability that cannot be economically duplicated by a machine; thus, a carefully designed man/machine communication link is required.

The above approach and some innovations have been incorporated into the FILMCLIP system – a particular man/machine configuration, developed and operational since September 1968, which is being successfully used to produce N(h) profiles from high altitude Alouette II and ISIS–1 data. This system was assembled almost entirely with hardware already available at Ames Research Center.

SYSTEM DESCRIPTION

The FILMCLIP system (fig. 3) is a dual-computer configuration connected with a high-speed core-to-core link. The master computer (IBM 1800) performs all control functions for the system, while the slave computer (IBM 360/50) provides a periodic computational capability, for example, N(h), $\overline{h_O'(f)}$, $\overline{h_Z'(f)}$. In addition to the standard computer peripherals, the system includes a digitizer (Benson Lehner OSCAR–F film reader) and graphic display unit (IBM 2250).

A specially built analog-to-digital converter (ADC) provides a one-way interface from the digitizer to the master. Two manual rotary decimal switches, which are used to label virtual range markers, frequency markers, and resonances, also have inputs to the master through the ADC from the calibration switch box.

The graphic display unit (GDU), with character and vector generation capability, is used primarily to display scaled and computed data for operator comparison. It has a 8-K bytes buffer for automatic regeneration of displays. The configuration includes a light pen, an alphanumeric keyboard, and a programmed function keyboard (PFK), which are the operator's primary controls of FILMCLIP.

The IBM 1800 has a 32 K core, two 2310 disk drives, a card reader/punch, and a printer. The card reader and printer are used only for compiling and loading the 1800 software.

The IBM 360/50 has a 512 K core, six 2311 disk drives (to be replaced by a 2314), a card reader/ punch, two high-speed printers, and four tape drives. A printer is used for outputting results, and a magnetic tape is used for data storage.

The master-slave arrangement, although not necessary for the dedicated FILMCLIP system, is useful in the Ames computing environment; it frees the slave for other background jobs on a noninterfering basis because the slave is rarely called on by the master for its computational requirements. The system software was specially written to reflect this arrangement.

The major design problem was to adapt the 360 operating system to support a nonstandard peripheral (the 1800) in such a manner that data could be read from it, and written to it, using Fortran programs. On the 360 side, the interface consists of an initialization routine that recognizes an 1800 interrupt code requesting communication of a particular type, and an input/output routine to perform the data transfer. These routines were incorporated into the operating system using standard software interfaces to permit normal operating system activity.

The master (IBM 1800) software has three major components:

1. An executive program that continuously monitors the reading of all input data from the digitizer and rotary switches via the ADC and the handling of all interrupts from the GDU

2. A set of key programs (written in Fortran) that perform the various functions assigned to the PFKs on the GDU

3. A set of utility programs (most written in basic assembly language) that perform all the basic functions required by the system (i.e., plotting points, drawing vectors, adding messages and displays to the GDU)

The slave (IBM 360) software consists of standard ionogram reduction techniques and procedures (ref. 3), restructured to handle the iterative computations. The program structure consists of a root segment (permanent core resident) executive program and several overlays:

1. Programs to compute satellite position and magnetic field parameters based on the ionogram ID data entered as calibration data and on orbit parameters for the particular satellite

2. Overlays to compute N(h) profiles and magnetoionic trace points $(\overline{h'(f)})$ from scaled X-, O-, or Z-trace data; used repeatedly as the operator modifies the data readings

OPERATIONAL MODES

This section describes and illustrates a few ways in which the operator may interact with the FILMCLIP system. The operator controls the system from the digitizer and GDU (fig. 4).

The PFKs (fig. 5) provide the major control of the FILMCLIP system. The labels characteristically describe the use for which each key is designed. Each PFK has a light beneath it that is turned on and off by the master to indicate whether the PFK may be used legally. The first 11 keys are normally used in the order shown to obtain computed results of the operator's first interpretation. The remaining keys supplement these to accomplish the iterative computations, if necessary. This step-by-step procedure is illustrated in detail below.

Primary Mode, Simple Ionogram

This mode of operation is briefly outlined above, that is, $h_X'(f) \rightarrow N(h) \rightarrow \overline{h_O'(f)},\overline{h_Z'(f)}$. The "excellent" Alouette II ionogram shown in figure 1 is chosen for illustration. The corresponding GDU display of the scaled X, O, Z points is shown in figure 6. Table 2 lists the procedures leading to this figure. Note that iterations are not required between steps 11 and 12. In this case the scaled and computed h′(f) data (fig. 8) are in sufficient agreement that the computed N(h) profile is accepted for final output.

An important feature on the GDU is the scaling cursor character shown as a plus symbol (+) on the left center of figure 6. This cursor character indicates the relative position of the digitizer cross hairs with respect to the ionogram projected on the digitizer screen. This feature provides a two-way mapping between the GDU and the digitizer, and is the connecting link that closes the processing loop through the operator.

During calibration, enough frequency and range markers are read in that the system can make first-order corrections on any possible nonlinearity in the digitizer projector optics. The calibration program also performs coordinate rotation corrections to accommodate any misalinement between the coordinate axes of the projected ionogram and the digitizer.

The current position of the cursor character in a corrected coordinate system in engineering units is displayed at the bottom of the GDU. In figure 6, the coordinates of the cursor character are frequency (0.36 MHz) and virtual range (2298 km). H-count (0591) and V-count (2032) are the digitized values of the digitizer horizontal and vertical cross-hair positions. As the positions of the cross hairs are changed, all four alphanumeric displays on the GDU change accordingly.

Primary Mode, Complex Ionogram

Ionograms of the quality of figure 1 could indeed by processed by the open-loop method described above. However, for most ionograms, an example of which is shown in figure 9, it is not clear where one should scale within the spread X-trace. The O- and Z-traces are less spread, on the other hand, so that the iterative feature of FILMCLIP provides the basic capability for scaling and a self-consistent verification of the computed results.

TABLE 2.– OPERATIONAL PROCEDURE

PFK	System/Operator Response	GDU Display
1. START IONOGRAM	Preset system for analysis of new ionogram. If initial ionogram in pass, depress START PASS.	– – –
2. ENTER ID	Enter ionogram ID and a quality factor (QL = 11) via alphameric keyboard.	figure 6 – (A) (compare with fig. 1)
3. CALIBRATE TIME	Enter time calibration from second markers on film via DIGITIZER.	Displayed as two spots below ID but not visible in figure 6.
4. CALIBRATE FREQUENCY	Enter frequency calibration from frequency markers on film via DIGITIZER and Calibration Switch Box.	figure 6 – (B)
5. CALIBRATE RANGE	Enter virtual range calibration from range markers on film via DIGITIZER and Calibration Switch Box.	figure 6 – (C)
6. SCALE RESONANCES	Enter fzS, fN, fT via DIGITIZER and Calibration Switch Box.	figure 6 – (D)
7. COMPUTE	Display list of items to be computed (fig. 7). Then depress "1" via alphameric keyboard and ENTER PFK. Compute fxS by four methods: (1) $fxS = fzS + fHS$ (2) $fxS = \frac{fHS}{2} + \frac{1}{2}\sqrt{4fNS^2 + fHS^2}$ (3) $fxS = \frac{fHS}{2} + \frac{1}{2}\sqrt{4f_T^2 - 3fHS^2}$ (4) $fxS = \frac{fNS^2}{fzS}$	figure 6 – (E) Digits 1–4, shown overlapping in figure 6 – (E), are computed fxS by the four methods.
8. X DATA	Scale X-trace via DIGITIZER, starting with fxS results of step (7). Then depress ENTER PFK.	figure 6 – (F)
9. O DATA	Scale O-trace via DIGITIZER. Then depress ENTER PFK.	figure 6 – (G)
10. Z DATA	Scale Z-trace via DIGITIZER. Then depress ENTER PFK.	figure 6 – (H)
11. COMPUTE	Display list of items to be computed (fig. 7). Then enter "2" via alphameric keyboard and ENTER PFK to compute N(h) profile and inverse traces ($\overline{h_O'(f)}$, $\overline{h_Z'(f)}$).	figure 8 (A) $\overline{h_O'(f)}$ – shown as * (B) $\overline{h_Z'(f)}$ – shown as E
12. OUTPUT	Display list of quality factors. Then enter appropriate number via alphameric keyboard and ENTER PFK. Scaled and computed data written on tapes for storage and printout.	

The initial procedure for scaling this ionogram is identical to that described in table 2 (steps 1-11) for the simple ionogram. The resulting mapping from digitizer to GDU and the computed traces are shown in figure 10. Note that the fxS calculated by the four methods yields different results (1, 2 overlap; 3 and 4 straddle these). The operator chose to start the X-trace at the overlap position of 1 and 2. The results of the initial scaling are clearly inadequate as large differences exist between scaled and computed O- and Z-traces shown in figure 10. The operator must now decide whether (1) to rescale the X-trace, or (2) to rescale the O- and Z-traces to attempt a better fit. In this example, the operator decided to iterate on the X-trace as the X-trace is spread while the O- and Z-traces are well defined. The operator may (1) add new points to the initial set of scaled X-trace points, (2) delete some points from the initial set, (3) delete as well as add a few points, or (4) delete the initial set and rescale the X-trace completely. To add a new point, the operator positions the digitizer cross hairs and depresses the read-out button. To delete a scaled point, the delete/modify PFK is generally used in conjunction with the light pen or scaling cursor. When an entire set is to be discarded the wipeout PFK is simply depressed.

For the case shown in figure 10, the operator used the wipeout PFK, rescaled the X-trace and recomputed. The results are shown in figure 11. The rescaled X-trace data points are shown as "D" on the GDU. The newly computed traces closely agree with their scaled counterparts after one iteration. As a final check, the computed N(h) profile is displayed on the GDU by depressing the N(h) PFK (fig. 12). The O (old) points represent the computed profile based on the initial scaling and the N (new) points represent the latest profile based on the rescaling. The significant difference between the N(h) profiles demonstrates the accuracy improvement capability of FILMCLIP (one iteration) over open-loop processing (initial scaling).

Secondary Modes

The X-trace has generally been used for N(h) analysis of Alouette I ionograms. Although X-trace data have been primarily used for N(h) computation with Alouette II and ISIS–1 data, it is often desirable (because of the poor quality of the X-trace) to compute N(h) from scaled O-trace data or scaled Z-trace data alone. These features are incorporated into the FILMCLIP compute PFK repertoire (fig. 7). The secondary mode FILMCLIP procedure is almost identical to that described above, and only the final results of scaling the O-trace of figure 9 are illustrated in figures 13 and 14. An optional system feature is illustrated in figure 13. The scaled X- and Z-trace points have been replaced by smooth curves computed via the curve fit PFK, represented as splines (continuous piecewise cubics). The use of curves rather than points for comparison is often desirable. The computed X- and Z-trace data compare very favorably with their respective curves because the O-trace is less spread and can be more reliably scaled. The profiles computed from the X-trace scaling in the primary mode (fig. 12) and O-trace scaling in the secondary mode (fig. 14) agree satisfactorily. If scaled Z-trace data are used to start the computation, usually only a truncated N(h) profile near the satellite height is obtained.

Mixed Modes

The combined flexibility of the primary and secondary modes provides a method to mix "simultaneously" the scaled data from two or even all three traces on an ionogram to compute the N(h) profile. This technique allows the operator to select only the well-defined features of all the traces for N(h) computation. This application is extremely useful for ionograms having well-defined but fragmentary O-traces:

1. Scale fxS and the initial portion of the X-trace to compute a partial N(h) profile; compute fNS and the first part of the O-trace from the partial N(h) to cover the region of O-trace missing on the ionogram.

2. Repeat step (1), with the use of Z-trace data.

3. Scale the visible portion of the O-trace and compute the N(h) profile using scaled O-points and the computed points from steps (1) and/or (2).

FUTURE DEVELOPMENTS

The FILMCLIP system is an enormous improvement over the open-loop analysis procedure used earlier for Alouette I data. High altitude Alouette II and ISIS–1 data (and later ISIS–B), which cannot be processed by the open-loop method, are being routinely and reliably reduced to N(h) profiles by means of the primary and secondary modes described above.

Inasmuch as the FILMCLIP system was developed with limited funds and assembled with existing hardware available to the authors, it is an excellent system for improving the accuracy and reliability of topside ionogram processing. Its successful implementation clearly demonstrates the feasibility and desirability of intimate man/machine interaction in data processing. It was also clear from the outset of development that the FILMCLIP system does not represent the most efficient system in at least two areas, accuracy and speed (refs. 17, 18). The optimum processing accuracy is not achieved because (a) a significant amount of information, particularly echo amplitude, is lost on conversion of the sounder video from tape to film storage; and (b) the inherent accuracy of the digitizer is far below that of the computers and GDU. The optimum processing speed is not achieved because a great share of the operator's time is used for transcribing data from film to the GDU instead of being used for pattern recognition, data interpretation and verification. As a result, the volume of reduced N(h) profiles relative to the available topside ionograms, and relative to that scientifically desirable for analysis, is small.

Both accuracy and speed can be imporved by a newly designed system called TAPECLIP (closed-loop ionogram processor from magnetic tape). In this system the tape-recorded sounder data, instead of film data, are used as input; thus amplitude data would be readily available to the operator for use in trace identification and selection. This feature, and the elimination of the digitizer, would improve accuracy in data interpretation. The processes of calibration and A/D conversion would be performed automatically by electronics instead of by the operator, thus eliminating entirely the time-consuming task of transcribing information. It is estimated that the processing speed should be increased by a factor of 5 to 10.

The TAPECLIP system has been completely designed (ref. 21), and will be developed in the near future. Figure 15 is a block diagram of the combined FILMCLIP and TAPECLIP systems. The FILMCLIP system has been used as a successful test bed for several advanced processing modes to be incorporated in the TAPECLIP system. It is hoped that when fully implemented to include all the desired modes of operation, the TAPECLIP system could process most of the simple ionograms automatically without operator interference. On more complex ionograms the operator should interface with the system for pattern recognition, data interpretation and verification.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., 94035, July 28, 1970

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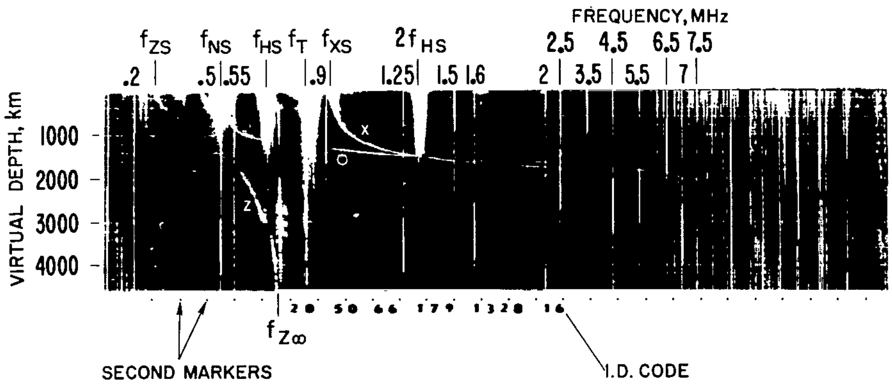

Figure 1.— An annotated Alouette II ionogram. The ID code identifies the ionogram: (20) Alouette II; (50) station, ULASKA; (66) year 1966; (179) the 179th day of the year or June 27; (132816) the UT of the second marker immediately preceding the code (13 hr, 28 min, 16 sec).

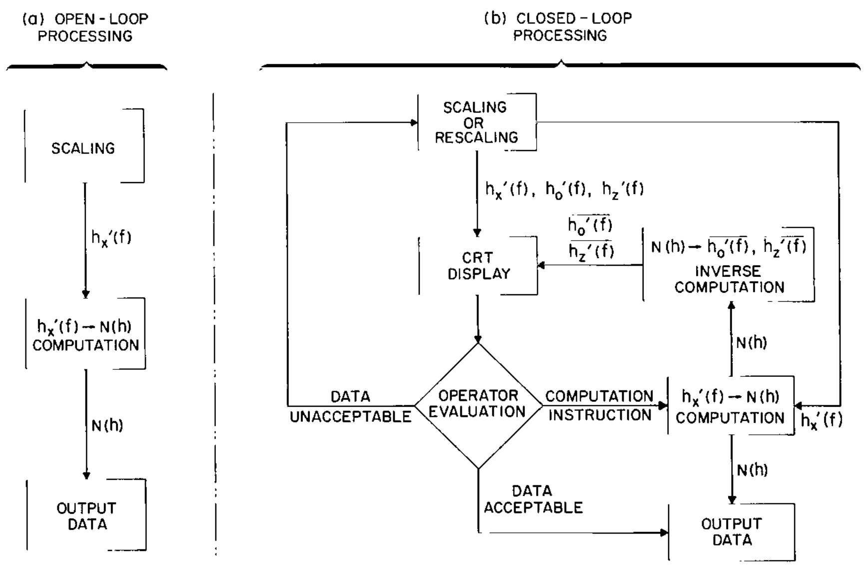

Figure 2.— Schematic representations of the (a) open-loop and (b) closed-loop iterative processing modes of computing N(h) profiles.

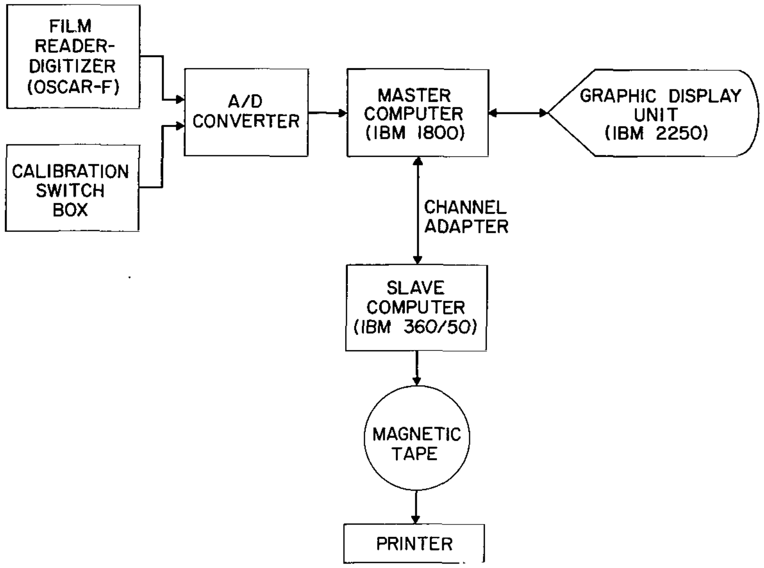

Figure 3.— FILMCLIP block diagram.

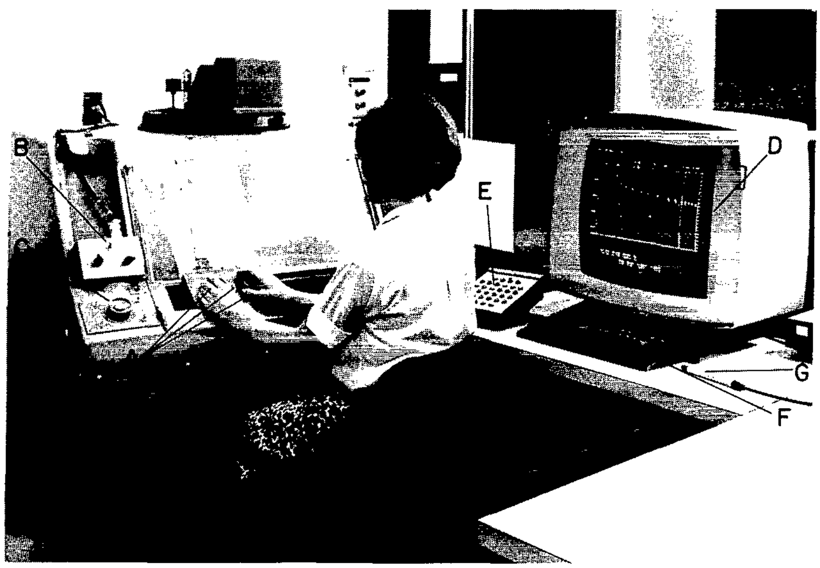

Figure 4.— Operator scaling ionogram on DIGITIZER (left) with GDU display of "mapped" ionogram (right). (a) DIGITIZER cross-hair positioning knobs and digital read-out button, with which the ionogram traces are scaled; (b) calibration switch box to label frequency and range markers during input of calibration data and resonances; (c) film advance, to advance or retreat the 35-mm ionogram film at fast or slow speeds; (d) GDU on which input and output data and command options are displayed; (e) PFK with which the operator signals the next function to be performed; (f) alphanumeric keyboard with which the operator may enter alphanumeric information such as the ionogram ID information; (g) light pen with which the operator may indicate points on the GDU that are to be deleted both from storage and from the GDU during a correction phase of operation.

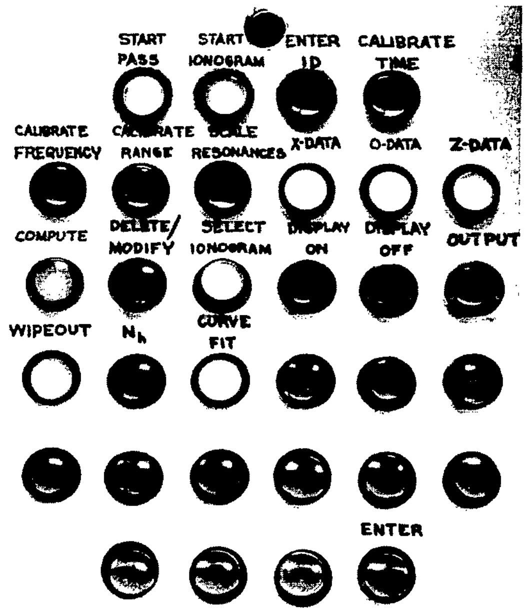

Figure 5.— Closeup view of PFKs.

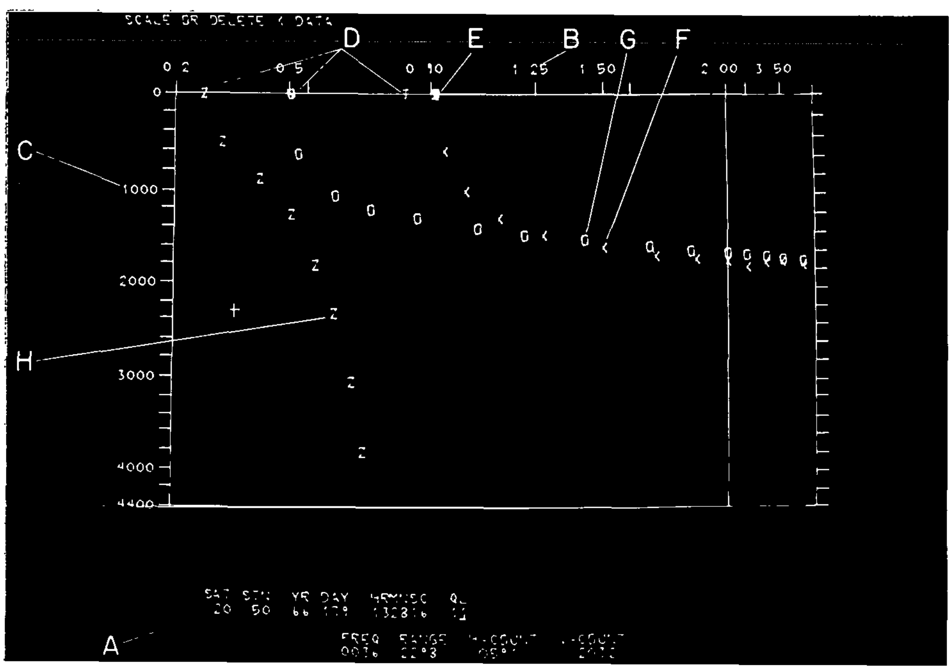

Figure 6.— GDU display of scaled resonances and scaled X, O, Z points for ionogram in figure 1; labels are explained in table 2.

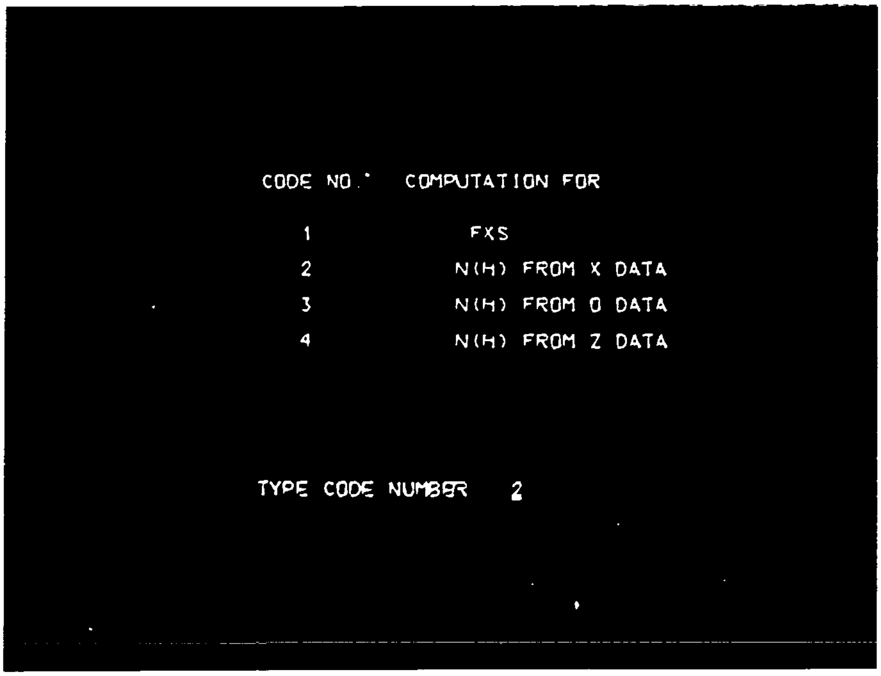

Figure 7.– GDU display of COMPUTE list.

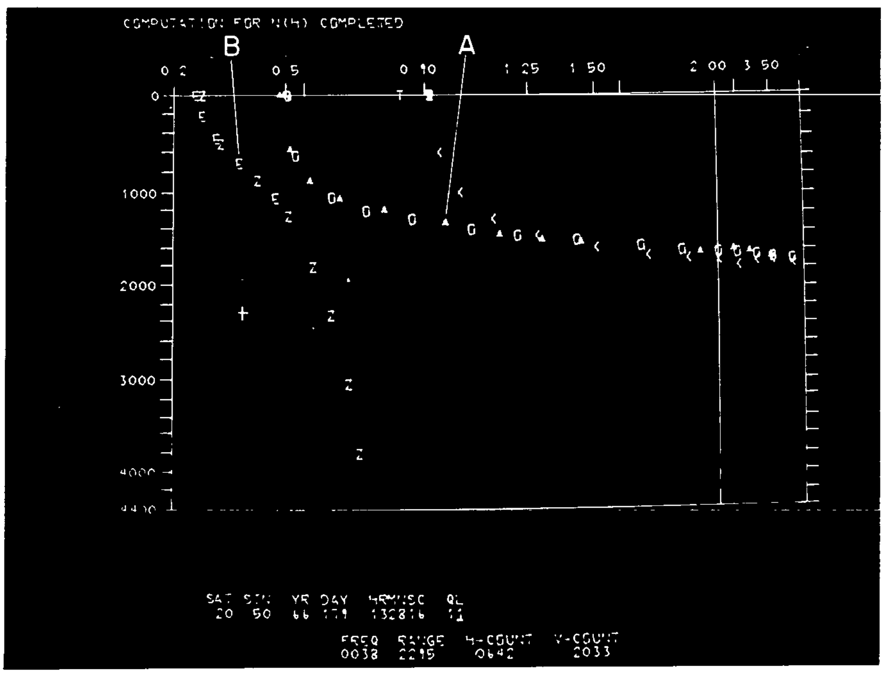

Figure 8.– GDU comparison of scaled X, O, Z points and computed O (shown as *) and Z (shown as E) points for ionogram in figure 1.

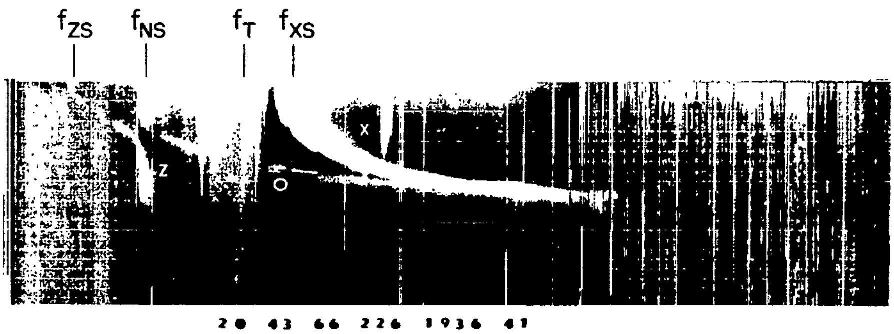

Figure 9.— An Alouette II ionogram-(20 43 66 226 193641)-showing spread X-trace with relatively thin O-, Z-traces.

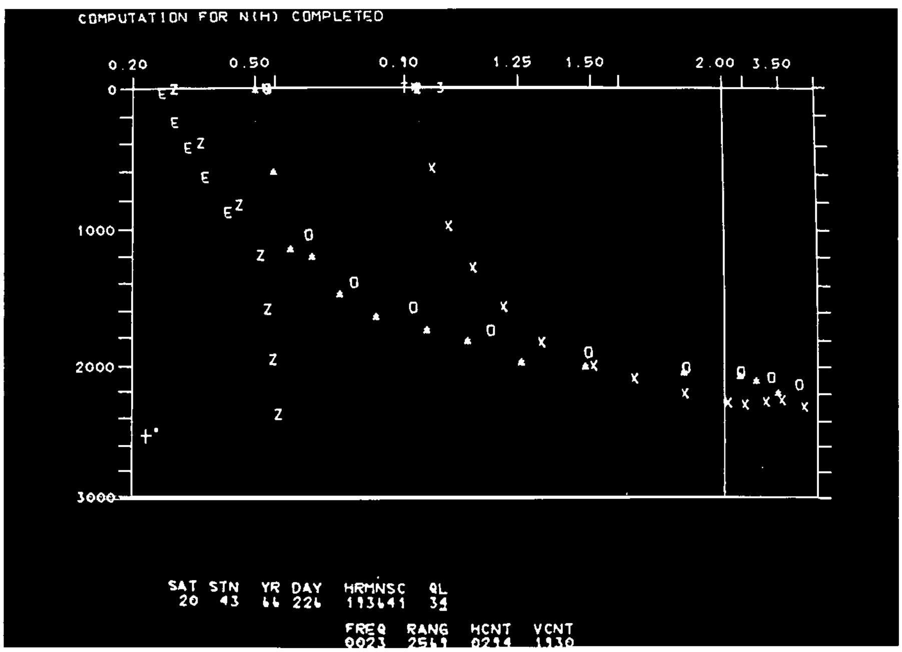

Figure 10.— GDU comparison of the scaled X, O, Z points and the computed O (shown as *) and Z (shown as E) points for ionogram in figure 9.

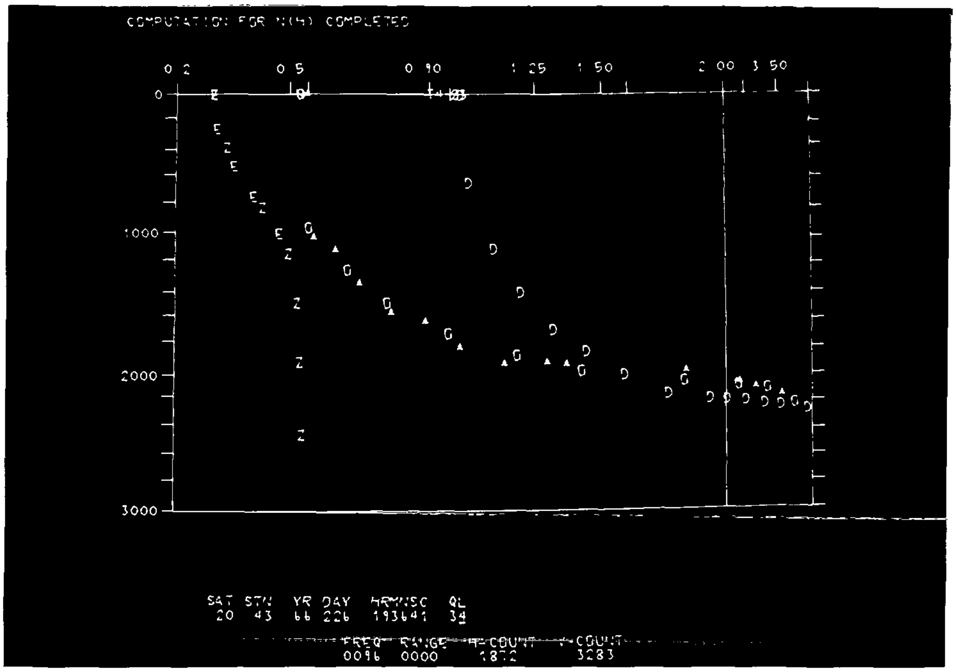

Figure 11.– GDU display of rescaled X points (shown as D), initially scaled O, Z, points and recomputed O (shown as *) and Z (shown as E) points for ionogram in figure 9.

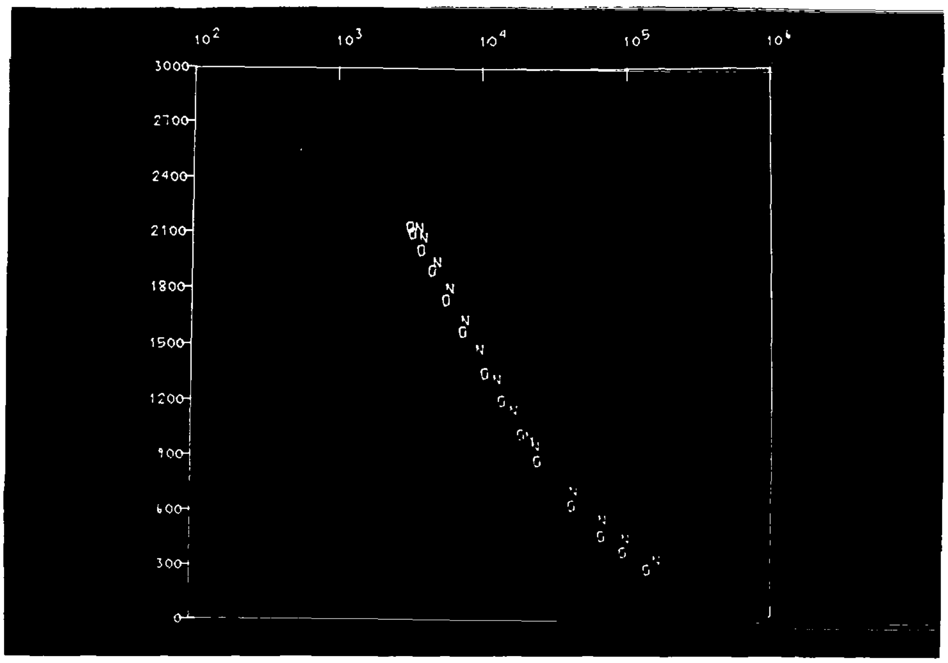

Figure 12.– GDU comparison of computed N(h) profile for ionogram of figure 9. The O (old) points are the computed profile using the initially scaled X-trace data (fig. 10), and the N (new) points are the computed profile for the rescaled X-trace data (fig. 11).

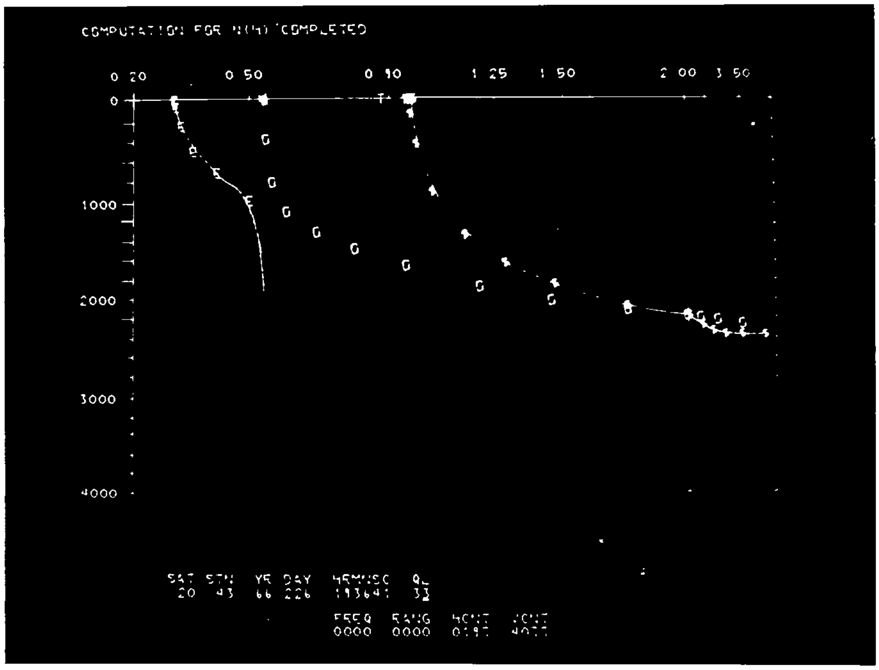

Figure 13.– GDU display of scaled X, O, Z points and computed X (shown as *) and Z (shown as E) points for ionogram in figure 9. In this case, a secondary processing mode was used $(h_O'(f) \rightarrow N(h) \rightarrow \overline{h_X'(f)}, \overline{h_Z'(f)})$.

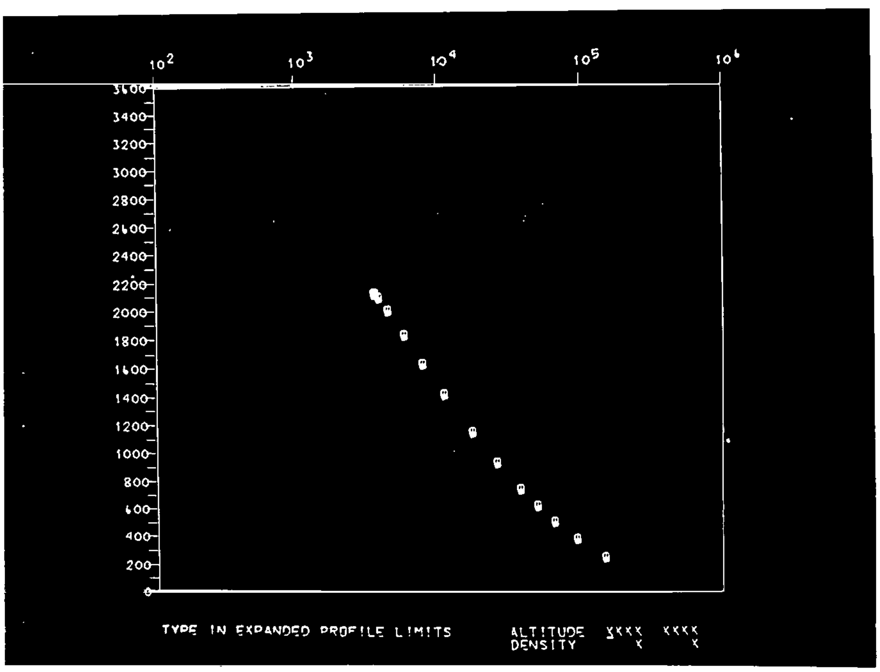

Figure 14.– GDU display of N(h) profile for the data shown in figure 13.

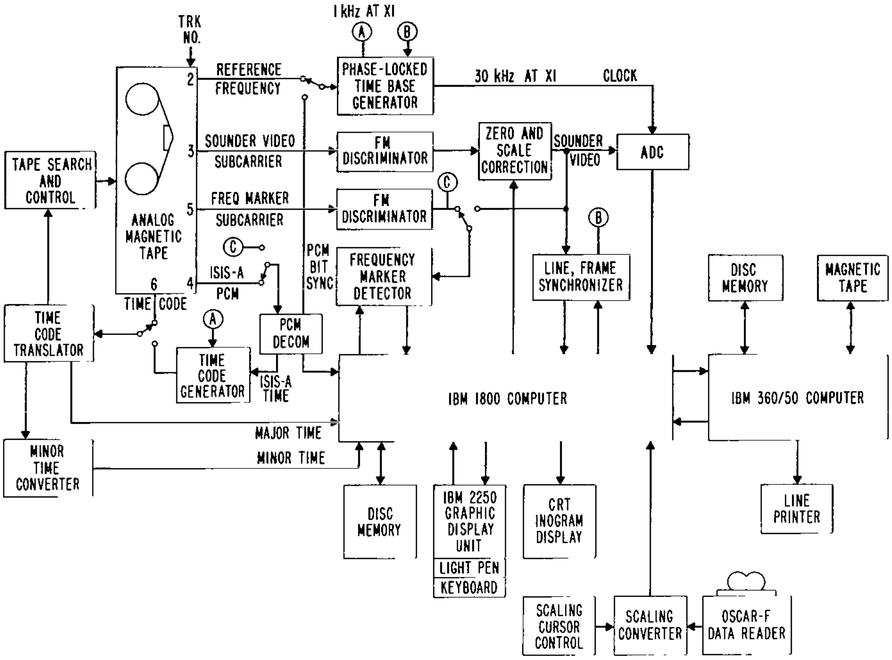

Figure 15.– Combined TAPECLIP and FILMCLIP system block diagram.

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