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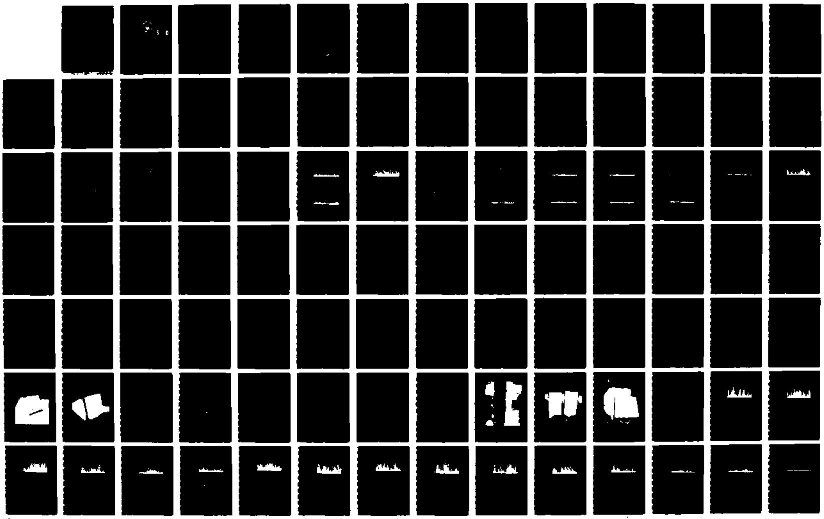

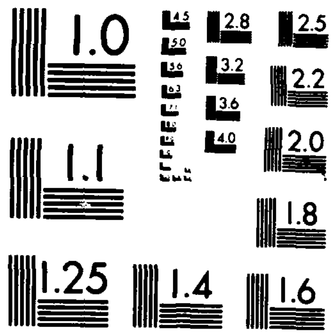

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Monterey, California

THESIS

DEVELOPMENT OF A DATA ANALYSIS SYSTEM
FOR THE DETECTION OF
LOWER LEVEL ATMOSPHERIC TURBULENCE
WITH AN ACOUSTIC SOUNDER

by

Michael Raymond Wroblewski

June 1987

Thesis Advisor: D. L. Walters

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During this thesis research, a high frequency acoustic sounder was developed to analyze this turbulent layer. The

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Development of a Data Analysis System for the Detection of Lower Level Atmospheric Turbulence with an Acoustic Sounder

by

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Lieutenant, United States Coast Guard
B.S., United States Coast Guard Academy, 1980

Submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

Atmospheric density fluctuations induce phase perturbations that degrade the spatial coherence of a laser beam propagating through the atmosphere. These degradations spread the laser beam and alter the centroid and intensity profile stochastically. Turbulent conditions are found at virtually all levels of the atmosphere. A substantial fraction of the optical turbulence along a vertical path arises from the heat flux between the atmosphere and the Earth's surface. This type of turbulence is typically within the first 100 to 200 meters above the surface.

During this thesis research, a high frequency acoustic sounder was developed to analyze this turbulent layer. The primary focus was the development of the command and control software required to coordinate the data collection and reduction. The system was used at two sites and should prove useful in quantifying the effects of optical turbulence within the surface boundary layer on laser and optical system performance.

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ACKNOWLEDGEMENTS

I express my gratitude to all who have made my graduation from the Naval Postgraduate School a reality. First and foremost I would like to thank my wife, Beth. Without her support and love I doubt I ever would have been able to accomplish this task.

I would also like to say "Thanks" to Professor Donald Walters who gave of his time and knowledge. He supplied us with the tools and motivation (As he always said: "Well, if you want to graduate ...") to complete the job.

Finally, to my friend, colleague, and partner on this project, LT. Frank Weingartner, I wish the best of the future to him and his fiancee' Karen.

I. INTRODUCTION

A coherent laser beam propagating through the atmosphere is very susceptible to numerous turbulence inflicted degradations. As electromagnetic waves transit the turbulent regions, atmospheric irregularities randomize the amplitude and phase of the wave. In order to quantify the altitude dependence of the atmospheric turbulence, a high resolution turbulence profiler is needed. Acoustic echosounders are frequently used to detect and measure atmospheric density and velocity irregularities resulting from air currents, temperature inversions, humidity variations, mechanical turbulence and other density fluctuations.

Presently two atmospheric optical parameters, the spatial coherence length (r_0) and the isoplanatic angle (θ_0) are measures of the perturbation of an electromagnetic wave propagating through the atmosphere, and are accurately measured by optical systems developed by Walters [Refs. 1 and 2]. Although these systems measure a path integral of atmospheric turbulence with high accuracy, a major drawback of each system is that no provision is available for determining the height of the atmospheric disruptions. If these disturbances are found to exist very near the surface, it may be possible to negate their effect by elevating the optical systems or controlling the generation of turbulence.

This thesis deals with the design, construction and implementation of a high frequency, acoustic echosounder which will accurately analyze the atmospheric density fluctuations within approximately 200 meters of the surface. As this project is a product of the research and efforts of two students, the work was appropriately divided. My particular task was to devise a computer program which would control all aspects of the echosounder operation. Areas of particular interest were the integration of hardware and software within the data acquistion system, developing plotting algorithms, controlling the system timing, and setting the input parameters which determine the range and sensitivity of the device. My colleage, LT. Weingartner [Ref. 3], dedicated his efforts toward the actual design and hardware development of the echosounder.

Acoustic echosounders have been developed and in use for many years and have proven to be valuable probes for analyzing the structure and dynamics of the lower atmosphere [Refs. 4 through 7]. Devices similar to ours have been used to obtain profiles of the atmospheric density and temperature fluctuations [Refs. 8 and 9]. Our device used a high speed HP217 computer to control and monitor the echosounder which provided real time information. Additionally, we had the ability to store and reproduce the atmospheric profile plots at will. This information was crucial in analyzing the atmospheric turbulence degradations on laser and electro-optical system's performance.

This document shall address the theoretical background of acoustic sounder operation in Chapter II. Chapter III shall present a synopsis of the system design and associated software. A summary of actual data collected at two sites is analyzed in Chapter IV and Chapter V discusses the conclusions and recommendations found as a result of our research.

II. BACKGROUND

Acoustic echosounders probe the atmosphere by transmitting a pulse of acoustic power which is subsequently scattered back from the atmosphere by temperature and velocity inhomogeneities. The echosounder (echosonde) equation, often referred to as the radar equation in meteorology, is used to determine the backscattered acoustic power. This equation is summarized by Neff in Reference 10 and is based upon the work of Tatarski [Ref. 11] and Little [Ref. 5].

$$P_R = E_R [\ P_T E_T\ ][\ \exp(-2\alpha R)\ ][\ \sigma_0(R,f)\ ][\ \tfrac{1}{2} c\tau\ ][\ AGR^{-2}\ ]$$

where

P_R is the electrical power returned from a range R,

P_T is the electrical power transmitted at frequency f,

E_R is the efficiency of conversion from acoustic power to electrical power by the transducer,

E_T is the efficiency of conversion from electrical power to acoustic power by the transducer,

$\exp(-2\alpha R)$ is the round trip power loss due to attenuation where α is the average attenuation (meters^{-1}) to the scattering volume at the range R (meters),

$\sigma_0(R,f)$ is the scattering cross section per unit volume at a distance R and frequency f,

c is the local speed of sound (meters/second),

τ is the pulse length (seconds),

A is the aperture area of the antenna ($meters^2$),

R is the range (meters), and

G is the effective-aperture factor of the antenna.

Empirically measuring or calculating the values for all other terms, one can use this equation to determine $\sigma_0(R,f)$, the scattering cross section per unit volume; that is, the fraction of incident power backscattered per unit distance into a unit solid angle at a frequency f. Based upon experimental results, Tatarski [Ref. 11] expresses the acoustic backscatter cross section per unit volume, $\sigma_0(R,f)$, in the equation,

$$\sigma_0(R,f) = 0.0039\ k^{1/3}\ \frac{C_T^2}{T_0^2},$$

where

$k = 2\pi/\lambda$ is the incident acoustic wavenumber at wavelength λ,

T_0 is the local mean temperature in degrees Kelvin, and

C_T^2 is the temperature structure parameter.

Combining this equation with the echosonde equation, one obtains a volume-averaged measure of C_T^2.

$$C_T^2 = \frac{1}{0.0039} \frac{1}{E_R E_T} T_0^2 k^{-1/3} \frac{2}{c\tau} \frac{1}{AG} \frac{P_R}{P_T} R^2 \exp(2\alpha R)$$

Hall and Wescott [Ref. 12] calculated a beam-shape compensation factor of 0.40 for a piston source antenna with a uniformly illuminated square aperture. This value is the same as the effective-aperture factor, G, and can be substituted into the above equation. Approximating the aperture area of the antenna to be equivalent to 25 times the aperture area of a single speaker having a diameter of 7.620 centimeters, we get a value of 0.1140 square meters. Combining these values with the numerical constants in the above equation, we can simplify the equation for C_T^2.

$$C_T^2 = 11245 \frac{1}{E_R E_T} T_0^2 k^{-1/3} \frac{1}{c\tau} \frac{P_R}{P_T} R^2 \exp(2\alpha R)$$

The acousto-electrical efficiency factors for our echosounder were measured with a calibrated microphone and an anechoic chamber. The calculated values for E_R and E_T are each 0.5. Substituting these values into the above equation, we can further simplify the equation for C_T^2.

$$C_T^2 = 44980 k^{-1/3} \frac{T_0^2}{c\tau} \frac{P_R}{P_T} R^2 \exp(2\alpha R)$$

The above equation was incorporated into the computer program that provides the system control, data acquistion and data processing techniques [Appendix A]. The reduced data was then used to measure the temperature structure parameter as a function of time of day and altitude for various sites.

III. SYSTEM DESIGN AND EQUIPMENT DEVELOPMENT

A. HARDWARE

Most of the hardware used in this system was standard scientific equipment and is illustrated in Figure 1. The

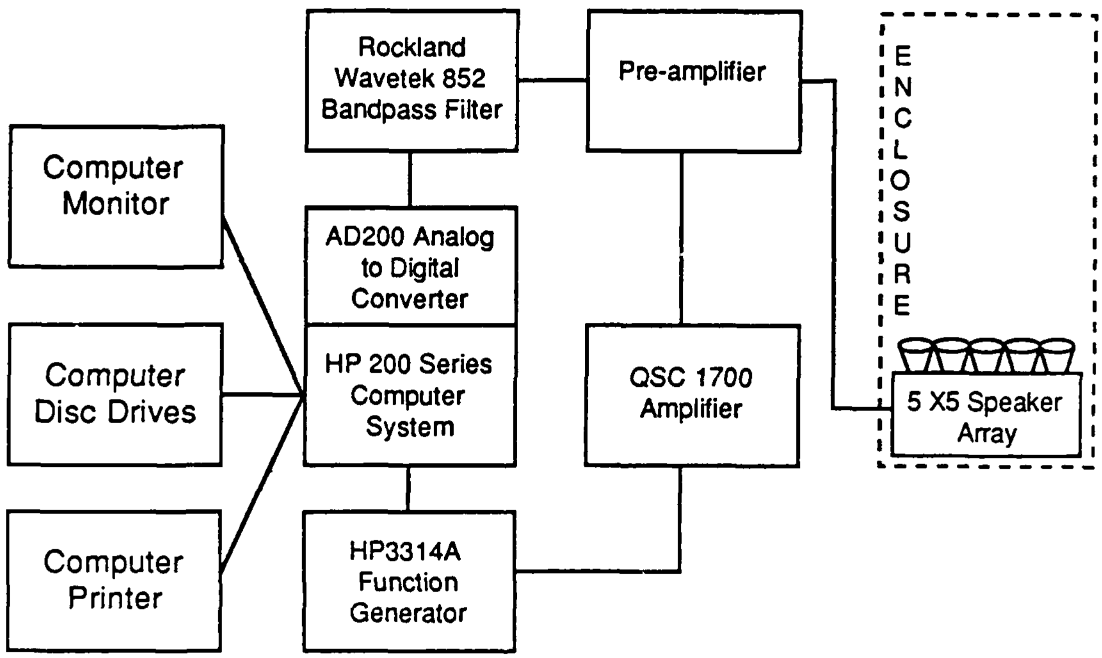


Fig. 1. Echosounder Equipment Arrangement

pieces which were specially designed by LT Weingartner [Ref. 3] are the acoustic array and the enclosure for this array. The design considerations for the speakers and the array format are given in Appendix B and the design of the enclosure to house this array is outlined in Appendix C. Aside from these two pieces of equipment, there are primarily six other components which comprise this echosounder. Below is a brief description of each of these additional components.

1. HP200 Series Computer

The Hewlett-Packard (HP) 200 Series Computer includes a 20 megabyte hard disk drive, a floppy disk drive and an associated printer and monitor. The HP200 Series Computer was the central control component for the entire echosounder arrangement. The computer used was an HP217 programmed in Basic 3.0 and equipped with an Infotek BC203 Basic Compiler and an Infotek FP210 Floating Point Accelerator to enhance the speed of program execution. The program defined all parameters for the HP3314A Function Generator as well as execute the trigger command which produced the echosounder transmitted acoustic pulse. The computer also received the data from the acoustic array via the pre-amplifier, bandpass filter and analog to digital converter. The computer then conducted the data reduction routines to produce and display a high resolution atmospheric profile.

2. HP3314A Function Generator

The Hewlett-Packard (HP) 3314A Function Generator was a multimode function generator capable of providing sine, square and triangular wave functions as well as any desired waveform ranging in frequency from 0.001 Hertz to 19.999 Megahertz. The HP3314A Function Generator was used to supply a pulse of an integer number (usually 100) of sinusoidal cycles of constant amplitude to the QSC Model 1700 Audio Amplifier. A constant frequency setting of 5000 Hertz was used for all data runs.

3. QSC Model 1700 Audio Amplifier

The QSC Model 1700 Audio Amplifier is a high power amplifier which can supply 350 watts over an 8 ohm load. This amplifier was used to boost the output voltage of the function generator by a factor of 20 from 1.5 volts to 30 volts. The power supplied to each speaker in the array during operation was then 37.5 watts.

4. Pre-amplifier

The pre-amplifier was designed and constructed by Walters [Ref. 13] to supply a gain of 1000 to the returned signal and isolate the data acquistion components from the transmitted pulse. The pre-amplifier may be thought of as a safety and switching mechanism for the system. An LT 1037 and an LT 1007 Operational Amplifier were selected for use in the pre-amplifier based upon their low noise properties which were evaluated by physically incorporating them into the device and measuring their noise and gain characteristics with an HP3561 Spectrum Analyzer. The diodes used are IN 4000 Series Rectifiers capable of carrying one ampere. These rectifiers serve to isolate the power amplifier from the amplifier input stage and to limit the voltage applied to the operational amplifiers. The electrical diagram of this device is outlined Figure 2.

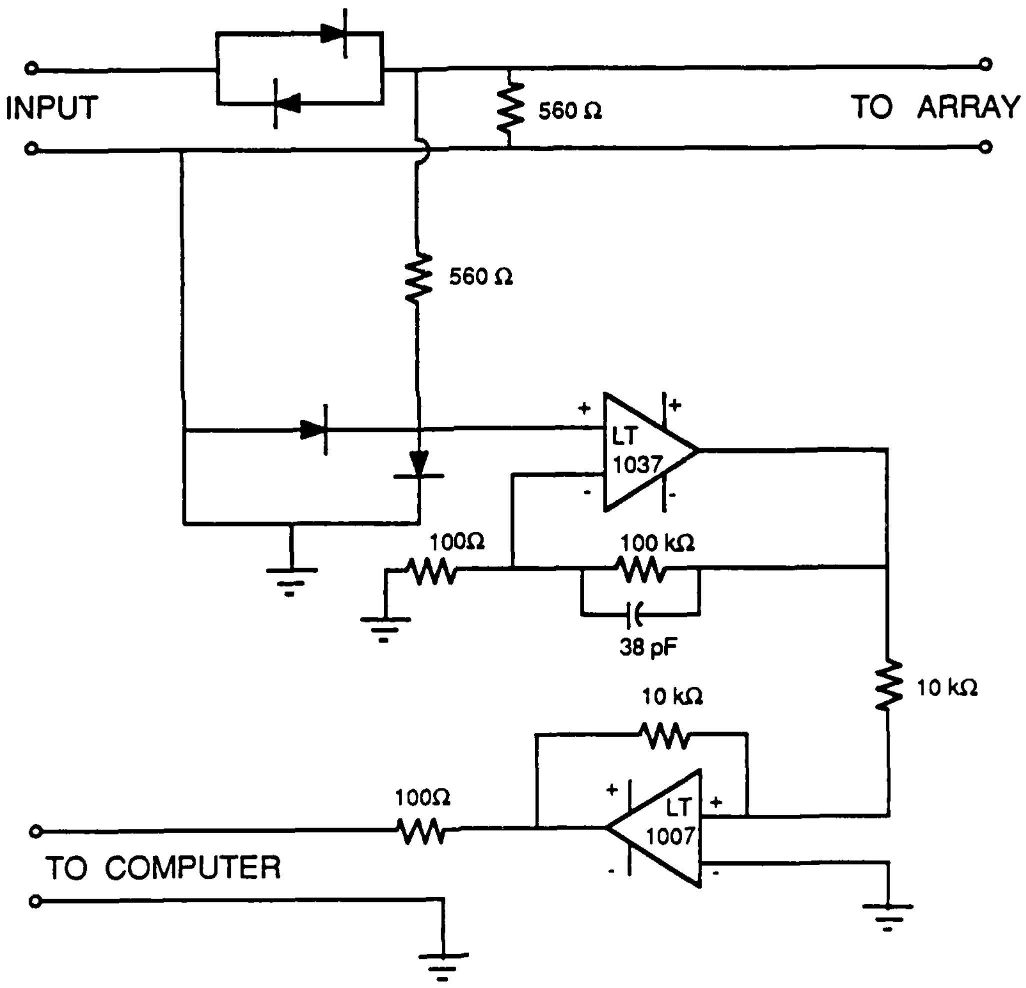


Fig. 2. Schematic of Pre-amplifier

5. <u>Rockland Wavetek Model 852 Filter</u>

The Rockland Wavetek Model 852 Filter operated as a 48 db per octave bandpass filter to suppress the broadband noise of the system. High and low bandpass settings of 5500 Hertz and 4500 Hertz respectively were used. The filter response at these settings is illustrated in Figure 3.

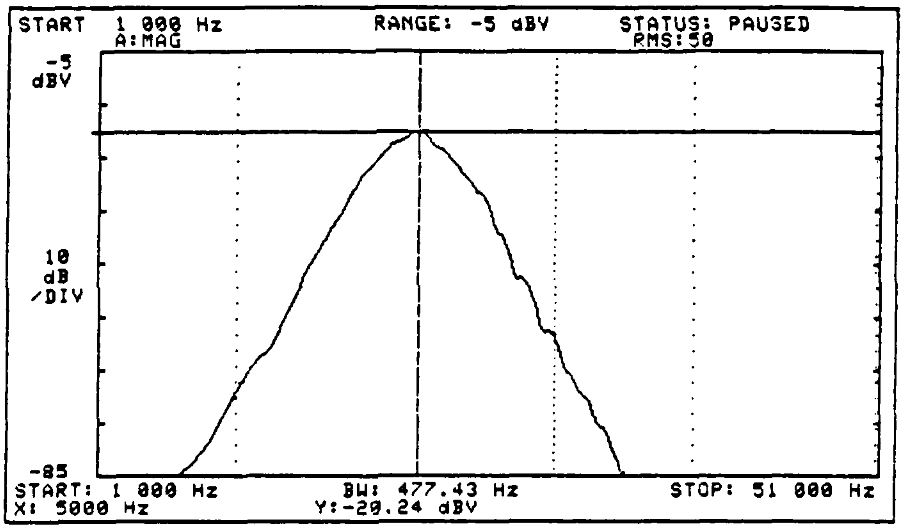


Fig. 3. Bandpass Filter Response

The three db (half power) bandwidth is approximately 1 KHz wide. Although it would be desirable to reduce the bandpass to between 50 and 100 Hertz without impairing signal response, the Rockland Wavetek Model 852 Filter was the best filter available. It performed adequately in spite of the large 1KHz bandwidth.

6. Infotek AD200 Analog to Digital Converter

An Infotek AD200 12 bit Analog to Digital Converter was used to digitize the signal voltage for the computer system at a 12.5 to 20 KHz sample rate.

B. SOFTWARE

The software and HP200 Series Computer system were responsible for controlling and monitoring every operational phase of the hardware components. The program which accomplished this task was entitled "ACRDR" and is listed in Appendix A. This program was modeled after a program written by Walters [Ref. 13] but each program performs a distinctly different computational task. This program was written in HP Basic 3.0 and was compiled by an Infotek BC203 Basic Compiler to enhance the speed of execution.

The program "ACRDR" is easily broken down into a number of blocks and subroutines which performed specific operations. These sections are outlined in a flowchart (Fig. 4). Each block is straightforward in its purpose. and the program is designed to be as helpful to the user as possible. As a prologue to the actual program code, there is a listing of all the program variables with a short description of their use. Such a listing familiarizes a user with the computations to be made and also provides quick references for any future modifications to be implemented.

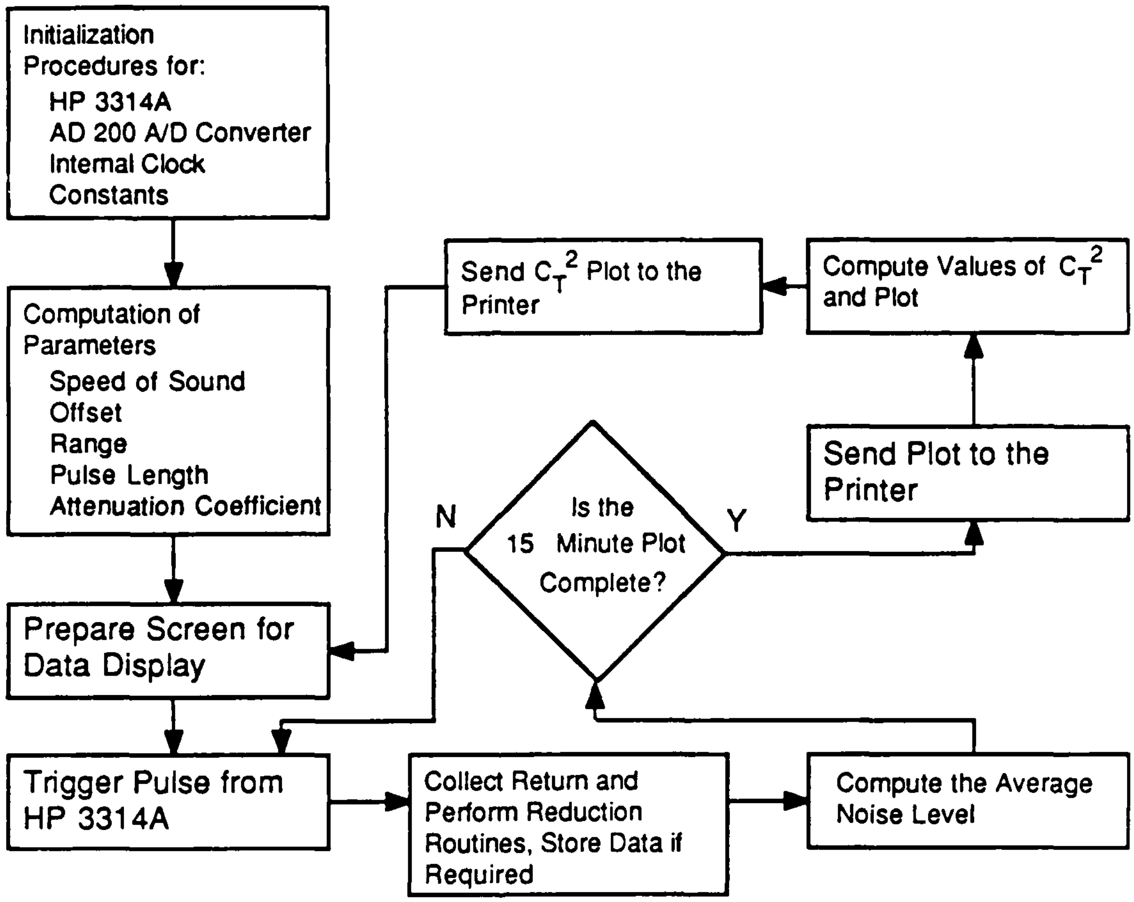


Fig. 4. Flowchart of Fundamental Program Operations

The initialization procedures which set all the parameters necessary for data collection follow the variable definition section. These parameters control such things as the contrast between background and return signal and the setting of the computer's internal clock. All options of the HP3314A Function Generator are decided by the user at this phase. Another initialization involves preparing the Infotek AD200 Analog to Digital Converter for operation. Finally, internal arrays are dimensioned, integer variables are defined and the computer function keys are redefined to suit the "ACRDR" program.

Now that the system is ready to operate, certain quantities must be determined based upon atmospheric conditions at the time of data collection. From the ambient temperature, a speed of sound in air is determined by the equation in Kinsler, et al, [Ref. 14: p. 106]

$$C = C_o \left[1 + (T/273) \right]^{1/2},$$

where

C is the local speed of sound,

C_o is the speed of sound in air at 0° Celsius (331.6 m/s), and

T is the local temperature in degrees Celsius.

Using this speed with a user decided sampling frequency and number of data points, the maximum range of the traces is determined by the relation,

$$\text{RANGE} = C/2 \cdot 1/(\text{SAMPLE FREQUENCY}) \cdot N \,,$$

where

RANGE is the range of the echosounder in meters,

SAMPLE FREQUENCY is the user desired rate of data acquisition, and

N is the number of data points per trace.

Typically, the values of many of the parameters are not varied. The value of N above is almost always taken to be the allowed maximum of 16301 data points and the speed of sound can be -afely estimated to be 340 m/s at room temperature. By using a typical sample frequency of 20000 Hz, a range of approximately 135 meters is obtained.

Another parameter determined is the atmospheric attenuation coefficient. This calculation is done in a subroutine obtained from Reference 15 and is necessary in this program for the calculation of $C_T{}^2$. Other computations made prior to program execution include the pulse length, wavenumber, and the D-C offset of the equipment.

At this point, the computer is finally ready for data collection. The screen setup displays a distance versus time plot and the internal clock of the computer is synchronized with the pulse from the HP3314A Function Generator. Following transmission of the pulse, the return signal is received, digitized, stored in an array and data reduction commences. A block averaging technique is used in which a block of data points the size of the number of emitted cycles is summed and averaged. Returns are plotted as darkened areas on the echosounder traces with the intensity of the darkened area linearly related to the magnitude of the return signal. This same procedure is used in the computation of $C_T{}^2$ with some very important differences. Aside from simply correcting for πr^2 spherical divergence, $C_T{}^2$ is corrected for electronic gain, the ratio of power returned to power transmitted, the efficiency of the speakers as transmitters and receivers, the area of the speaker array, the atmospheric attenuation, the pulse length, the temperature, the scattering cross section per unit volume at a specific range and frequency and finally the effective aperture factor of the antenna. Additionally, $C_T{}^2$(Range) is averaged for a particular altitude over 15 minute intervals. Finally, after each pulse is reduced, a corresponding mean square noise level is determined. This is done by averaging each block average at maximum range until at least ten values have been used in the average. An upper limit of five over the average noise figure (this corresponds to voltage fluctuations on the order of 10^{-7} volts) is set on the routine to avoid averaging any strong return signals or anomalies such as passing aircraft. After the ten values are averaged, every subsequent pulse is averaged into all the preceding noise levels and removed from each subsequent return signal.

Ultimately, after each 15 minute interval, or at the users request, the display terminal image is printed. At this time the $C_T{}^2$ computations are conducted and plotted on the screen and printer as range versus $\log_{10}$ of $C_T{}^2$. Upon completion of the printing of these plots, the system begins the data processing for the next 15 minute interval.

There are certain options built into the program to allow a user to change various aspects of operation. The function keys allow the user to change the local temperature, sample frequency or intensity factor during program execution. Additionally, the user can quit or restart the program, print the partial trace on the screen or elect to save a trace on a floppy disc. The save routine is invoked for the subsequent 15 minute interval after the appropriate function key is depressed. Saving a future trace may seem awkward, especially if a user would like to keep an interesting trace which is presently on the terminal. This problem cannot be readily solved unless each trace is recorded to disc without user intervention. At present, this is not done because only 8 traces (2 hours of data) can be written to a floppy disc before it is full.

IV. DATA ANALYSIS

A. ECHOSOUNDER PERFORMANCE

An analysis of the acoustic echosounder output was conducted to determine the validity of previously determined echosounder parameters. The e^{-1} decay time constant for applied voltage was calculated in Appendix B to be approximately 900 μs or for convenience, 1 ms. Reviewing typical echosounder traces and C_T^2 plots [Appendix D], it was evident that the recovery time was typically found to be on the order of 33 ms or roughly six meters past the end of the transmitted pulse length of 3.4 meters. The recovery time is consistent with the time required for the 30 volts on the drivers to decay to the microvolt level. A more detailed analysis of the hardware is found in Reference 3.

B. SITE EVALUATION

Echosounder data was collected at two different locations. The primary data collection site was the upper roof of Spanagel Hall at the Naval Postgraduate School, Monterey, California. This site was chosen simply for convenience. Data gathered at this location is believed to represent the California coast during the spring near sea level. The second site chosen was in the vicinity of the 24 inch telescope at Lick Observatory, San Jose, California. This site is located atop Mt. Hamilton at an altitude of approximately 5700 feet and nearly 20 miles inland from the coast.

These two data collection sites represent areas of differing atmospheric air pressures, water vapor pressures, local temperature ranges, and local wind velocity ranges. These characteristics all play important roles in effecting the local atmospheric turbulent conditions and thereby the atmospheric structure parameter, C_T^2.

In addition to collecting echosounder data at Lick Observatory, simultaneous measurements of the isoplanatic angle (θ_0) and spatial coherence length (r_0) were made with systems developed by Walters [Refs. 1 and 2]. A basic knowledge of these two systems is necessary to understand the correlation procedures made. The isoplanatic angle (θ_0) is primarily an upper atmospheric measurement which indicates atmospheric disruptions at a range of 2 to 15 kilometers. The spatial coherence length (r_0) is a measure of the effects of the entire atmospheric blanket on coherent light transmission. A close comparison of all three data sets should give us an accurate description of both the lower and upper troposphere as well as the stratosphere above.

Based upon isoplanatic angle (θ_0) and spatial coherence length (r_0) measurements at Mt. Wilson in California, a strong correlation between the two measurements occurs if the low altitude boundary layer contribution is sufficiently small. This strong correlation helps to reinforce the overall description of the atmosphere at the time of data collection. Figures 5 and 6 graphically illustrate the atmospheric measurements made at Mt. Wilson on 2 April 1987 by Walters.

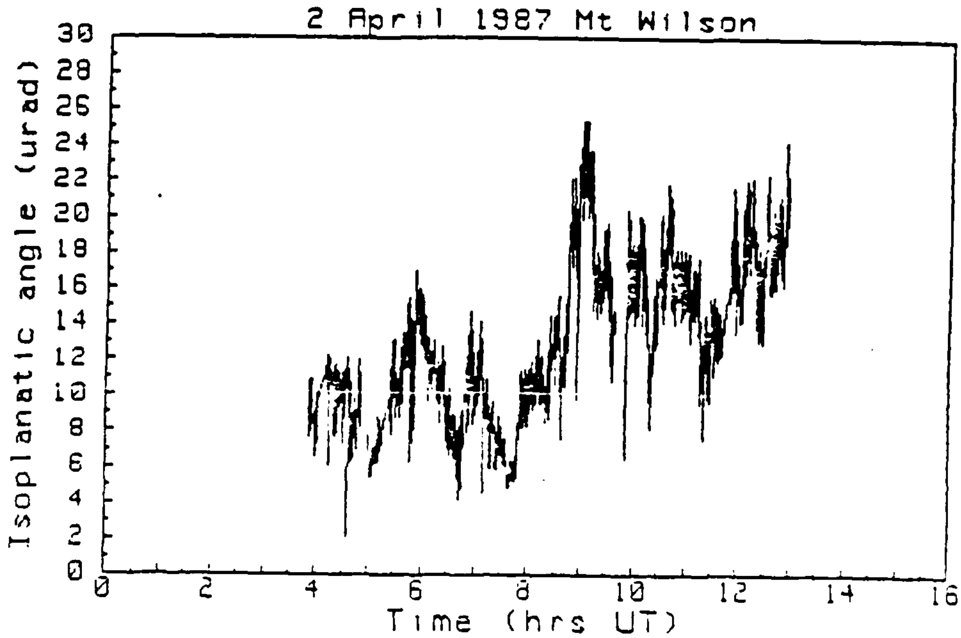


Fig. 5. Isoplanatic Angle Measurements, Mt. Wilson

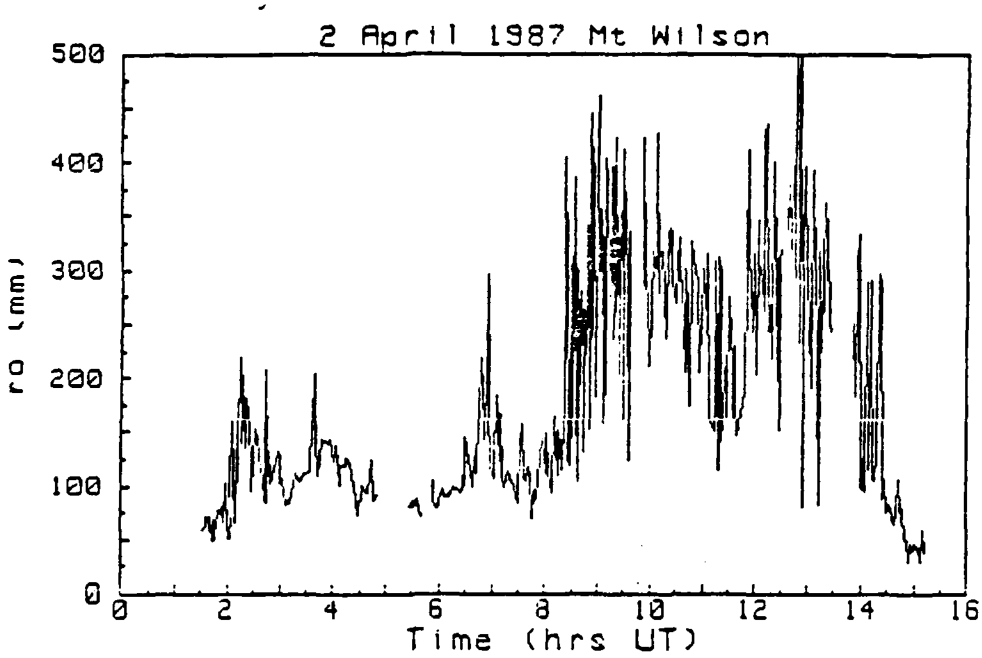


Fig. 6. Spatial Coherence Length Measurements, Mt. Wilson

The strong correlation between the isoplanatic angle (θ_o) and the spatial coherence length (r_o) is especially evident between the hours of 0700 and 1300 universal time. The close tracking of these two measurements during this time interval indicate that the upper atmospheric conditions, as measured by θ_o, are dominating the entire atmospheric profile as measured by r_o. Unfortunately, the existence or non-existence of any turbulent surface effects cannot be ascertained by the employment of the above two systems alone. However, employment of these two systems together with the acoustic echosounder should enable us to produce a complete atmospheric profile with strong correlation between all three atmospheric measurements.

On 9 and 10 April 1987, all three systems were operated at Lick Observatory. Again, a good correlation between the isoplanatic angle (θ_o) and the spatial coherence length (r_o) measurements was noted. In addition, a strong correlation between the spatial coherence length (r_o) and echosounder measurements was present. A comparison of the atmospheric data in Figures 7 and 8 shows a good correlation between the two parameters especially during the 0930 to 1130 time interval on 9 April 1987. However, during subsequent hours the isoplanatic angle (θ_o) measurements remain high ($\approx$12 μrad) indicating relatively calm turbulent conditions in the upper atmosphere while the spatial coherence length (r_o) values drop sharply after 12:00 Universal Time indicating dominant and increasing lower atmospheric turbulence. This increase in the low level turbulence should be evident in the echosounder data commencing around 1200 universal time (0400 local standard time) on 9 April 1987. A comparison of the echosounder data in Figures 9 through 11 illustrates this increase in the local surface turbulence.

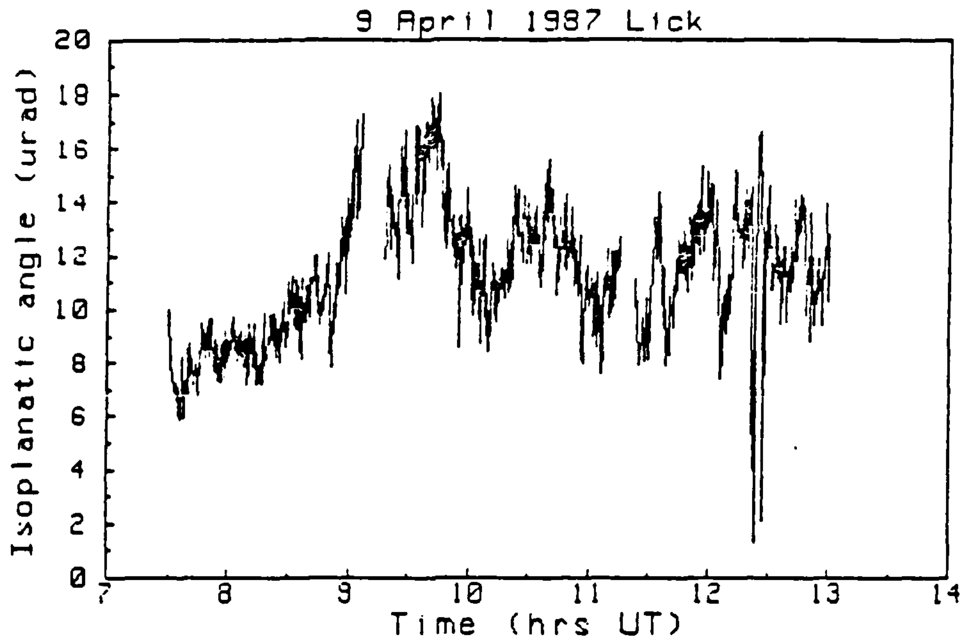


Fig. 7. Isoplanatic Angle Measurements, Lick Observatory

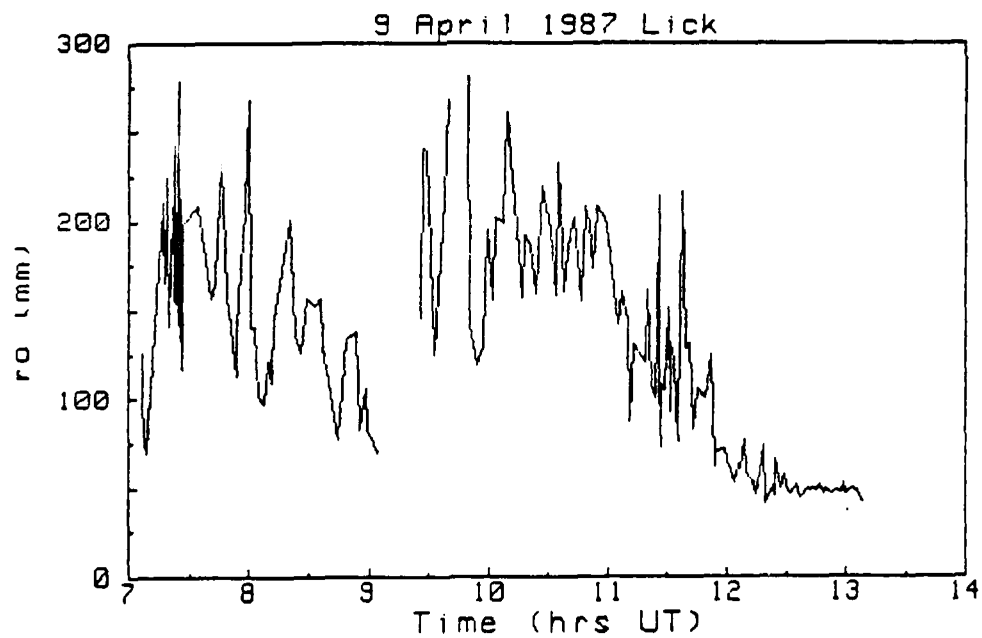


Fig. 8. Spatial Coherence Length Measurements
Lick Observatory

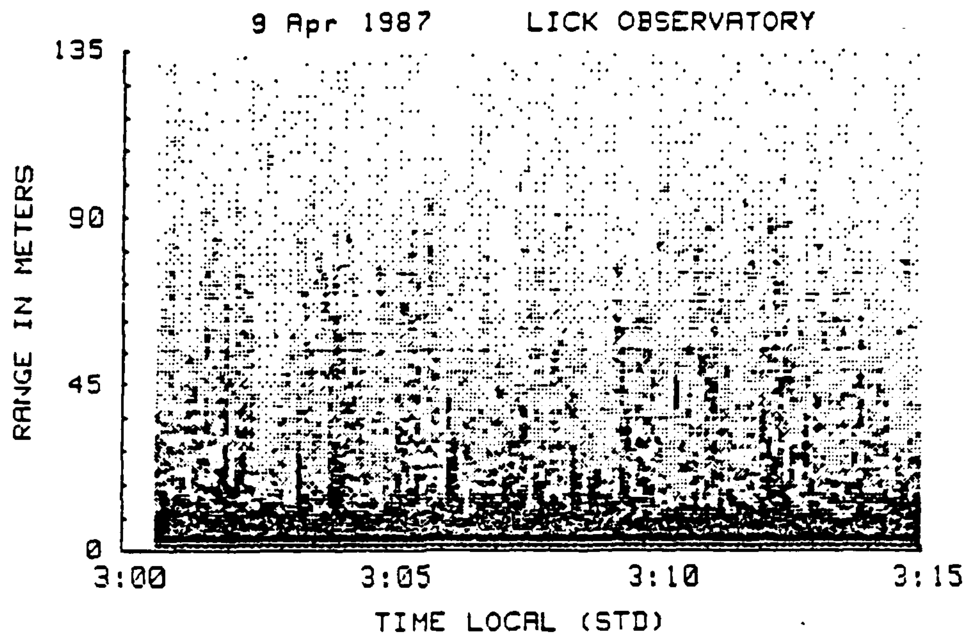


Fig. 9. Echosounder Trace, Lick Observatory

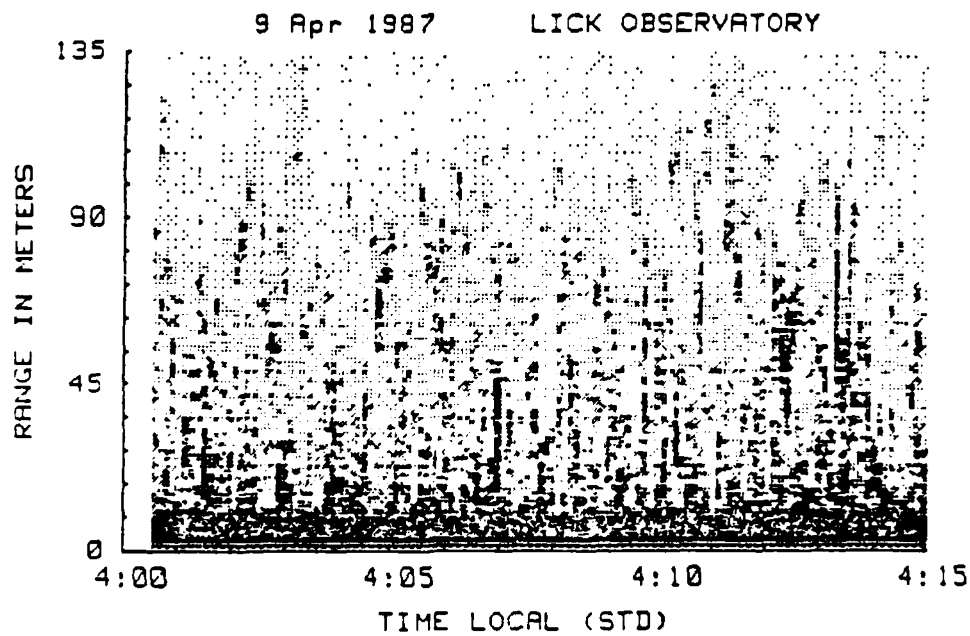


Fig. 10. Echosounder Trace, Lick Observatory

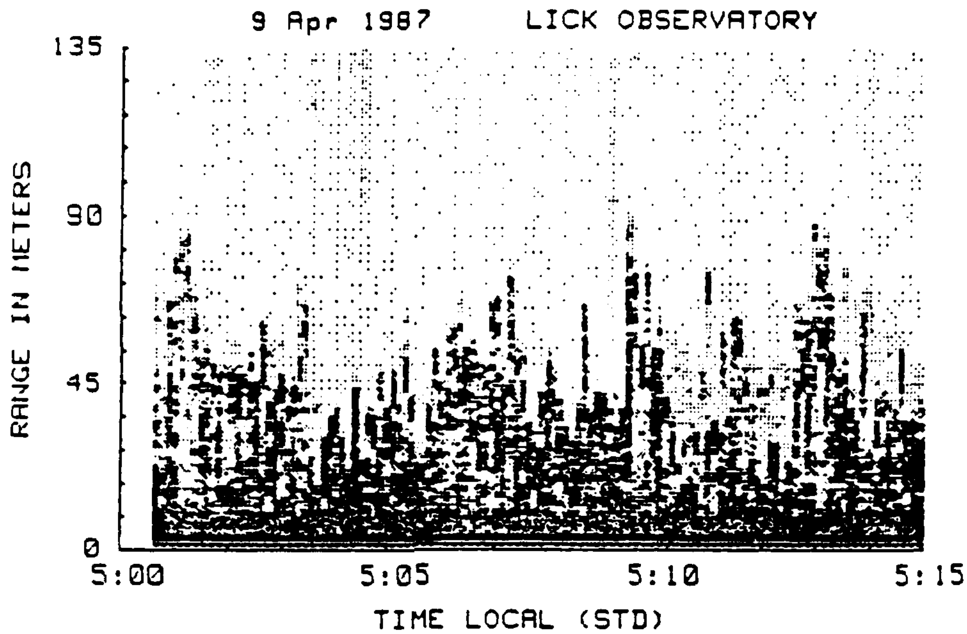


Fig. 11. Echosounder Trace, Lick Observatory

The strong correlation between the echosounder data around 4:00 to 5:00 Standard Time and the ro measurements around 12:00 Universal Time combined with the lack of correlation between the θo and ro measurements indicate that the lower atmospheric and surface turbulence are dominating the atmospheric profile during this time period.

Data collected on 10 April 1987, again illustrate the strong correlation between the three atmospheric measurements made. A comparison of the θo and ro measurements during the time interval of 0700 and 1300 Universal Time indicate steady turbulent conditions in the upper atmosphere and greatly varying turbulent conditions at lower atmospheric levels. This is evident in Figures 12 and 13 by the consistent values of θo during the time period compared with the steady increase and eventual decline of the ro values during the same time interval. The trace variations in Figure 13 during the hours of 0800 and 1200 are indicative of a period of decreasing lower atmospheric or surface turbulence followed by the onset of an increasingly turbulent period around 1200. This turbulent trend is strongly supported by the echosounder data in Figures 14 through 21.

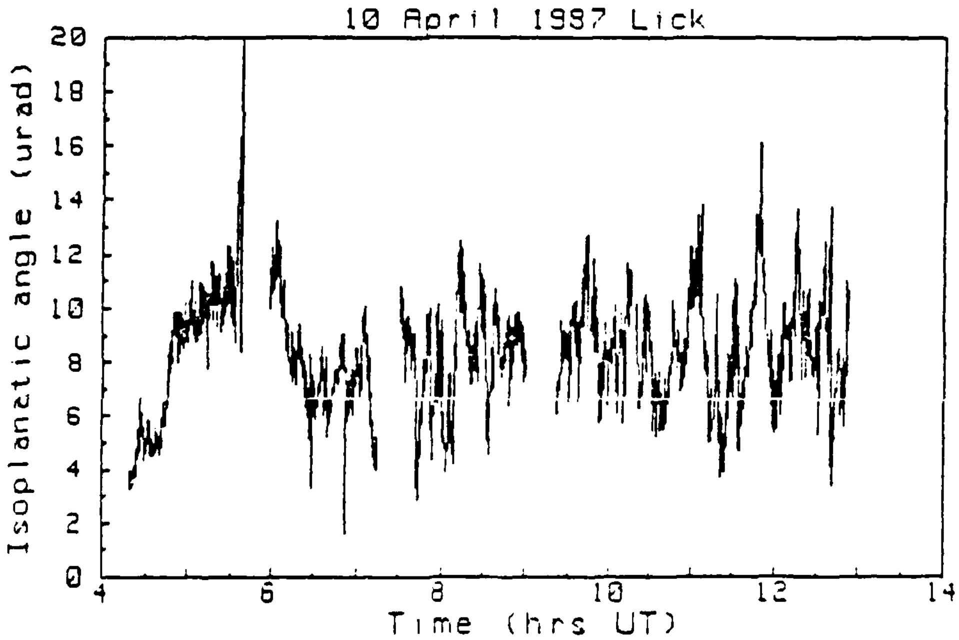


Fig. 12. Isoplanatic Angle Measurements, Lick Observatory

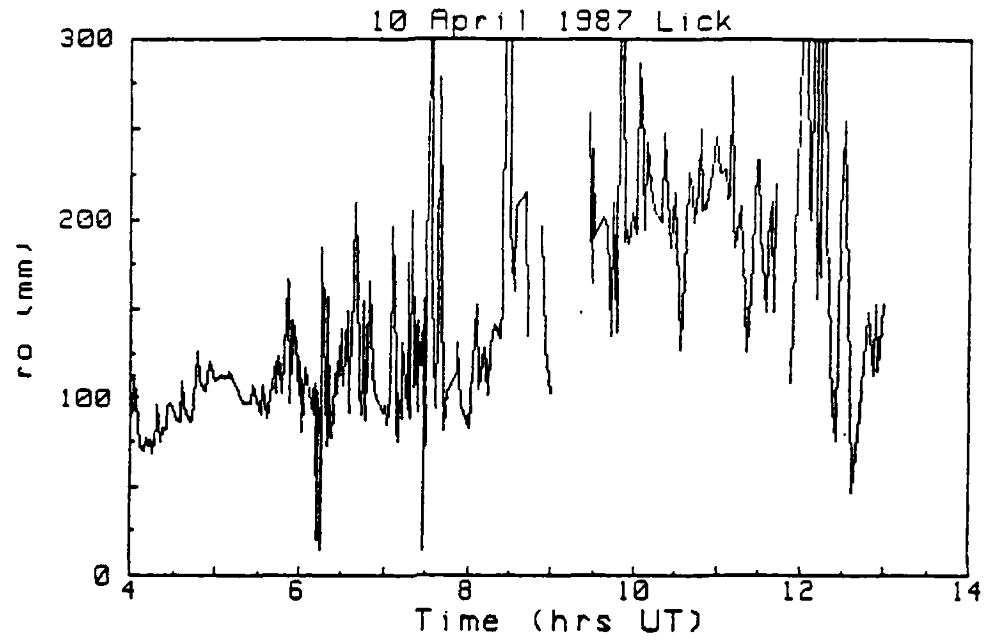


Fig. 13. Spatial Coherence Length Measurements, Lick Observatory

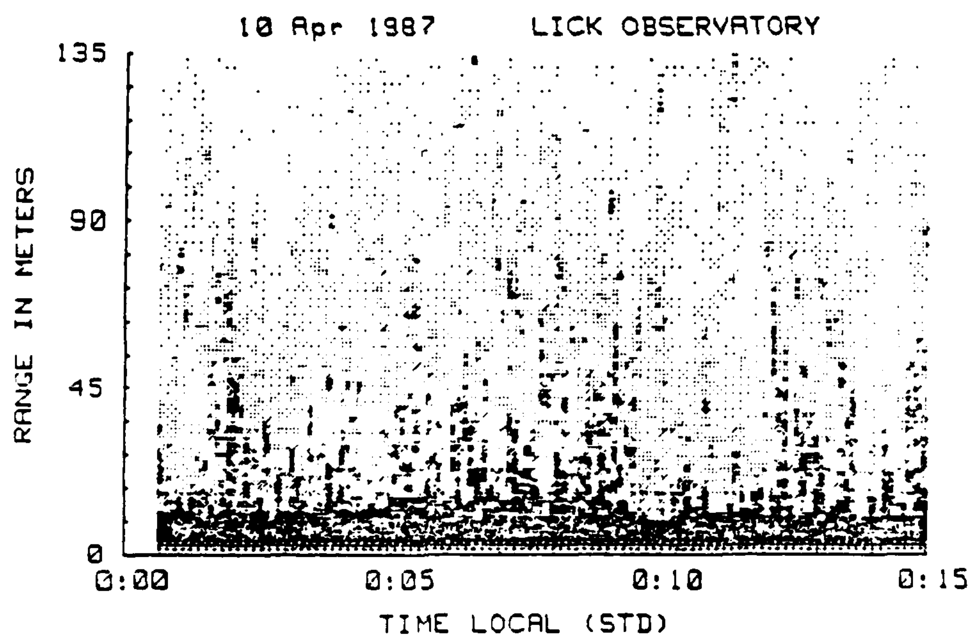


Fig. 14. Echosounder Trace, Lick Observatory

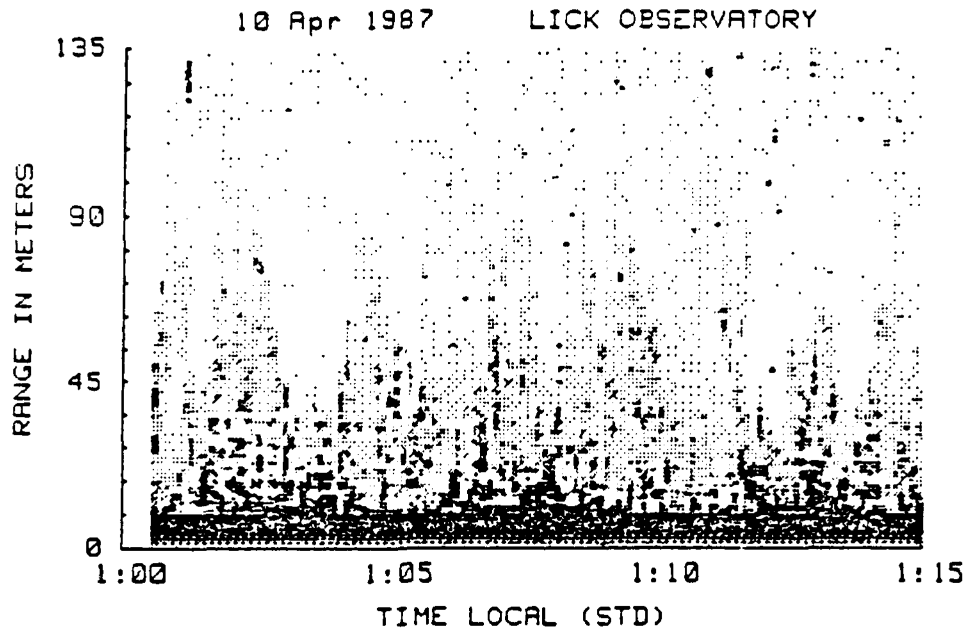


Fig. 15. Echosounder Trace, Lick Observatory

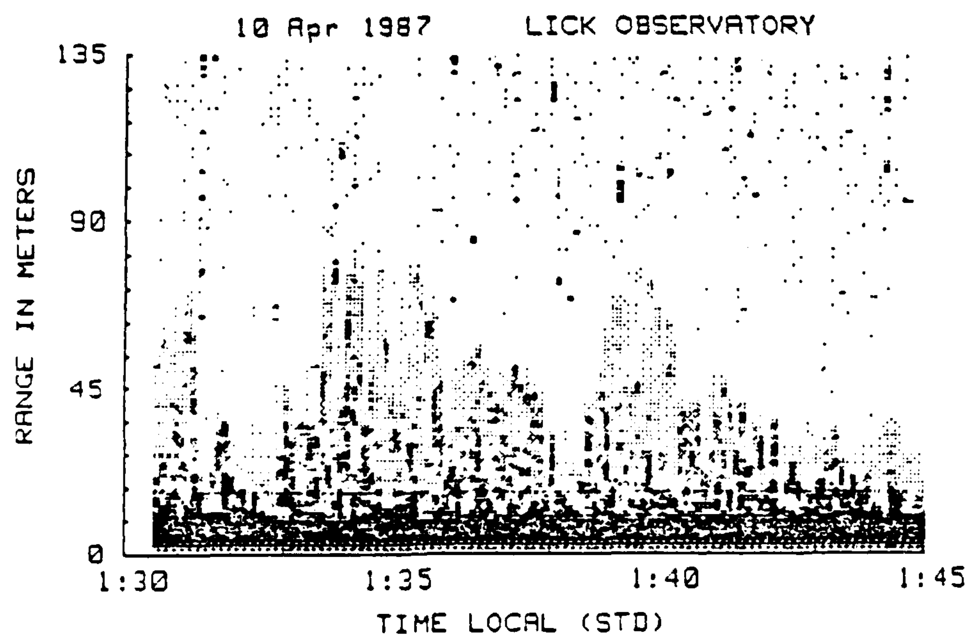


Fig. 16. Echosounder Trace, Lick Observatory

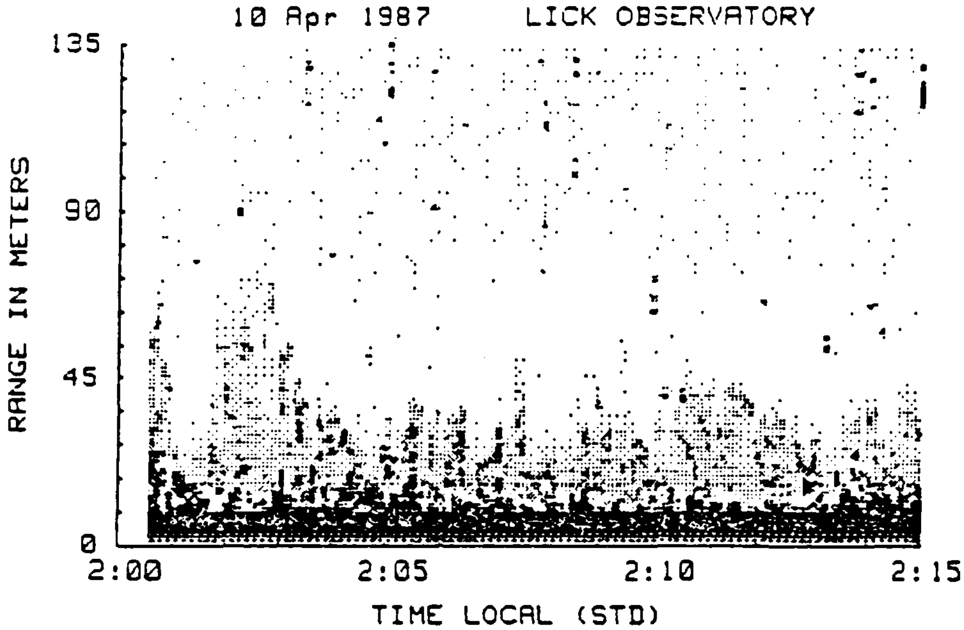


Fig. 17. Echosounder Trace, Lick Observatory

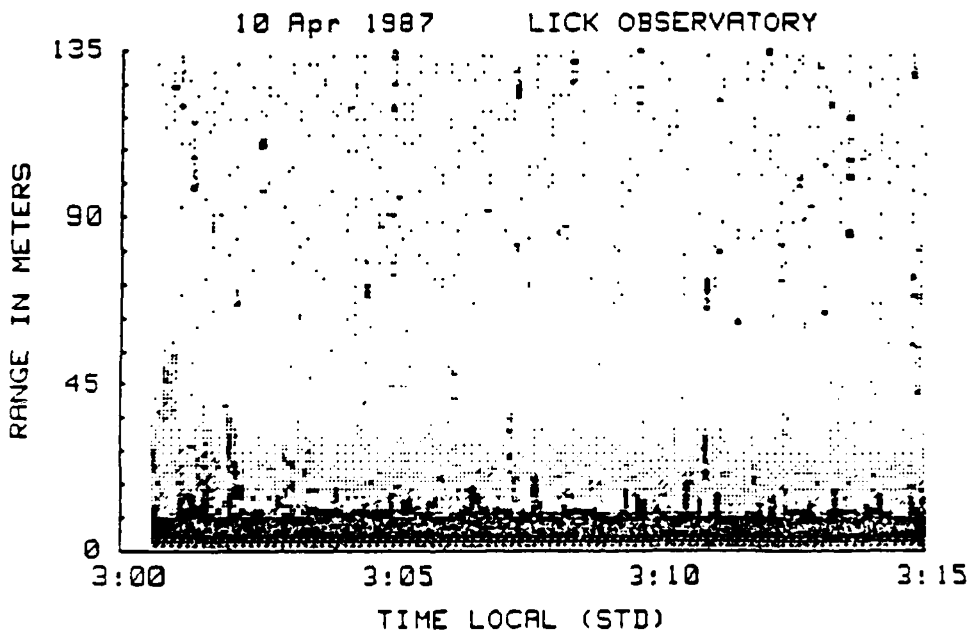


Fig. 18. Echosounder Trace, Lick Observatory

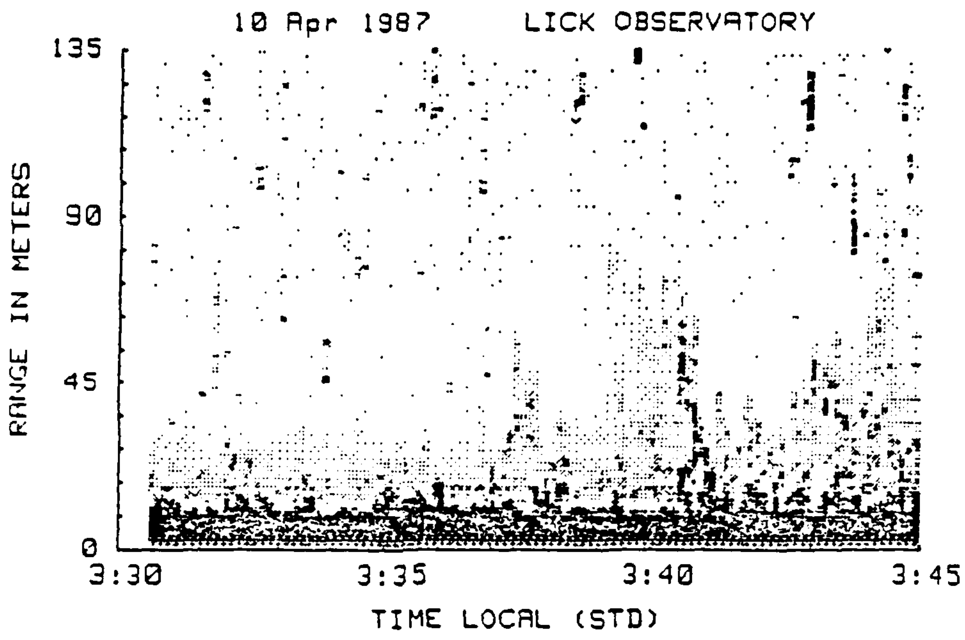


Fig. 19. Echosounder Trace, Lick Observatory

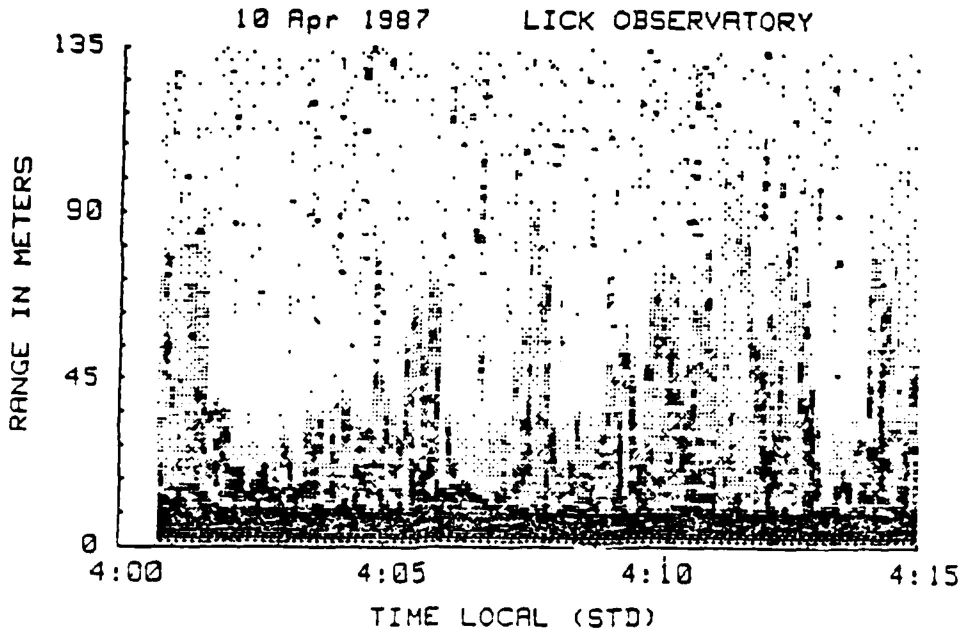


Fig. 20. Echosounder Trace, Lick Observatory

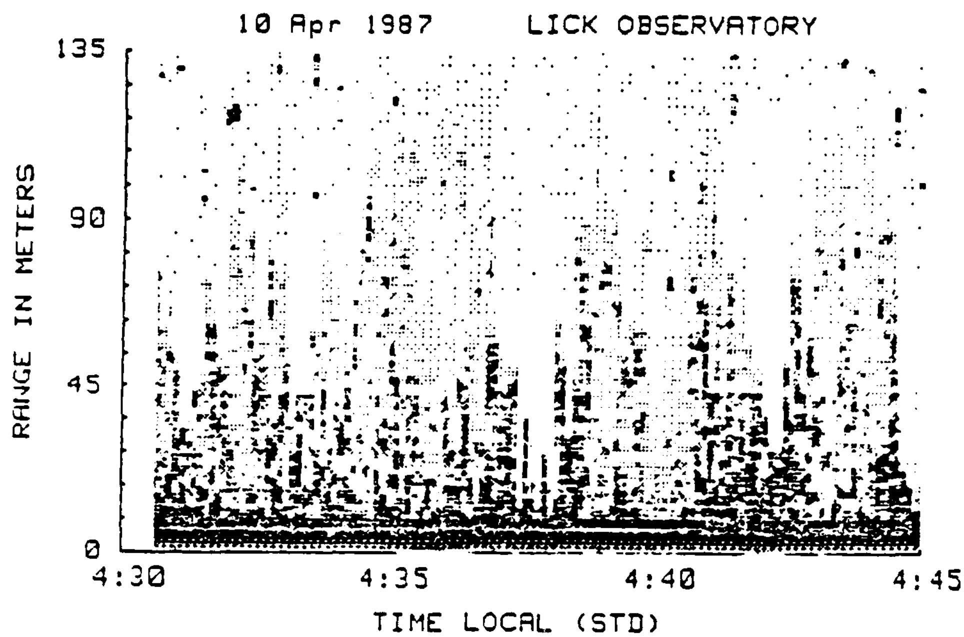
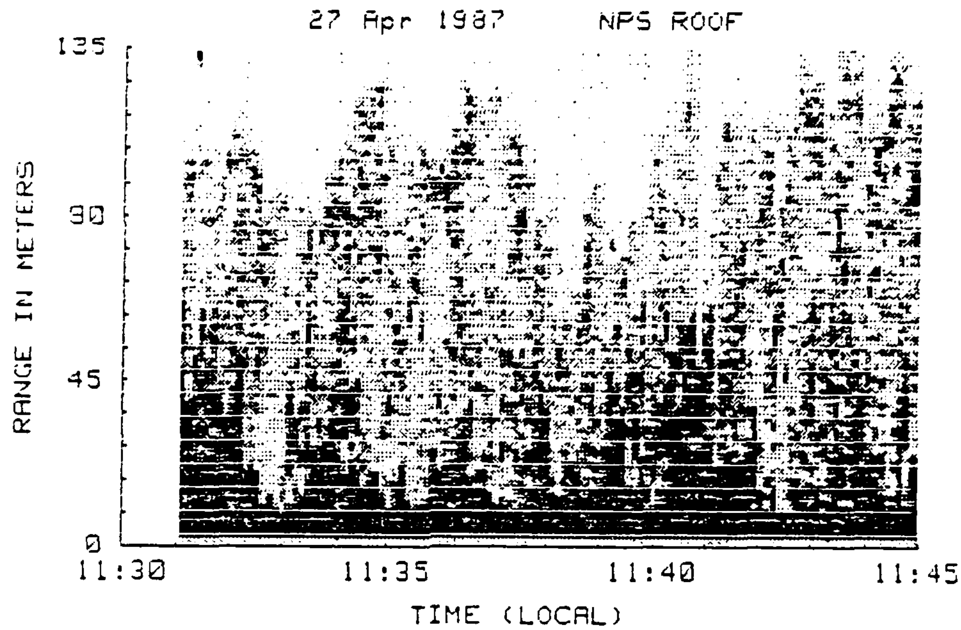


Fig. 21. Echosounder Trace, Lick Observatory

The large 200mm coherence lengths around 11:00 Universal Time are consistent with the low turbulence evident in the echosounder profiles around 3:00 Standard Time followed by a pre-dawn increase in the surface turbulence.

Only acoustic sounder atmospheric measurements were made on the upper roof of Spanagel Hall at the Naval Postgraduate School. Data runs on 26 and 27 April 1987, included both echosounder data and the associated C_T^2 plots. A representative sample of the data collected during this period is included in Appendix D. Of particular interest is the data in Figure 22, which shows the maritime boundary inversion layer at about 100m and being perturbed by convective plumes at lower altitudes.



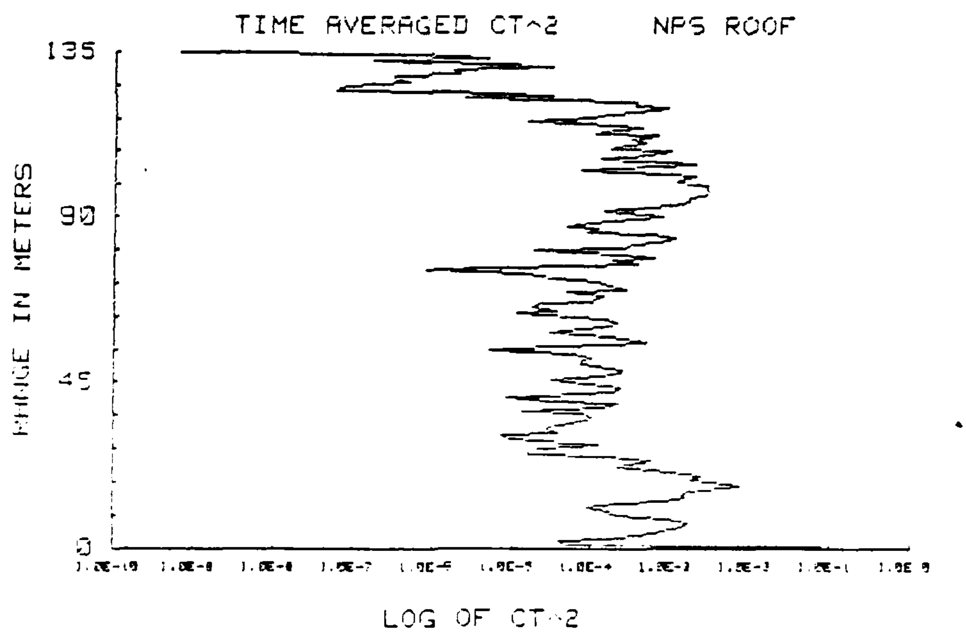


Fig. 22. Echosounder Trace and $C_T{}^2$ Plot, NPS Roof

V. CONCLUSIONS AND RECOMMENDATIONS

A high frequency (5KHz) phased array echosounder constructed to measure low level turbulence appears to work within the 10 to 135 meter altitude range. When using the device, detailed profiles of the short range atmospheric density fluctuations were obtained. The profiles were found to correlate very well with the measurements of the isoplanatic angle (θ_0) and the spatial coherence length (r_0) during periods of simultaneous operation. This short range echosounder, when used in conjunction with the other atmospheric measuring devices, is an invaluable tool. The graphical output provides us with a more complete description of the atmosphere that can be used to calculate C_n^2, the atmospheric index of refraction structure parameter.

Further software development such as the incorporation of Fast Fourier Transform routines into the echosounder program will determine the radial velocity profile of the return signal. Such an improvement will determine the velocity of the probed air masses and plot these echosounder traces as a function of color intensity.

Other areas of further reasearch include the design and testing of different array patterns. One such pattern, the hexagonal array, is already undergoing tests. As the speaker array evolves, it is also evident that the enclosure must follow suit to accomodate the new array design and associated beam patterns. Further improvements in software routines are also inevitable. It is always desirable to store on a disc all data collected at a site. Presently, the floppy disc capacity is inadequate for the storage of more than two hours of data. Furthermore, if FFT and Doppler routines are to be added, the computational speed of the computer will inhibit the pulse repetition rate. A special data acquisition technique called "Direct Memory Access" may then have to be introduced into the HP computer to allow simultaneous data collection and processing.

Finally, this product may be used in various applications not already addressed. One such use may be to measure windshear at airports. Other researchers have expressed interest in using the echosounder to measure arctic atmospheric conditions during meteorological surveys. Assuredly, as the device evolves into a more compact and highly efficient instrument, its range of application will continue to expand.

APPENDIX A

ACOUSTIC ECHOSOUNDER PROGRAM

```
10    ! **********************************************************
20    ! *                        ACRDR                           *
30    ! *  COMPUTER SOFTWARE WRITTEN BT LT. M. WROBLEWSKI FOR AN  *
40    ! *     ECHOSOUNDER BUILT FOR A MASTERS OF SCIENCE THESIS   *
50    ! *        BY LT. M. WROBLEWSKI AND LT. F. WEINGARTNER      *
60    ! *                 ADVISOR: PROF. D. WALTERS               *
70    ! *                        JUN. 1987                        *
80    ! **********************************************************
90    !
100   !
110   ! The computer program receives information from an acoustic
120   ! array through an A-D converter.  This information is the
130   ! returned signal of an acoustic pulse as it passes through
140   ! the atmosphere.  The data is then used to display the return
150   ! intensity with distance as a function of time.  This is a
160   ! short range device (from 150m to 200m).
170   !
180   !
190   !  LIST OF VARIABLES
200   !
210   !
220   ! I & K & J  -  counters for loops
230   !
240   ! Rec_num  &  Nrec  -  real and integer representation of the
250   !                      record number for storage
260   !
270   ! Plotnum  -  counter used to insert form feeds between plots
280   !
290   ! Disc_address$  -  storage location of data file
300   !
310   ! File$  -  file name used to store data
320   !
330   ! N$ & Num  -  string and real representation of the number of
340   !              cycles and the number of points used in the
350   !              computation of the block average
360   !
370   ! Point(*)  -  real number representing the noise and range
380   !              corrected average over given number of points
390   !
400   ! Dat(*)  -  array of a-d converter output after sampling
410   !
```

```
420   ! O2(*)  -  array of reduced and averaged data including
430   !           offset, correction for noise, and range
440   !           corrections
450   !
460   ! Hrs  -  the integer hours
470   !
480   ! Min  -  the number of minutes
490   !
500   ! Qtrhr & Qtrmin  -  keeps track of the passage of each
510   !                    15 minute interval
520   !
530   ! Num1  -  counter for computation of block averages
540   !
550   ! Num2  -  counter for the number of block averages made
560   !
570   ! M  -  the counter used in the plot label routines
580   !
590   ! Timcnt  -  time interval between data samples in
600   !            nanoseconds
610   !
620   !
630   ! Kmax  -  total number of block averages computed
640   !
650   ! Freq$ & Freq  -  the frequency input of the HP3314A in kilohertz
660   !
670   ! Zone$  -  the appropriate time zone the operator desires
680   !
690   ! Site$  -  the name of the appropriate site of data collection
700   !
710   ! Save_plt & Cntrl  -  on/off toggles used to determine whether
720   !                      a particular run will be saved to a disc
730   !
740   ! Nplot  -  the number of increment along the entire
750   !           horizontal axis
760   !
770   ! Offset  -  the computed O-C offset for the system prior
780   !            to data acquisition
790   !
800   ! Noise  -  a running total of the noise accumulated at the
810   !           maximum range; used to find and remove the
820   !           average noise
830   !
840   ! Limit  -  the upper bound on the noise figure used to insure
850   !           that large returns are not included in the
860   !           noise computations
870   !
880   ! K1  -  a counter of the number of traces used to determine
890   !        the noise average
900   !
```

```
910   ! Samave  -  a sample average used in the computation of the
920   !             D-C offset
930   !
940   ! Off_ave  -  a toggle used to inhibit the firing of the
950   !              HP3314A during D-C offset computations
960   !
970   ! Count$ & Cnt  -  the string and real representation of
980   !                  the number of data points to be taken
990   !
1000  ! Samfreq  -  the user input sampling frequency desired
1010  !
1020  ! Tminc  -  1 over the sampling frequency; the time between
1030  !           samples
1040  !
1050  ! Time$  -  the string required by the A-D converter to
1060  !           sample at the desired rate
1070  !
1080  ! C0kelvin  -  the speed of sound at 0 degrees celcius in m/s
1090  !
1100  ! Temp  -  temperature of the surroundings in degrees celcius
1110  !
1120  ! Spd  -  the speed of sound in air computed for the input
1130  !         temperature
1140  !
1150  ! Rspd  -  the relative speed of sound that the echosounder
1160  !          sees which is half the computed speed
1170  !
1180  ! Rdist  -  the distance traveled in one time increment
1190  !
1200  ! Maxrng  -  the maximum range of the echosounder found
1210  !            by multiplying the distance per time increment
1220  !            by the number of time increments
1230  !
1240  ! Exrng  -  the range rounded to the nearest value evenly
1250  !           divided by 15; used solely for plotting
1260  !           purposes
1270  !
1280  ! Far  -  used to estimate the far field; this value keeps the
1290  !         range correction from being applied to data very near
1300  !         to the source
1310  !
1320  ! Ilvl  -  the user input intensity level divisor; this value
1330  !          sets the screen contrast in data return
1340  !
1350  ! Scale_y  -  the ratio of exrng to maxrng; this value is used
1360  !             to keep the plotted range of data accurate
1370  !
1380  ! Npoint & Npoint1 & Npoint2  -  variables used to keep track of
1390  !                                time passage between pulses
1400  !
```

```
1410  ! T2 & T1 & T0  -  used to synchronize data collection with the
1420  !                    clock
1430  !
1440  ! TIMEDATE  -  the internal clock of the computer
1450  !
1460  ! Dvd  -  divisor of the data average; used because computer
1470  !          multiplication is faster than division
1480  !
1490  ! R  -  the range of a block of data samples
1500  !
1510  ! Run_ave  -  the running sum of the block samples
1520  !
1530  ! X  -  the value of the data point less the D-C offset
1540  !
1550  ! Ns  -  the final average of the block of data points; also
1560  !         used in the computation of the noise figure
1570  !
1580  ! Corr  -  the noise correction applied to the data samples
1590  !
1600  ! Time  -  the horizontal position of the trace on the plot
1610  !
1620  ! Timedist  -  the horizontal width of the trace on the plot
1630  !
1640  ! End_pt  -  the last point of the plot vertically taking
1650  !             into account the scaling factor scale_y
1660  !
1670  ! Inc  -  The vertical increment along the plot
1680  !
1690  ! Z  -  The final reduced data points which are output on the plot
1700  !
1710  ! Dis  -  The vertical height of the trace on the plot
1720  !
1730  ! Ap$,Frq$,Nm$,En$,Vo$,Hz$  -  strings needed to set the HP3314A
1740  !
1750  ! Amp$  -  userv input amplitude for tha HP3314A
1760  !
1770  ! Pls_lng  -  the pulse length of the burst
1780  !
1790  ! Ct(*)  -  the atmospheric temperature structure parameter
1800  !
1810  ! Y  -  the number of traces used in computing Ct(*)
1820  !
1830  ! Ypl  -  the vertical position on the Ct plot
1840  !
1850  ! Pnt  -  the horizontal position on the Ct plot
1860  !
1870  ! K3  -  the wave number to the 1/3rd power
1880  !
1890  ! A  -  The area of the receiver (array)
1900  !
```

```
1910  ! G   -  The effective aperature factor
1920  !
1930  ! Er   -  efficiency of coversion of acoustical power
1940  !         to electrical power on the recieve side
1950  !
1960  ! Et   -  the efficiency of conversion of electrical
1970  !         power to acoustical power on the transmit side
1980  !
1990  ! Pt   -  The computed transmitted power to the
2000  !         acoustic array
2010  !
2020  ! Gain   -  the electronic gain of the equipment
2030  !
2040  ! Zimp   -  the speaker array impedence
2050  !
2060  !
2070  !
2080  OPTION BASE 1
2090  !
2100  !
2110  ! initialize the arrays  &  set dimensions
2120  ! declare all integer variables
2130  !
2140  !
2150    DIM Disc_address$[20],File$[30],Point(300),Ct(200)
2160    INTEGER I,Hr,Plotnum,Print_key,Num,Num1,Num2,M,K
2170    INTEGER Rec_num,Kmax
2180    INTEGER D2(300),Dat(16301) BUFFER
2190  !
2200  !
2210  !   initialization routines....set time, set HP3314A Function
2220  !   Generator
2230  !
2240  !
2250 Rstrt:CALL Freq_init(Freq$,N$)
2260      CALL Init_ad200
2270      CALL Set_time(Zone$)
2280      INPUT "SITE NAME ",Site$
2290      Save_plt=0
2300      Cntrl=0
2310    !
2320    !
2330    ! keyboard set_up   -  sets labels on the computer function
2340    !                       keys
2350    !
2360    !
2370         OUTPUT KBD;"SCRATCH KEYE";     ! CLEAR THE KEYS
2380         CONTROL 2,2;1
2390         ON KEY 1 LABEL "NEW      TEMP" GOTO Speed
```

```
2400         ON KEY 2 LABEL "INTENS.   FACTOR" GOTO Lvl
2410         ON KEY 4 LABEL "PRINT    TRACE" GOTO Prt_dmp
2420         ON KEY 5 LABEL "SAVE NXT  PLOT" GOTO Svpt
2430         ON KEY 6 LABEL "CHANGE  SMPL FRQ" GOTO Sfrq
2440         ON KEY 7 LABEL "RESTART" GOTO Rstrt
2450         ON KEY 8 LABEL "QUIT" GOTO Quit
2460     !
2470     !
2480     ! Set constants
2490     !
2500     !
2510      Disc_address$=":,700,1,0"
2520      Maxrec=720
2530      Nplot=900
2540      Plotnum=1
2550      Offset=0
2560      GINIT
2570      Noise=0
2580      Limit=10
2590      Y=0
2600      K1=0
2610      Samave=0
2620      A=.1140
2630      G=.4
2640      Er=.496
2650      Et=.496
2660      Gain=73126^2
2670      Zimp=12.12
2680      !
2690      !
2700      !   Input and calculation of terms used by the A-D converter and
2710      !   the computation of range
2720      !
2730      !
2740      PRINT "Enter the number of data points desired (max 16301)"
2750      PRINT "Use increments of the number of cycles then add 1"
2760      PRINT "ex: (150 cycles X 100 data points/cycle)+1=15001"
2770      PRINT "RECOMMEND USING MAX VALUE OF 16301"
2780      INPUT Count$
2790      !
2800      !  Output power computed assumed
2810      !  Aamplifier settings
2820      !
2830      Pt=(Et*(30^2))/(2*Zimp)
2840      !
2850 Sfrq:PRINT "Input the sampling frequency desired.  This frequency will"
2860      PRINT "determine the range of the sounder.  Examples are:"
2870      PRINT "    SAM. FREQ. = 12500.......RANGE = 225 M"
2880      PRINT "    SAM. FREQ. = 20000.......RANGE = 135 M"
2890      INPUT "ENTER THE SAMPLE FREQUENCY",Samfreq
```

```
2900      GCLEAR
2910      Tminc=1./Samfreq
2920      Timcnt=1000*INT(Tminc/1.E-6)
2930      Time$="TIME "&VAL$(Timcnt)
2940      Cnt=VAL(Count$)
2950      C0kelvin=331.6
2960      Num=VAL(N$)
2970      Freq=VAL(Freq$)*1000
2980  !
2990  !
3000  !  Computation of the D-C offset prior to program run
3010  !
3020  !
3030   Off_ave=1
3040   Offset=0
3050   FOR I=1 TO 10
3060       CALL Read_ad200(Dat(*),Count$,Time$,Off_ave)
3070       FOR K=1 TO (Cnt-1)
3080           Samave=Samave+Dat(K)
3090       NEXT K
3100       PRINT "COMPUTING D-C OFFSET"
3110   NEXT I
3120   Off_ave=0
3130   Offset=Samave/(10*(Cnt-1))
3140   PRINT "OFFSET IS :",Offset
3150  !
3160  !
3170  !  computation of the speed of sound at a given temp and the
3180  !  range of detection of the device
3190  !
3200  !
3210 Speed:INPUT "Enter the temperature (celsius) ",Temp
3220      Spd=C0kelvin*(SQR(1+(Temp/273)))
3230      Rspd=Spd/2
3240      Rdist=Tminc*Rspd
3250      Maxrng=Cnt*Rdist
3260      Exrng=((INT(Maxrng/30))+.5)*30.0
3270      Far=1./(Tminc*Spd)
3280      Lambda=Spd/Freq
3290      K3=((2*PI)/Lambda)^(1/3)
3300      Pls_lng=(Rspd*Num)/Freq
3310      CALL Attenuation(Freq,Temp,Atten)
3320      !
3330      !
3340      PRINT "Enter the relative intensity division level.  This "
3350      PRINT "value is used to determine the plot intensity by "
3360      PRINT "dividing the block average sum by this number.  "
3370      PRINT "This value is dependent upon the gain of"
3380      PRINT "the device and will probably need adjustment"
3390      PRINT "during run.  Start with a value of about 4000"
3400      PRINT Pt
```

```
3410 Lvl: INPUT Ilvl
3420      !
3430      !
3440      !  set up the plot
3450      !
3460      !
3470 Again:CALL Plot_setup(Nplot,Site$,Maxrng,Scale_y,Exrng,Zone$)
3480      Nrec=0
3490      FOR I=1 TO 200
3500        Ct(I)=0
3510      NEXT I
3520      Y=0
3530      Npoint1=0
3540  OUTPUT KBD;"L";
3550      !
3560      !
3570 Sync: !  synchronize data collection with clock
3580      T1=INT(TIMEDATE MOD 86400)
3590      IF T1<T0 THEN T0=T0-86400
3600      IF T1-T0<1 THEN GOTO Sync
3610      T0=T1
3620      !
3630      !
3640      !   Data collection and reduction
3650      !
3660      !
3670 Read_sig:   !  read the A-D converter
3680      CALL Read_ad200(Dat(*),Count$,Time$,Off_ave)
3690      Npoint=INT(T1 MOD 3600 MOD Nplot)
3700      Npoint2=Npoint-Npoint1
3710      Num1=Num-1
3720      Num2=Cnt-Num
3730      Dvd=1./(Num)
3740      K=0
3750      !
3760      !
3770  FOR I=1 TO Num2 STEP Num
3780      R=I*Rdist
3790      IF I<Far THEN R=1
3800      K=K+1
3810      Run_ave=0
3820      FOR J=I TO I+Num1
3830         X=Dat(J)-Offset
3840         Run_ave=Run_ave+X*X
3850      NEXT J
3860      Ns=SQR(Run_ave*Dvd)
3870      Point(K)=R*(Ns-Corr)
3880      IF K1>10 THEN
3890           Ct(K)=Ct(K)+((Point(K)^2)*EXP(2*R*Atten))
3900           Ct(K)=(Ct(K)*((3.339E-8)^2)*Er)/Zimp
3910      END IF
```

```
3920        IF Point(K)>ABS(32767) THEN Point(K)=32767
3930        D2(K+10)=INT(Point(K))
3940  NEXT I
3950  IF K1>10 THEN
3960      Y=Y+1
3970  END IF
3980  !
3990  !
4000  !   Noise correction routine
4010  !
4020  !
4030        IF Ns<(Limit+5) THEN
4040             Noise=Noise+Ns
4050             K1=K1+1
4060             IF K1>10 THEN
4070                  Corr=Noise/K1
4080                  Limit=Corr
4090             ELSE
4100                  Corr=0
4110             END IF
4120        END IF
4130        !
4140        !
4150        !  Plotting of the data
4160        !
4170        !
4180  Kmax=K
4190  REDIM D2(Kmax+15)
4200  !
4210  !  positioning the data on the plot by time of trace
4220  !
4230  Time=(Npoint2/Nplot)*420
4240  Timedist=2+((Npoint2+Npoint1)/Nplot)*420
4250  IF Npoint1=0 THEN Time=5
4260  IF Npoint<6 THEN Timedist=6
4270  End_pt=Scale_y*260
4280  D2(2)=Kmax
4290  D2(3)=INT(Temp)
4300  D2(4)=INT(Time)
4310  D2(5)=INT(Timedist*10)
4320  WINDOW 0,420,0,260
4330  GRAPHICS ON
4340  !
4350  ! set the vertical increment
4360  !
4370  Inc=((Num*Tminc*Rspd*End_pt)/Maxrng)
4380  D2(6)=INT(Inc*1000)
4390  !
```

```
4400  ! compute the intensity of the return, move to the proper
4410  ! coordinates and plot the appropriate colored block
4420  !
4430  FOR K=1 TO Kmax
4440     Z=Point(K)/Ilvl
4450     IF Z>1 THEN Z=1
4460     IF Z<0 THEN Z=0
4470     AREA INTENSITY Z,Z,Z
4480     Dis=INT(K*Inc)+1
4490     MOVE Timedist,Dis
4500     RECTANGLE Time,Inc,FILL
4510  NEXT K
4520  !
4530  !  keep an account of the trace numbers taken on the plot
4540  !
4550  Nrec=Nrec+1
4560  Rec_num=INT(Nrec)
4570  D2(1)=Rec_num
4580  Npoint1=Npoint
4590  !
4600  !
4610  !  save routine  -  if function key is set then
4620  !                   the plot will be saved
4630  !
4640  !
4650  IF Cntrl=1 THEN
4660      ASSIGN @File1 TO File1$
4670      OUTPUT @File1,Rec_num;D2(*)
4680  END IF
4690  !
4700  !
4710  !  graphics dump of plot after 15 minute intervals
4720  !
4730  !
4740  IF Timedist>415 THEN
4750 Prt_dmp:    PRINTER IS 701
4760      PRINT "    "
4770      PRINT "    "
4780      PRINT "    "
4790      Plotnum=Plotnum+1
4800      DUMP GRAPHICS #701
4810      FOR I=1 TO Kmax
4820         Ct(I)=Ct(I)*((Temp+273)^2)*(1./.0033)*K3*(1./Y)
4830         Ct(I)=Ct(I)*(1./(A*G))
4840         Ct(I)=Ct(I)*(1./Pt)
4850         Ct(I)=Ct(I)/Pls_lng
4860         IF Ct(I)<1.0E-100 THEN Ct(I)=1.0E-100
4870      NEXT I
4880      !
```

```
4890    !
4900    ! CT^2 Computations and plots
4910    !
4920    !
4930    GCLEAR
4940    VIEWPORT 15,120,15,80
4950    WINDOW 0,300,0,Exrng
4960    AXES 30,Exrng/15,0,0,30,Exrng/3
4970    CLIP OFF
4980    CSIZE 2,.6
4990    LORG 6
5000    FOR M=0 TO 300 STEP 30
5010    MOVE M,-Exrng/45
5020    LABEL "1.0E";((M/30)-10)
5030    NEXT M
5040    MOVE 140,-15
5050    CSIZE 4
5060    LABEL "LOG OF CT^2"
5070    LORG 8
5080    FOR M=0 TO Exrng STEP INT(Exrng/3)
5090       MOVE 0,M
5100       LABEL M
5110    NEXT M
5120    LDIR PI/2
5130    LORG 6
5140    MOVE -40,Exrng/2
5150    CSIZE 4
5160    LABEL "RANGE IN METERS"
5170    LDIR 0
5180    LORG 4
5190    MOVE 150,Exrng+3
5200    LABEL "TIME AVERAGED CT^2      ";Site$
5210    CLIP ON
5220    MOVE 300,0
5230    FOR I=1 TO Kmax
5240       Ypl=(Maxrng/Kmax)*I
5250       Pnt=(LOG(Ct(I))/2.3025851)+10
5260       IF Pnt>10 THEN Pnt=10
5270       IF Pnt<0 THEN Pnt=0
5280       Pnt=Pnt*30
5290       DRAW Pnt,Ypl
5300    NEXT I
5310    DUMP GRAPHICS #701
5320    PRINT "


               "
5330    PRINTER IS CRT
5340    GCLEAR
5350    Kl=10
5360    Limit=Corr
5370    Noise=10*Corr
```

```
5380      IF Cntrl=1 THEN
5390           ASSIGN @File1 TO *
5400      END IF
5410      Cntrl=0
5420      !
5430      !
5440      !  if the  plot is to be saved, the file is created
5450      !  and named
5460      !
5470      !
5480      IF Save_plt=1 THEN
5490           CALL File_init(Disc_address$,Nrec,File1$)
5500           Save_plt=0
5510           Cntrl=1
5520      END IF
5530      !
5540      !
5550      !  start the next 15 minute plot
5560      !
5570      !
5580      GOTO Again
5590  END IF
5600  !
5610  !
5620  ! next trace
5630  !
5640  !
5650  GOTO Sync
5660  !
5670  !
5680  !  toggle set if plot is to be saved
5690  !
5700  !
5710 Svpt: Save_plt=1
5720        GOTO Read_sig
5730  !
5740  !
5750  ! completion routine
5760  !
5770  !
5780 Quit: STOP
5790        END
5800         !
5810         !
6000         !  SUBROUTINE SECTION
6010         !
6020         !
```

```
6030  SUB Freq_init(Freq$,N$)
6040  !
6050  !
6060  !      SETUP OF THE HP3314A  FUNCTION GENERATOR
6070  !
6080  !
6090     Ap$="AP"
6100     Frq$="FR"
6110     Nm$="NM"
6120     En$="EN"
6130     Vo$="VO"
6140     Hz$="KZ"
6150     INPUT "FREQUENCY DESIRED (kHZ) (5 RECOMMENDED)",Freq$
6160     INPUT "AMPLITUDE DESIRED (V . .1.5V MAX) ",Amp$
6170     IF VAL(Amp$)>1.5 THEN
6180         Amp$="1.5"
6190         PRINT "AMPLITUDE OF FUNCTION GENERATOR IS 1.5 V"
6200     END IF
6210     INPUT "NUMBER OF CYCLES PER BURST (INTEGER) (100 RECOMMENDED)",N$
6220     OUTPUT 707;"MO3"
6230     OUTPUT 707;"SR2"
6240     OUTPUT 707;Ap$&Amp$&Vo$&Frq$&Freq$&Hz$&Nm$&N$&En$
6250  SUBEND
6260  !
6270  !
6280  !
6500  SUB Init_ad200
6510  !
6520  !
6530  ! INITIALIZATION OF THE A-D CONVERTER
6540  !
6550  !
6560     Ad_sel_code=17
6570     Dummy=READIO(Ad_sel_code,3)
6580     WRITEIO Ad_sel_code,0;0
6590     CONTROL Ad_sel_code,0;1
6600  SUBEND
6610  !
6620  !
6630  !
```

```
7000  SUB Set_time(Zone$)
7010  !
7020  !
7030  !  SET THE TIME DATE RECORDER
7040  !
7050  !
7060        PRINT "WHAT TIME REFERENCE ARE YOU USING?  INPUT:"
7070        PRINT "     1 FOR UNIVERSAL TIME"
7080        PRINT "     2 FOR LOCAL TIME"
7090        PRINT "     3 FOR YOUR OWN CLASSIFICATION"
7100        INPUT K
7110        IF K=2 THEN
7120            Zone$="(LOCAL)"
7130        ELSE
7140            IF K=3 THEN
7150                 INPUT "WHAT IS YOUR TIME REFERENCE",Zone$
7160            ELSE
7170                 Zone$="(UTC)"
7180            END IF
7190        END IF
7200        IF TIMEDATE<DATE("14 AUG 1984") THEN
7210            INPUT "ENTER ""DD MMM YYYY""",Date$
7220            INPUT "ENTER ""HR:MIN:SC""",Time$
7230            SET TIMEDATE DATE(Date$)+TIME(Time$)
7240            PRINT DATE$(TIMEDATE),TIME$(TIMEDATE)
7250            Tstart=TIMEDATE
7260            T0=Tstart MOD 86400
7270        END IF
7280  SUBEND
7290  !
7300  !
7310  !
```

```
7500  SUB Read_ad200(INTEGER Dat(*) BUFFER,Count$,Time$,Off_ave)
7510  !
7520  !
7530  ! INFOTEK A-D ROUTINE SET UP FOR EXTERNAL TRIGGER
7540  !
7550  !
7560     Ad_sel_code=17
7570     !
7580     !INITIALIZATION OF THE A-D CONVERTER
7590     !
7600       OUTPUT Ad_sel_code;"RESET"
7610       OUTPUT Ad_sel_code;"INTERNAL","COUNT "&Count$,"HOLDON"
7620       OUTPUT Ad_sel_code;"DELAYON","SELECT 1s1  end",Time$
7630       OUTPUT Ad_sel_code;"STATUS"
7640       ENTER Ad_sel_code;Resp$
7650       IF Resp$="--------" THEN
7660          ASSIGN @Ad200 TO Ad_sel_code;WORD
7670          !
7680          !  triggering of the HP3341A
7690          !
7700          IF Off_ave=0 THEN
7710              TRIGGER 707
7720          END IF
7730          ASSIGN @Buf TO BUFFER Dat(*)
7740          TRANSFER @Ad200 TO @Buf;WAIT
7750          OUTPUT Ad_sel_code;" "
7760          OUTPUT Ad_sel_code;"STATUS"
7770          ENTER Ad_sel_code;Resp$
7780          IF Resp$<>"--------" THEN
7790               PRINT "ERROR= ";Resp$
7800          END IF
7810     ELSE
7820        PRINT "ERROR DURING INITIALIZATION =";Resp$
7830     END IF
7840  SUBEND
7850  !
7860  !
7870  !
```

```
8000    SUB Plot_setup(Nplot,Site$,Maxrng,Scale_y,Exrng,Zone$)
8010    !
8020    !
8030    ! SET-UP OF THE TIME PLOT ON THE CRT
8040    !
8050    !
8060         Scale_y=Maxrng/Exrng
8070         GRAPHICS ON
8080         LINE TYPE 1
8090         VIEWPORT 15,120,15,80
8100         WINDOW 0,Nplot,0,Exrng
8110         AXES Nplot/15,Exrng/15,0,0,Nplot/3,Exrng/3
8120         CLIP OFF
8130         CSIZE 4,.6
8140         LORG 6
8150         T1=TIMEDATE MOD 86400
8160         Hrs=T1 DIV 3600
8170         T2=T1 MOD 3600
8180         Min=T2 DIV 60
8190        Qtrhr=Min DIV 15
8200         FOR M=0 TO Nplot STEP INT(Nplot/3)
8210            MOVE M,-Exrng/45
8220            Qtrmin=Qtrhr*15+(M*3/Nplot)*5
8230            IF Qtrmin=60 THEN
8240               Qtrmin=0
8250               Hrs=Hrs+1
8260            END IF
8270            LABEL USING "DD,A,ZZ";Hrs;":";Qtrmin
8280         NEXT M
8290         MOVE Nplot/2,-15
8300         LABEL "TIME "&Zone$
8310    !
8320    ! LABEL ORDINATE
8330    !
8340         LORG 8
8350         FOR M=0 TO Exrng STEP INT(Exrng/3)
8360            MOVE 0,M
8370            LABEL M
8380         NEXT M
8390         LDIR PI/2
8400         LORG 6
8410         MOVE -Nplot/7,Exrng/2
8420         LABEL "RANGE IN METERS"
8430    !
8440    !  TITLE
8450    !
8460         LDIR 0
8470         LORG 4
8480         MOVE Nplot/2,Exrng+3
```

```
8490        LABEL DATE$(TIMEDATE);"     ";Site$
8500        CLIP ON
8510   SUBEND
8520  !
8530  !
8540  !
9000  SUB Attenuation(Freq,Temp,Atten)
9010  !
9020  !
9030  ! This subprogram calculates the attenuation of the
9040  ! sound in air based upon equations in Neff 1975
9050  ! (source of subroutine: Thesis of R. Fuller)
9060  !
9070  !  Variables
9080  !
9090  ! Atom_pres  -  input atmospheric pressure in mb
9100  !
9110  ! Atten  -  attenuation coefficient of acoustic wave
9120  !
9130  ! Att_max  -  Variable in program.  It is the attenuation
9140  !             at the frequency of the maximum attenuation
9150  !             for the given input conditions.
9160  !
9170  ! F  -  Ratio of the frequency to frequency at maximum
9180  !       attenuation.
9190  !
9200  ! Fmax  -  Frequency of the maximum attenuation
9210  !
9220  ! H  -  variable used in the integration of excess attenuation
9230  !
9240  ! Pstar  -  variable used in intermediate calculations
9250  !
9260  ! Tstar  -  variable used as an intermediate in calculation
9270  !           of attenuation.
9280  !
9290  ! Wat_pres  -  Atmospheric water pressure in mb.
9300  !
9310  INPUT "Enter the atmospheric pressure in mb",Atom_pres
9320  INPUT "Enter the atmospheric water pressure in mb",Wat_pres
9330  H=100*Wat_pres/Atom_pres
9340  Tstar=(1.8*Temp+492)/519
9350  Pstar=Atom_pres/1014
9360  Fmax=(10+6600*H+44400*H*H)*Pstar/Tstar^.8
9370  Att_max=.0078*Fmax*Tstar^(-2.5)*EXP(7.77*(1-1/Tstar))
9380  F=Freq/Fmax
9390  Atten=(Att_max/304.8)*((.18*F)^2+(2*F*F/(1+F*F))^2)^.5
9400  Atten=(Atten+1.74E-10*Freq*Freq)/4.35
9410  SUBEND
```

```
9420  !
9430  !
9500  SUB File_init(Disc_address$,Nrec,File1$)
9510  !
9520  !
9530  !   CREATE THE STORAGE FILE ON THE DISC FOR
9540  !   THE REDUCED DATA
9550  !
9560  !
9570      INPUT "ENTER THE REDUCED DATA OUTPUT FILENAME ",File$
9580      File1$=File$&Disc_address$
9590      CREATE BDAT File1$,180,400
9600      ASSIGN @File1 TO File1$
9610  !
9620  SUBEND
```

APPENDIX B

SPEAKER AND ARRAY ANALYSIS

In the design of our echosounder, it was determined that a rapid decay time was required to obtain accurate short range information. Weight restrictions involved with equipment transportation plus maximum response at high frequencies led to our decision to use piezo ceramic speakers. The Motorola KSN 1005A speaker was selected based on these requirements and the specifications charted in the Motorola catalog [Ref. 16] and reproduced below in Figures 23 through 25.

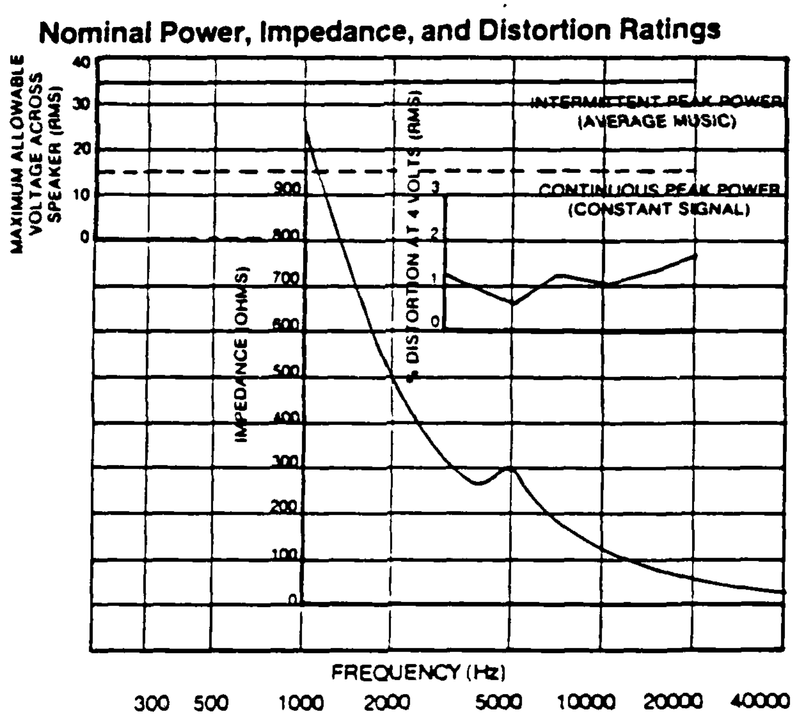


Fig. 23. Speaker Ratings

Typical Frequency Response

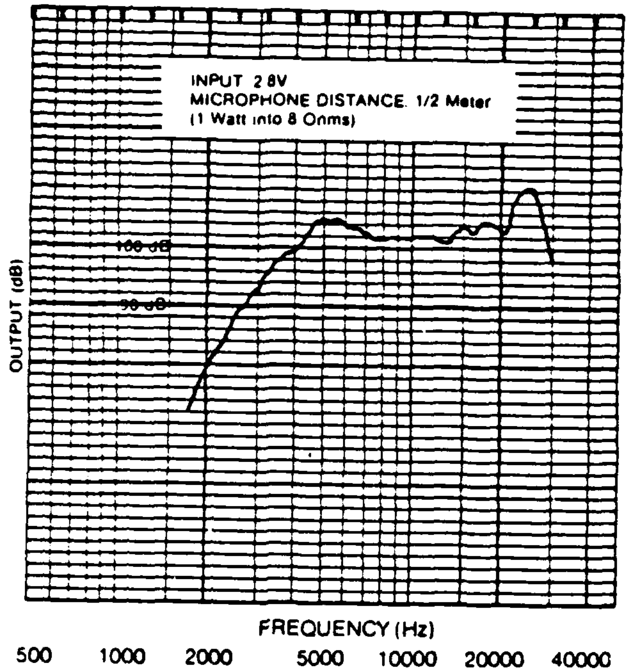


Fig. 24. Speaker Frequency Response

Dimensions: KSN 1005A, KSN 1003A

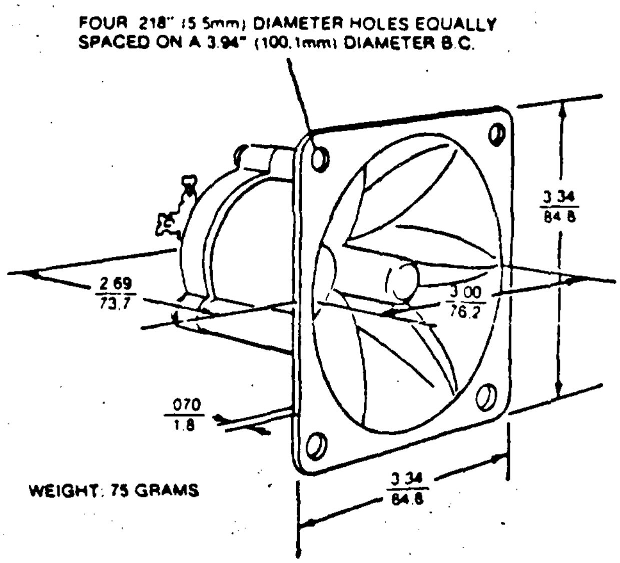


Fig. 25. Speaker Dimensions

The frequency response charts indicate that a maximum response for our speakers occurs at a resonant frequency of 5000 Hertz. This frequency was used as the baseline from which all our measurements are made.

Using the speakers in an anechoic chamber, the average e^{-1} voltage decay time was measured to be approximately 900 μsec (Fig. 26). This decay time translates into a sound propagation distance of just over 15.0 centimeters (at STP) from the speakers. Considering our requirements, this speaker is ideally suited to serve our purpose.

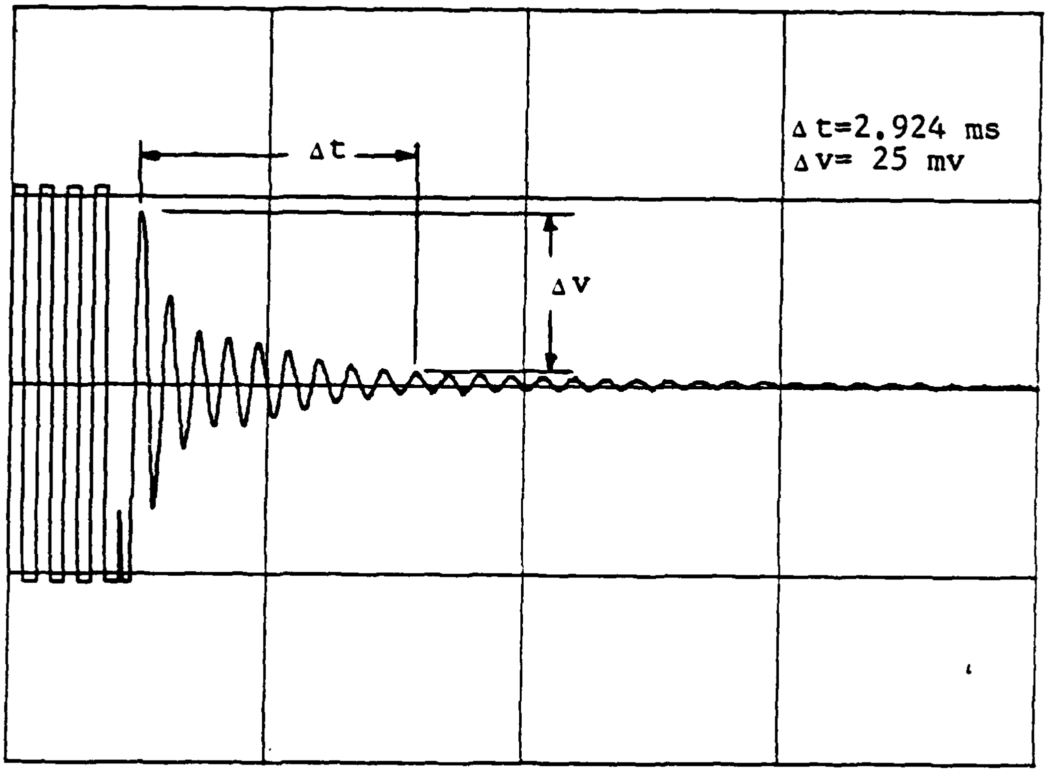


Fig. 26. Speaker Decay Time Trace

B. ACOUSTIC ARRAY

Our next consideration was the echosounder array pattern. Ideally, the acoustic sources should be placed exactly one half wavelength apart. At a frequency of 5000 Hertz, this would require spacings of 3.4 centimeters (at STP) which is physically impossible for the speakers we have chosen. The closest possible spacing is 7.62 centimeters between sources after shaving off the flange of the horn (Fig. 25).

From Kinsler, et al. [Ref. 14], the equation for the directionality factor of a simple line array is derived as:

$$H(N,\theta) = \left| \frac{1}{N} \frac{\sin\left(\frac{N}{2} kd \sin\theta\right)}{\sin\left(\frac{1}{2} kd \sin\theta\right)} \right| ,$$

where

k is the wave number ($2\pi/\lambda$),

d is the distance between sources,

N is the number of sources, and

θ is the angle measured from a line perpendicular to the array to the direction of interest.

However, this equation assumes simple point sources which does not adequately describe our speakers. It was necessary to couple this equation to the directional factor for a piston source which is also identified in Kinsler, et al. [Ref. 14: p. 108] as:

$$D(\theta) = \left| \frac{2 \ J_1 \ (\ ka \ \sin (\ \theta \ ) \ )}{ka \ \sin (\ \theta \ )} \right| ,$$

where

k is still the wave number,

a is the radius of the piston source,

θ is the angle measured from a line perpendicular to the array to the direction of interest, and

$J_1 (x)$ is a Bessel function of Order 1 with an argument x.

These two equations were combined together to form the equation of directionality for a linear array of piston sources, L(N,θ), by simple multiplication.

$$L(N,\theta) = H(N,\theta) \cdot D(\theta)$$

This equation was incorporated into a computer program, which may be found in Reference 3, and used to generate linear array patterns for various numbers of piston sources (Figs. 27 through 31).

It was concluded from these plots that five linear elements would provide the best combination of forward directionality, sidelobe suppression, physical size and a relatively low cost. Then, in order to enhance both array efficiency and symmetry, we settled on a five by five element array design with 7.26 centimeter spacing between

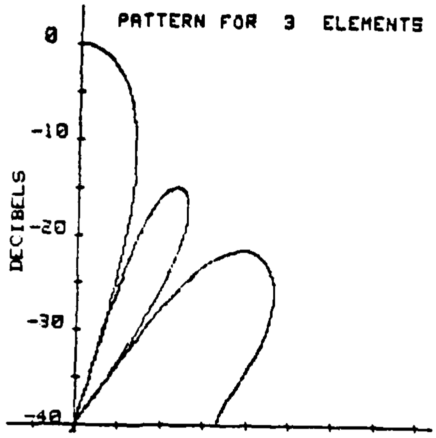


Fig. 27. Three Element Array

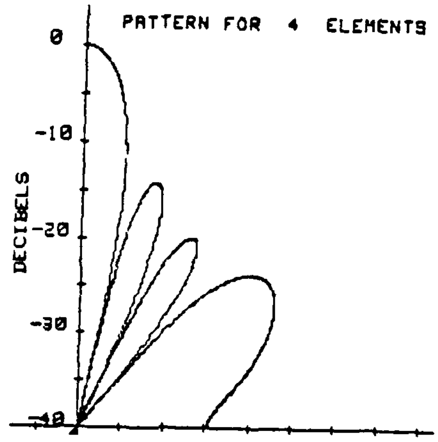


Fig. 28. Four Element Array

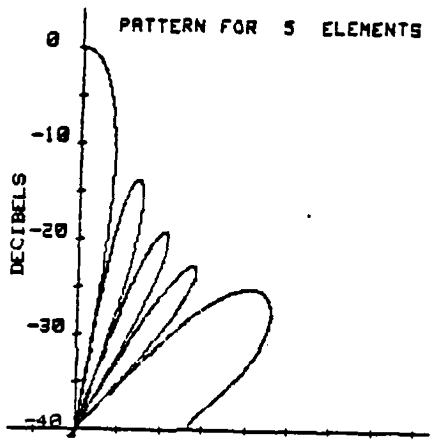


Fig. 29. Five Element Array

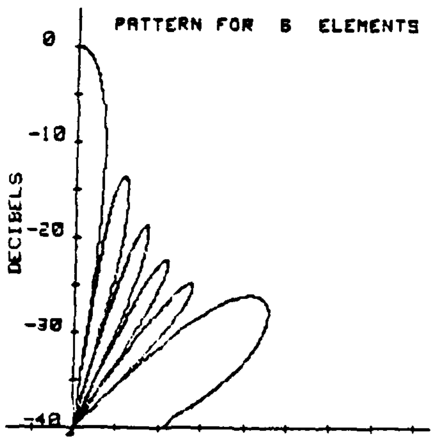


Fig. 30. Six Element Array

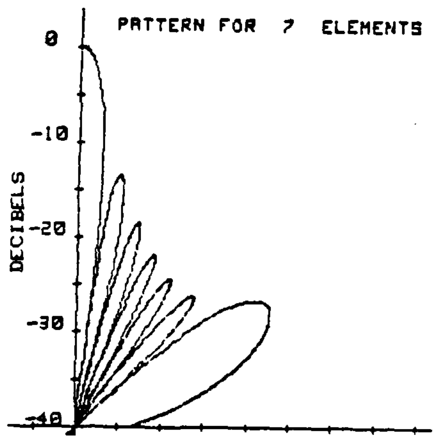


Fig. 31. Seven Element Array

speakers in both the vertical and horizontal directions.

After verifying the manufacturers polarity designation for 35 speakers, we obtained Lissajous plots for each individual speaker (Fig. 32). Based on the speaker's output to input voltage ratios as illustrated by these plots, we were able to rank all our speakers by signal efficiency. It was based upon this criteria that we selected the 25 most efficient speakers for the array, placing the best speakers at the center and subsequent ranking speakers further toward the sides and corners.

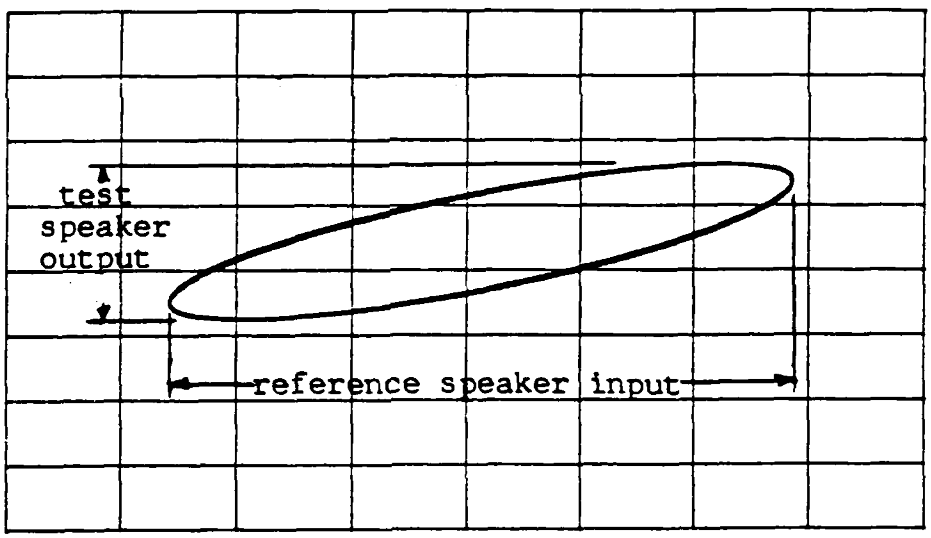


Fig. 32. Lissajous Plot

The 25 selected speakers were mounted in a five by five planar array on a balsa wood insulated bilayered sheet metal board. After wiring all the speakers in parallel, we surrounded all the electrical connections and speaker backs with two 3.0 centimeter layers of foam insulation sandwiching a 1.0 millimeter lead sheet. Then the entire array mounting was enclosed in a 44 by 44 by 5 centimeter sheet metal box. This design was chosen to suppress virtually all acoustic energy propagating out the rear hemisphere of the array, while shielding the array from any external electrical interference (Figs. 33 and 34).

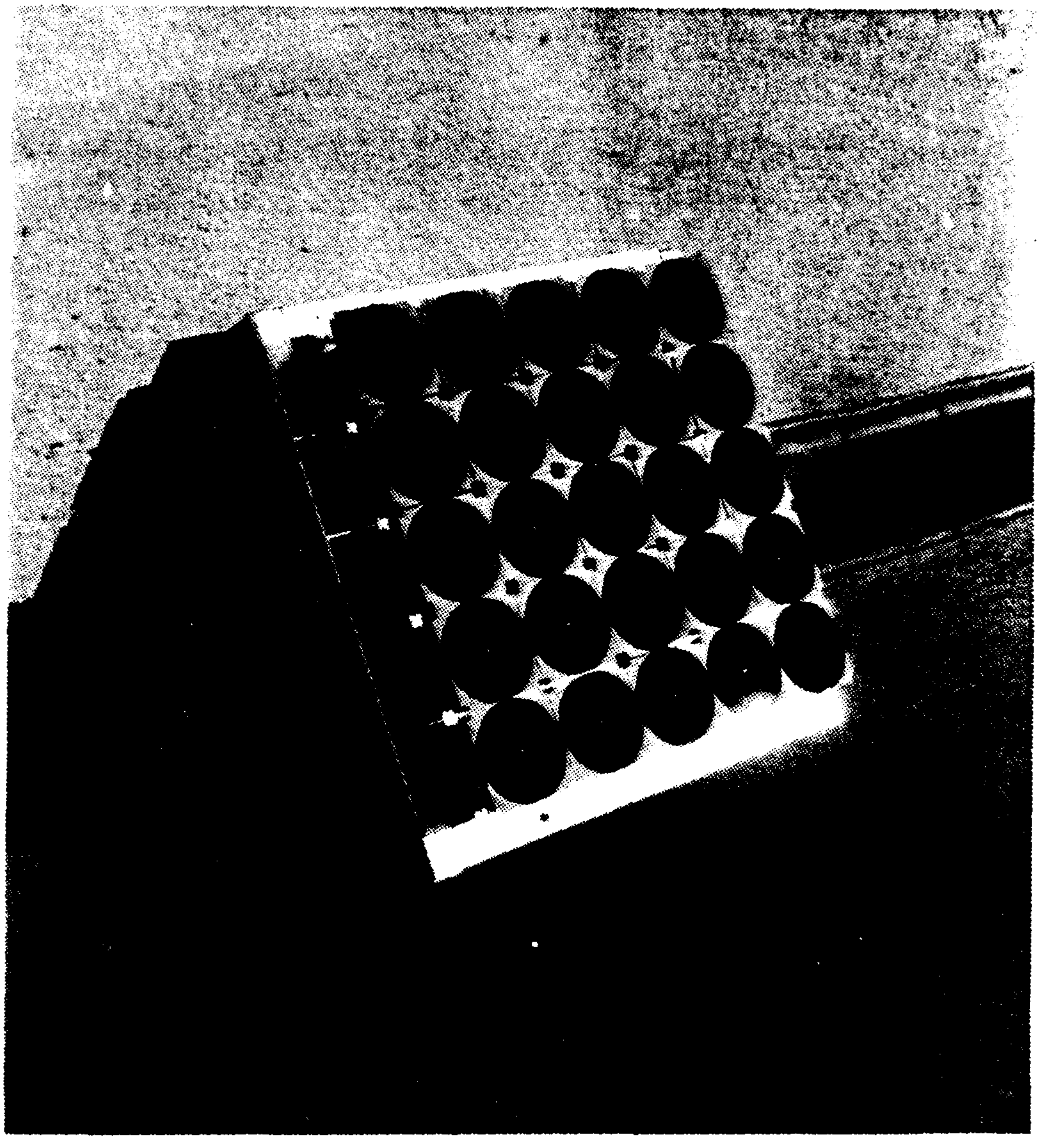


Fig. 33. Array Photo

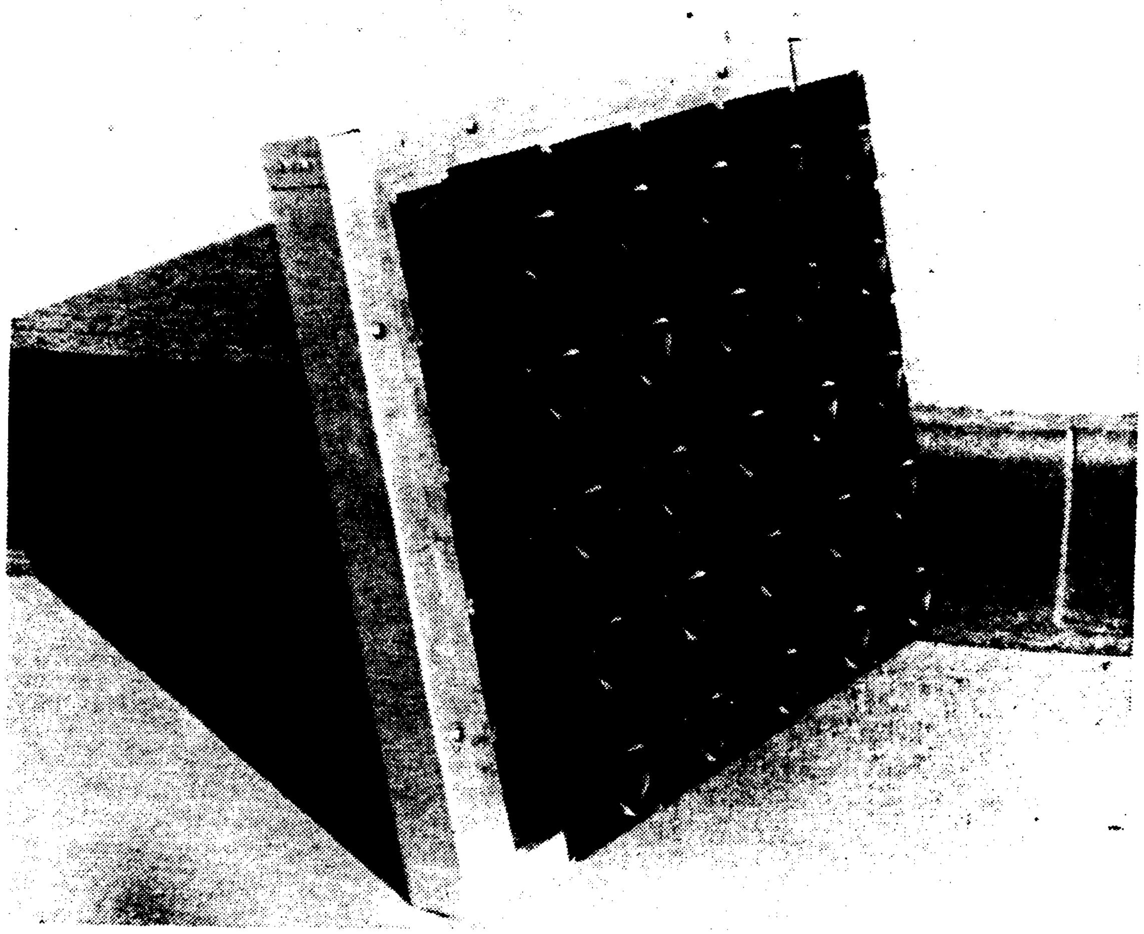


Fig. 34. Array Photo

APPENDIX C

ENCLOSURE DESIGN

Acoustic echosounding has proven to be an extremely useful technique for probing and analyzing the lower atmosphere. In order to most efficiently utilize the acoustic waves transmitted and later received by this remote sensing method, it is essential to have an efficient antenna with highly directive beams and strongly suppressed sidelobes. Antenna design becomes increasingly more important in a noisy environment where noise pollution within the sidelobes may dominate the desired signal within the main lobe. Hall and Wescott [Ref. 12] showed that sidelobe suppression improved with higher frequencies. Their studies showed that the measured 90 degree sidelobe suppression ranged from 38 dB at 1 KHz to 50 dB at 5 KHz. Furthermore, any significant improvement in sidelobe suppression could only be obtained by surrounding the antenna with an acoustic energy absorbing cuff or shroud.

In an effort to maximize our antenna main lobe to sidelobe power ratio, we intend to operate only at high frequencies as discussed in the previous section. Additionally, we have designed an acoustic energy absorbing enclosure. Many designs were considered based upon previous research in the field of echosounding [Refs. 17 through 20]. In addition, we obtained the actual acoustic beam patterns for our array using a computer program written by LCDR Butler [Ref. 21] which we modified for our purposes. This modified version of LCDR Butler's program may be found in Reference 3. By rotating the array in an anechoic chamber, we were able to produce highly accurate polar plots of the array beam patterns (Figs. 35 and 36).

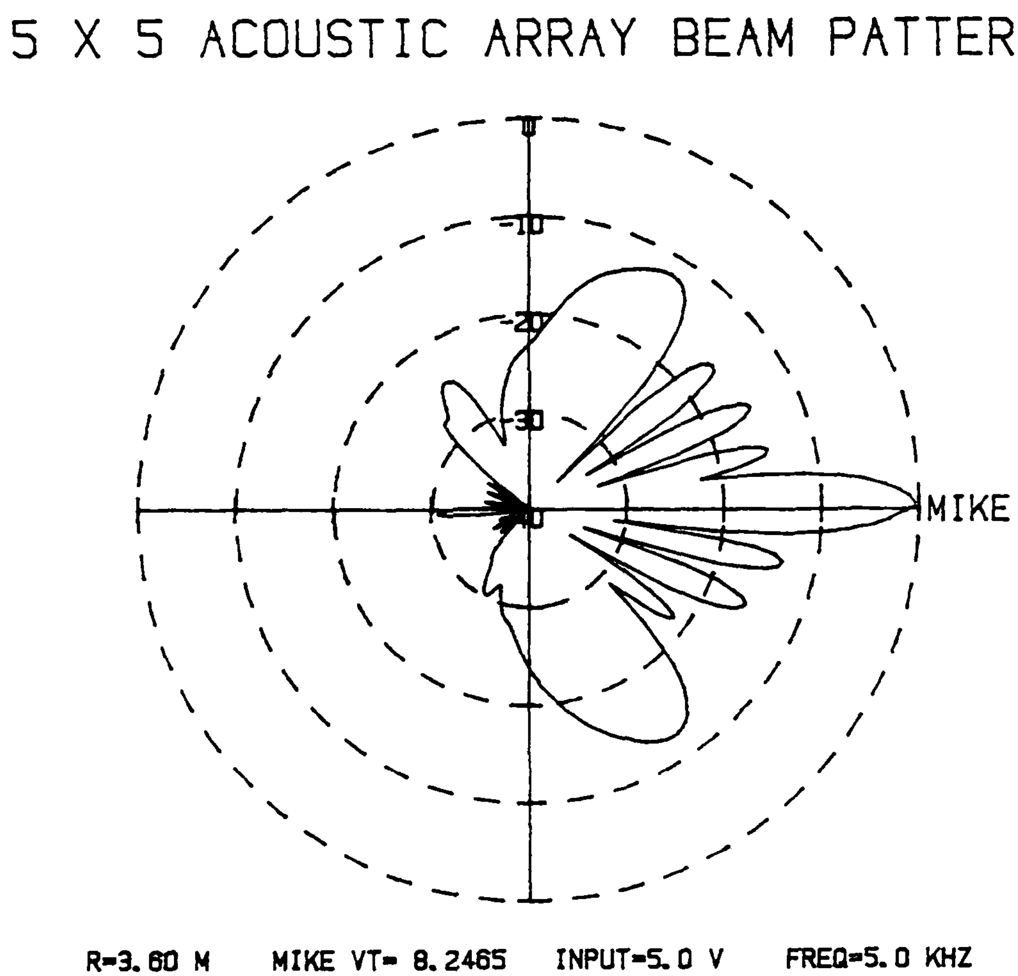


Fig. 35. Polar Plot of 5 X 5 Array Beam Pattern

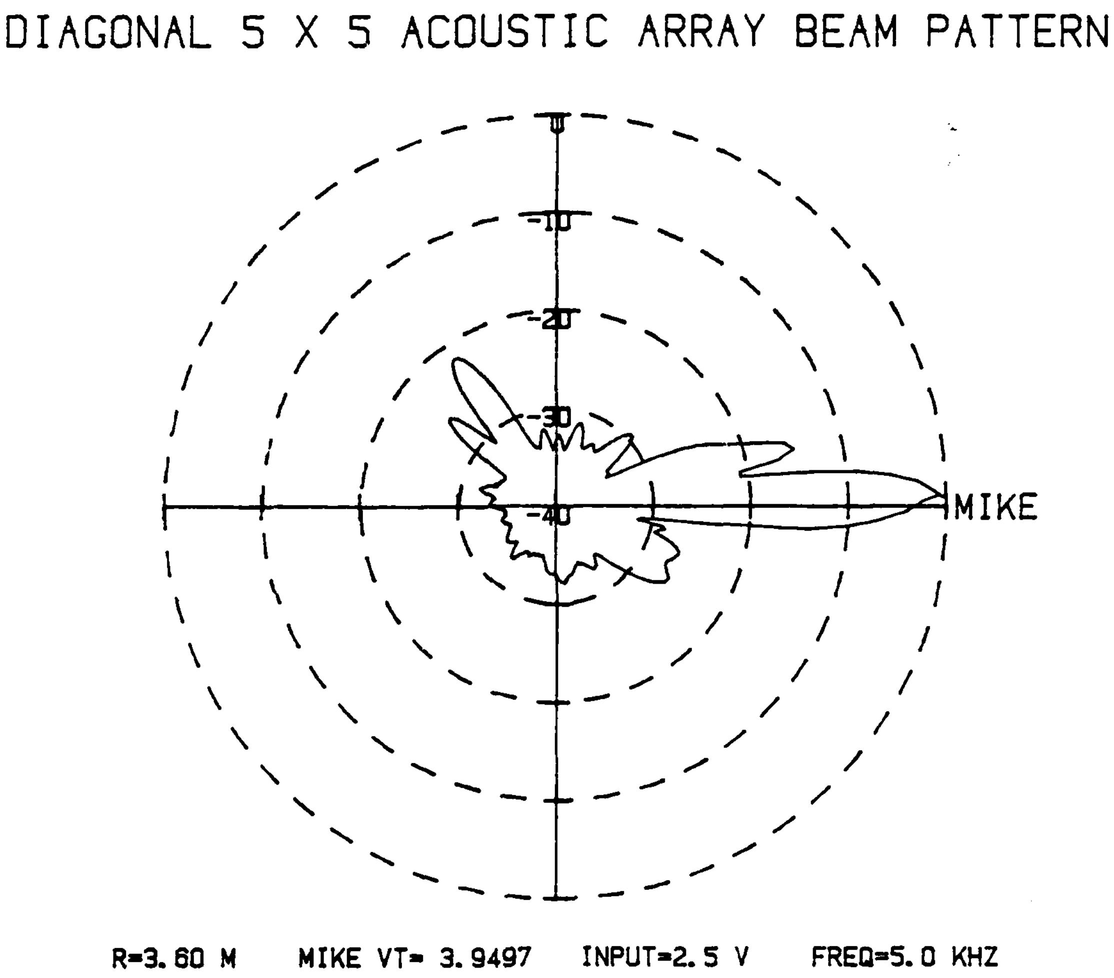


Fig. 36. Polar Plot of 5 X 5 Array Beam Pattern at a 45° Aspect

These polar plots and the actual coordinates corresponding to the individual data points confirmed the computer prediction for the five element line array (Fig. 29). Additional polar plots obtained by varying both the input array voltage and range between array and microphone further support our claim that for a 5 KHz carrier frequency, the main lobe is confined to a divergence angle of 20 degrees. Since it is our aim to suppress all sidelobes and utilize solely the main lobe, we chose not to taper our enclosure as most previous researchers had. Rather we designed the enclosure based upon the dimensions of the array itself and the acoustic beams it generated.

Plywood was used for the construction of the enclosure and provided not only a rigid, inexpensive framework, but also proved to greatly attenuate external noise interference. Anticipating all kinds of weather conditions during data collection, the plywood enclosure was first waterproofed with four coats of marine varnish. Grooved joints, caulking and weather stripping were also design considerations.

A millimeter layer of lead can suppress an acoustic signal as much as 40 dB (Figs. 37 and 38). About 7.0 centimeters of corrugated, egg-carton design foam can suppress a signal another 3 to 4 dB (Figs. 37 and 39). Together they make an extremely efficient absorbing material for use in our enclosure.

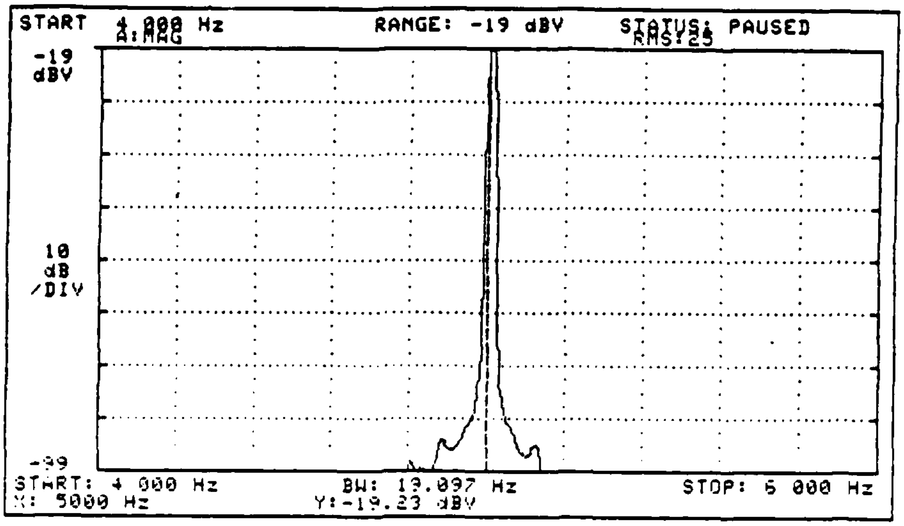


Fig. 37. Response Reference, No Insulation

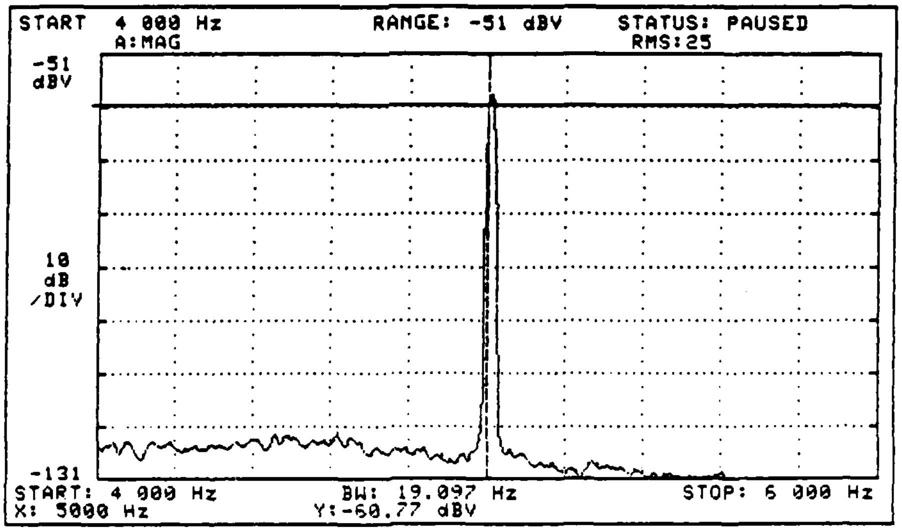


Fig. 38. Signal Suppression by Lead

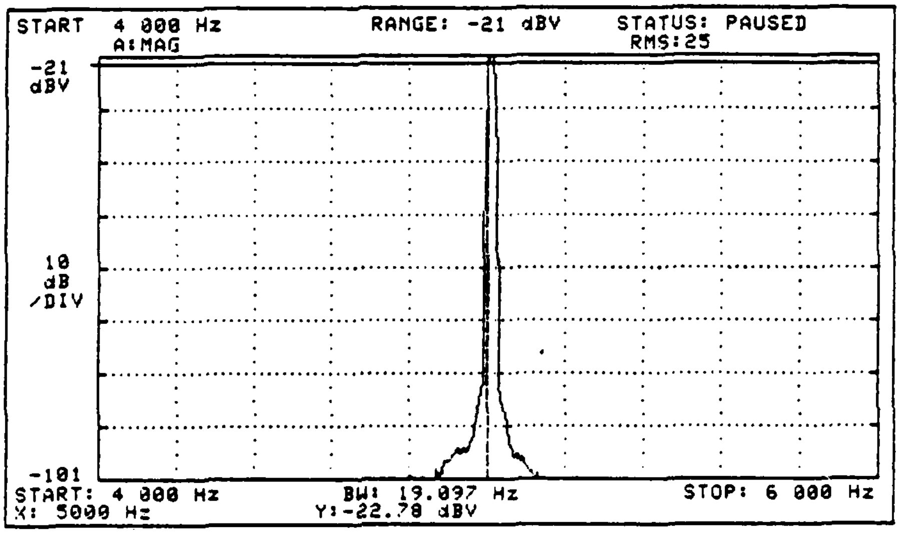


Fig. 39. Signal Suppression by Foam

Lead-lined absorbing foam was glued to all inner surfaces of the enclosure with two 1.0 millimeter layers of lead overlapping at all corners. Strong aluminum brackets were used to connect the four side panels to each other as well as to the enclosure base (Figs. 40 through 42).

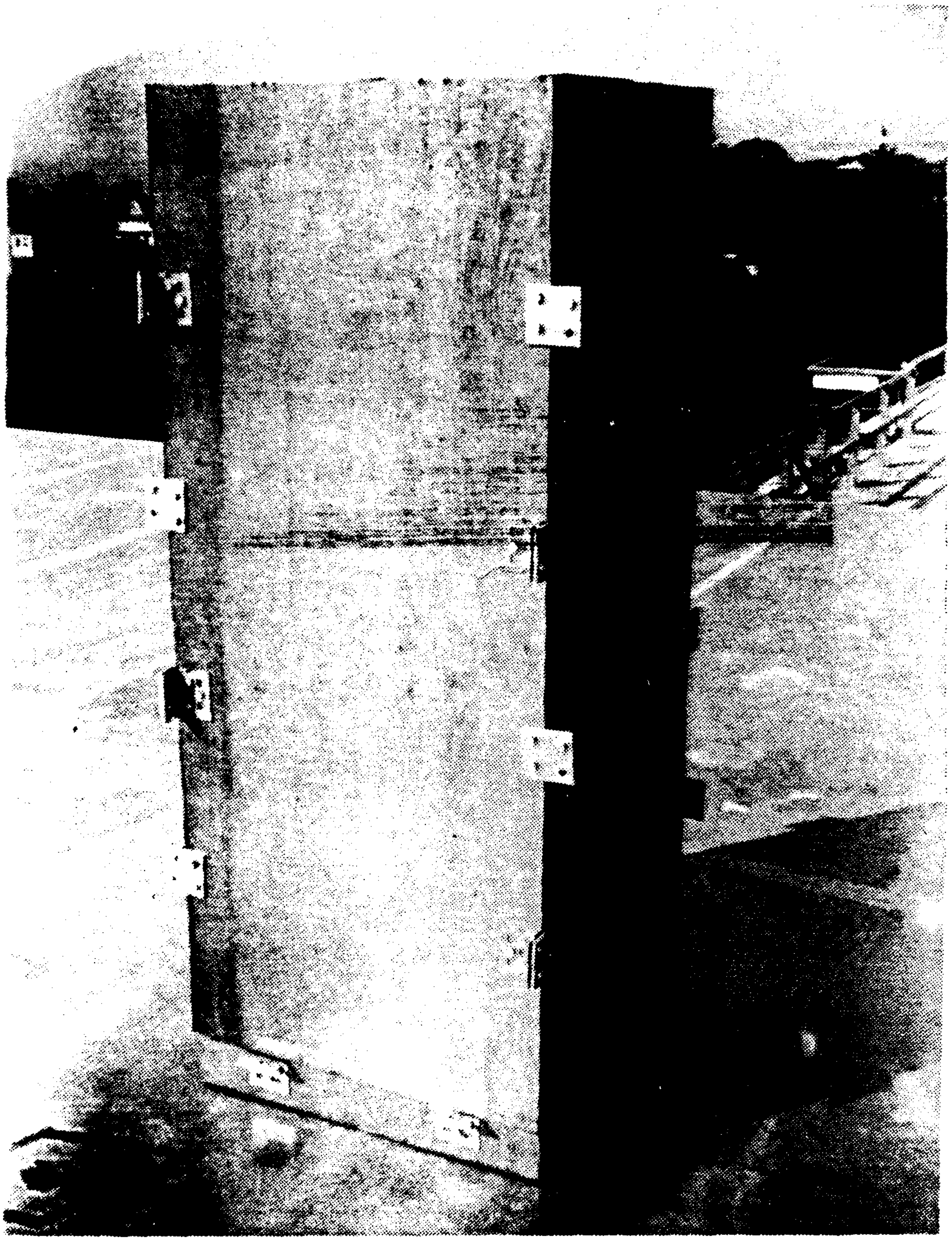


Fig. 40. Enclosure Photo, Fully Assembled

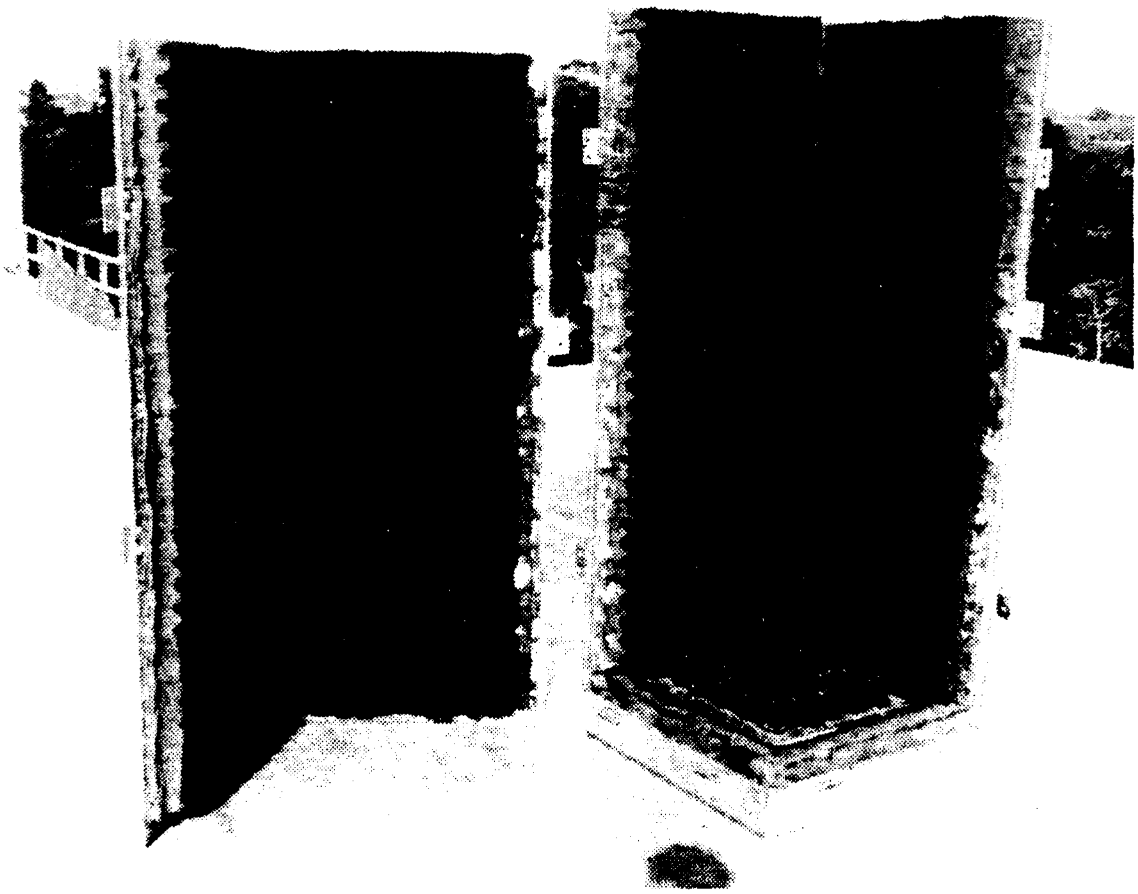


Fig. 41. Enclosure Photo, Interior

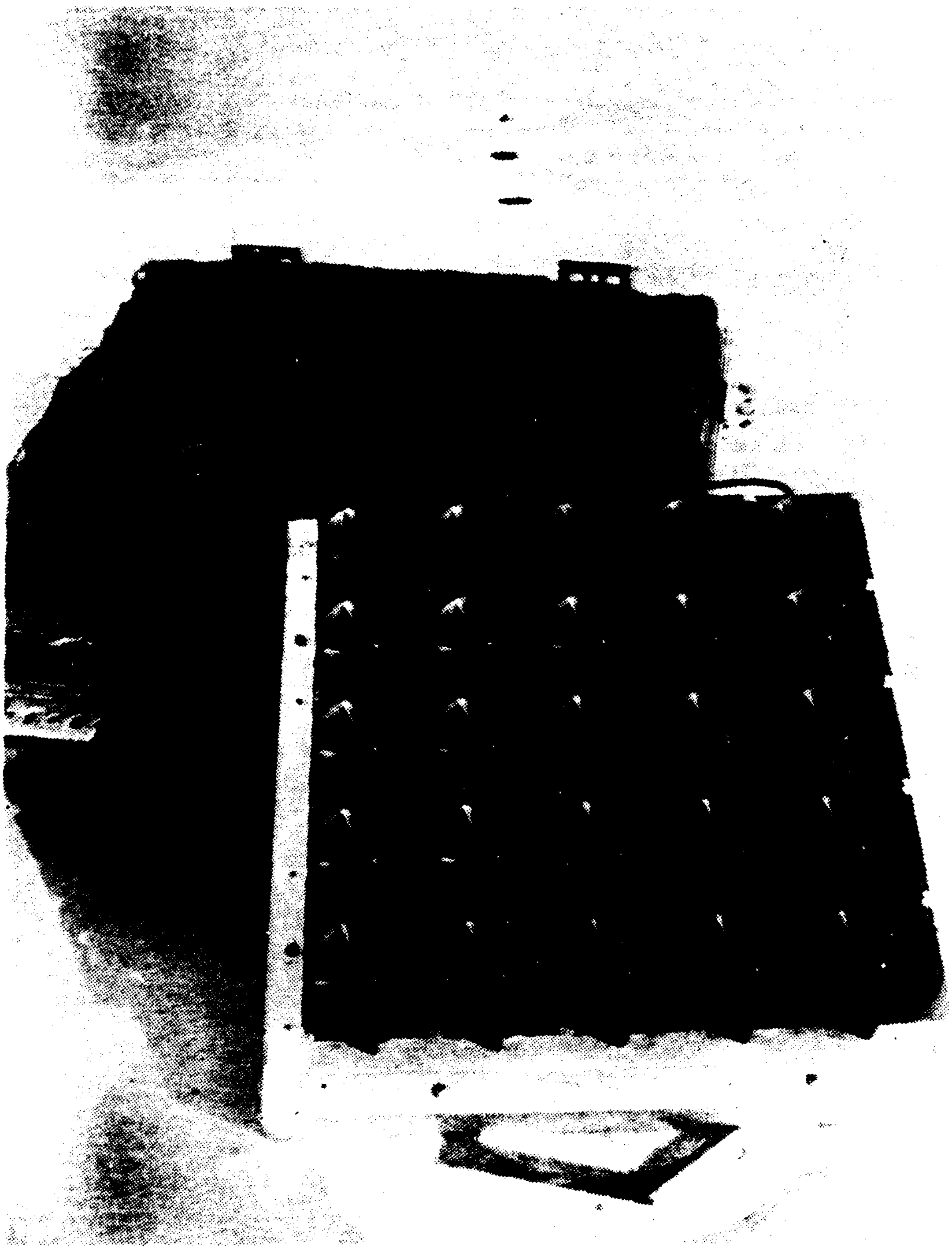


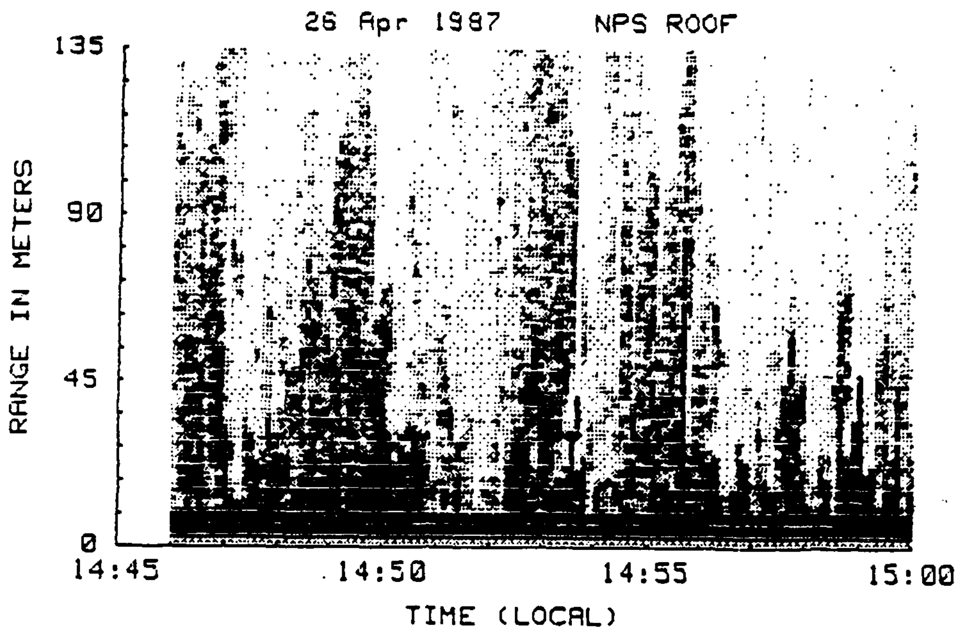
Fig. 42. Enclosure Photo, Base with Array

APPENDIX D

ECHOSOUNDER OUTPUT

Sixteen echosounder output traces were included to exhibit typical atmospheric activity. Many of the plots, such as the 14:45, 15:30, and the 17:30 of 26 April and the 10:00, 11:15, 13:00, 14:15, 15:15, 16:15, and the 17:15 of 27 April, have convective plumes which are prevalent whenever a heat flux between the surface and atmosphere exists. The plots of 18:15 and 19:15 on the 26th of April and of 18:00, 18:45 and 20:00 on the 27th of April clearly show the passage of the neutral event which is encountered when the atmospheric and surface temperature difference becomes negligible. Finally, the plot of 16:30 on 26 April can be associated with strong winds which exhibit a somewhat uniform return for all altitudes across the entire 15 minute interval of the trace.

The horizontal axis labels of the C_T^2 plots are small and may be hard to read. This axis is a log scale beginning with $1 \cdot 10^{-10}$ at the left side of the plot and ending with $1 \cdot 10^{0}$ at the right side of the plot. Each tick mark moving left to right along this axis represents an integer increase in the exponent of 10.


26 Apr 1987 NPS ROOF
RANGE IN METERS
135
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45
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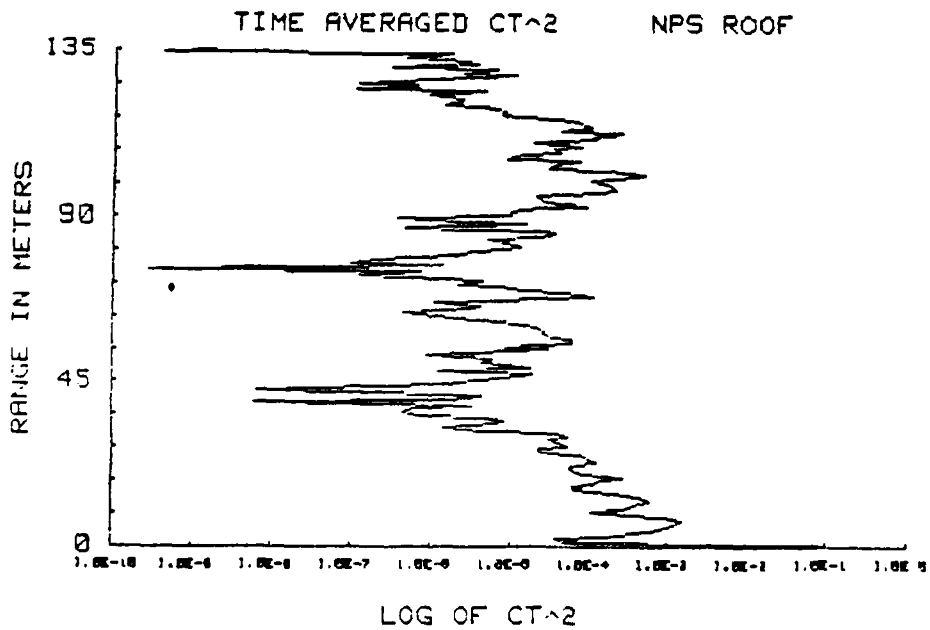
14:45
14:50
14:55
15:00
TIME (LOCAL)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RANGE IN METERS
135
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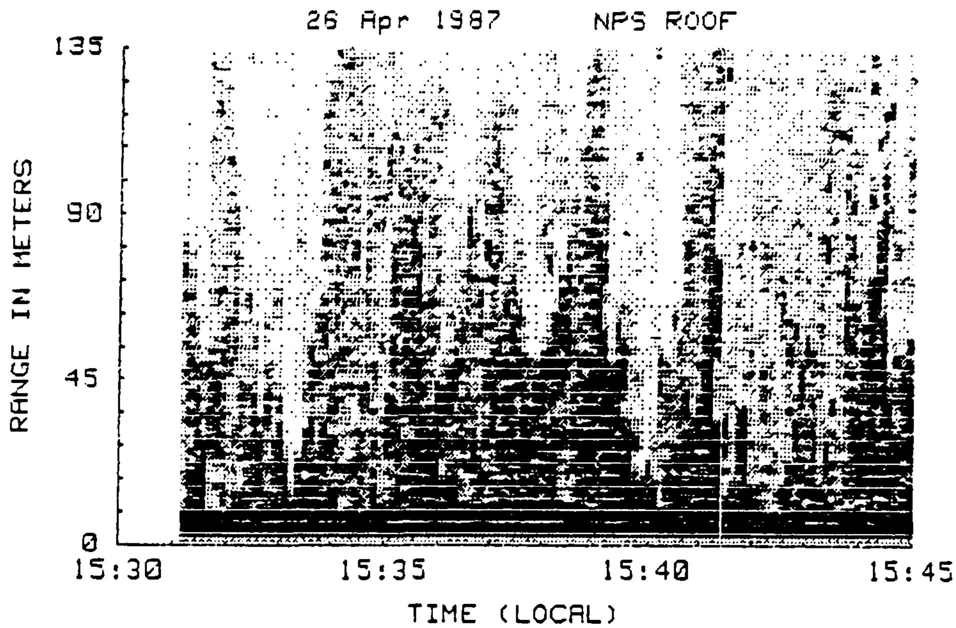
45
0
LOG OF CT^2



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RANGE IN METERS
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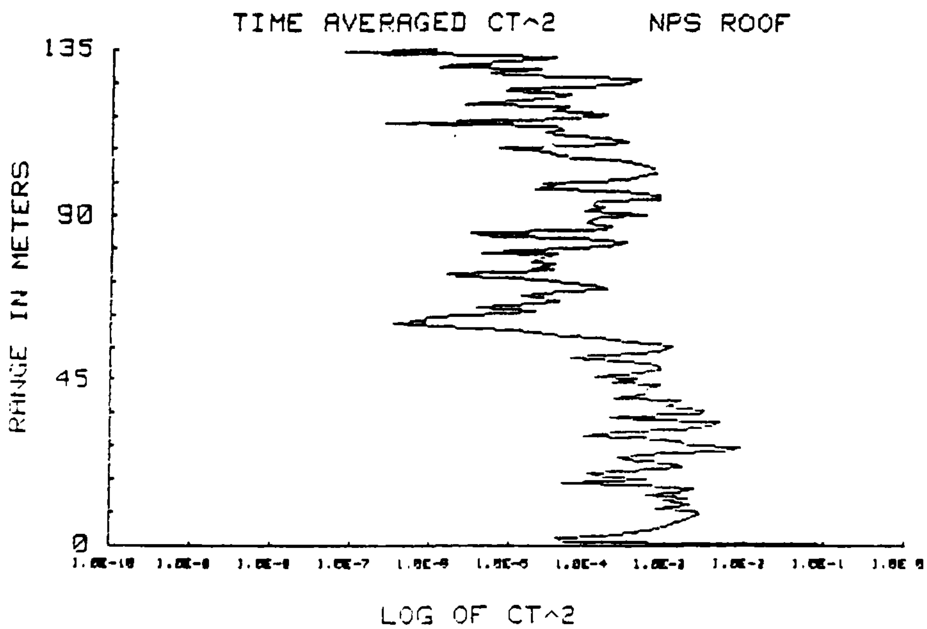
15:35
15:40
15:45
TIME (LOCAL)



TIME AVERAGED CT^2
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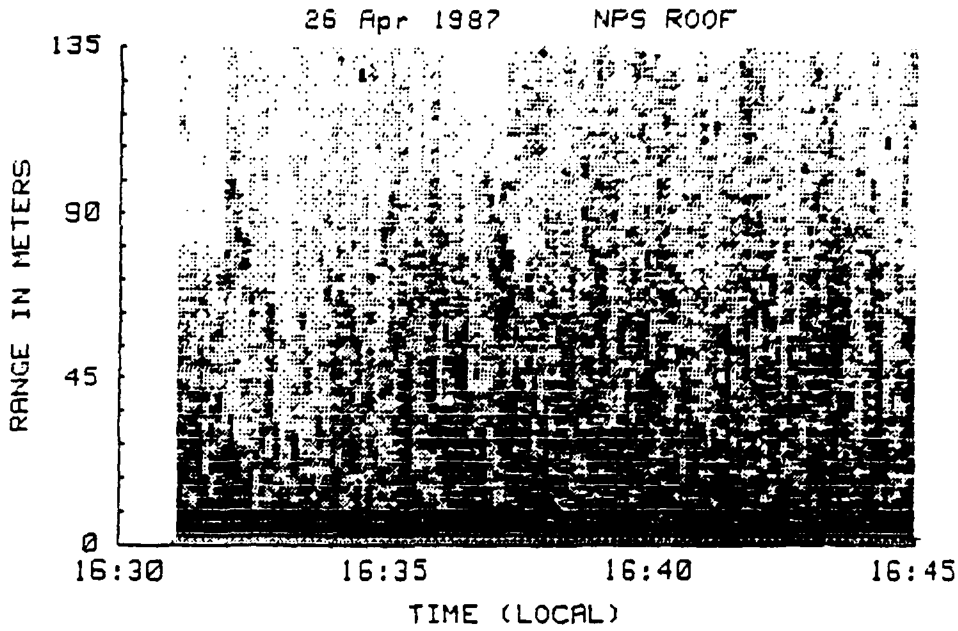
0
RANGE IN METERS
1.0E-7
1.0E-4
LOG OF CT^2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RANGE IN METERS
16:30
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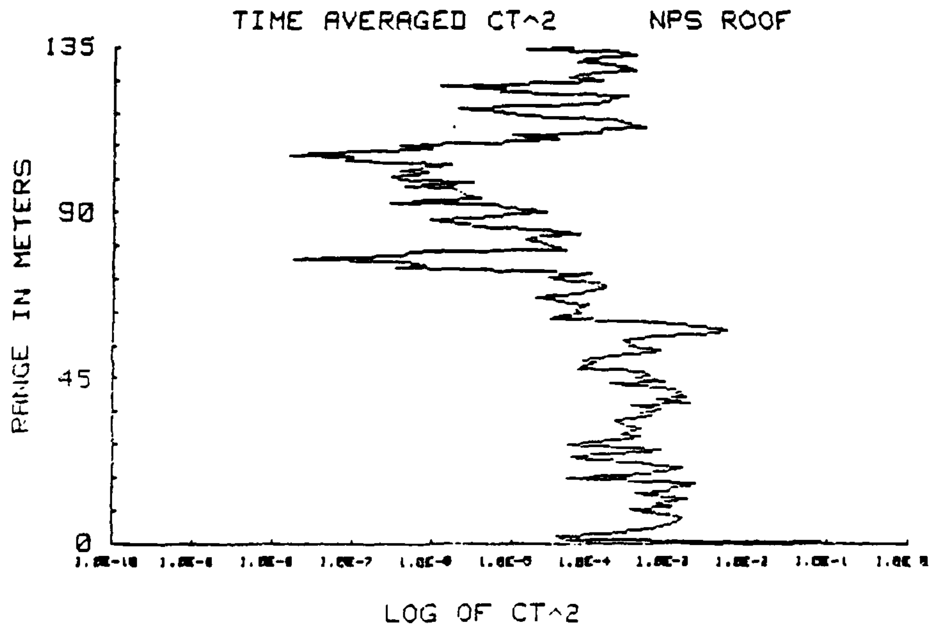
TIME (LOCAL)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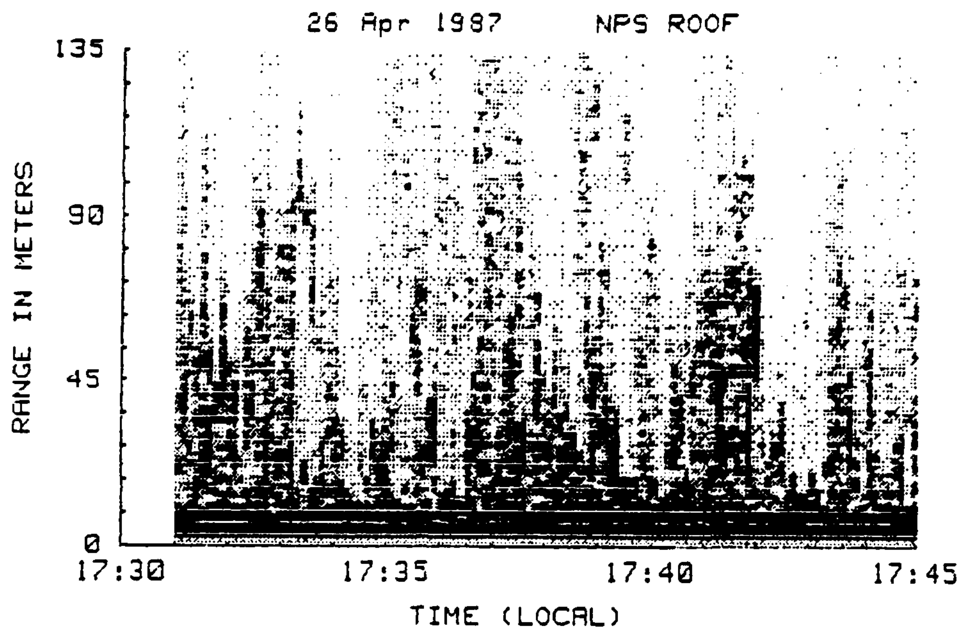
RANGE IN METERS
LOG OF CT^2



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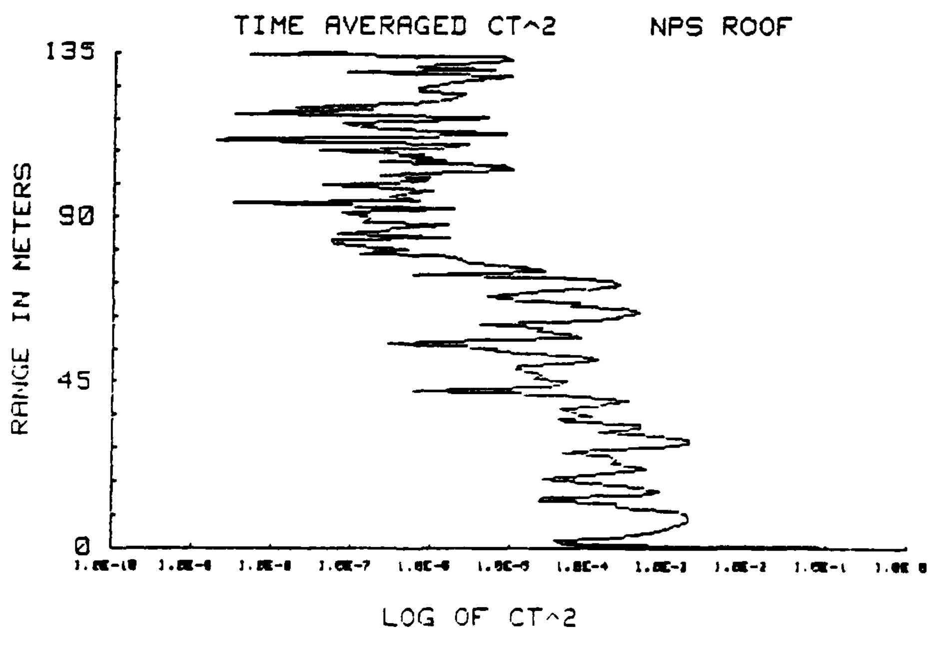
0
RANGE IN METERS
17:30
17:35
17:40
17:45
TIME (LOCAL)



TIME AVERAGED CT^2 NPS ROOF
135
90
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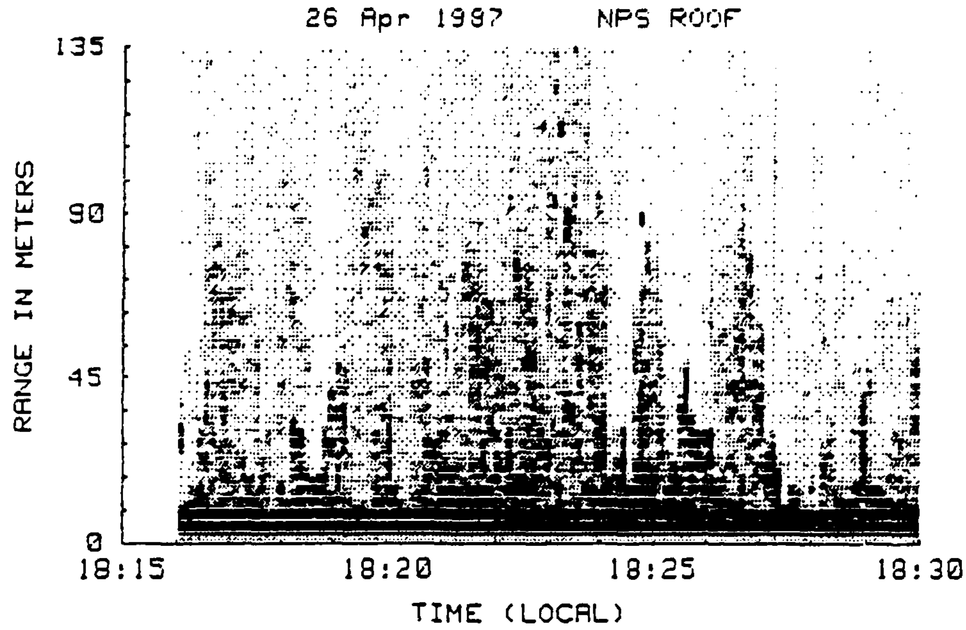
RANGE IN METERS
LOG OF CT^2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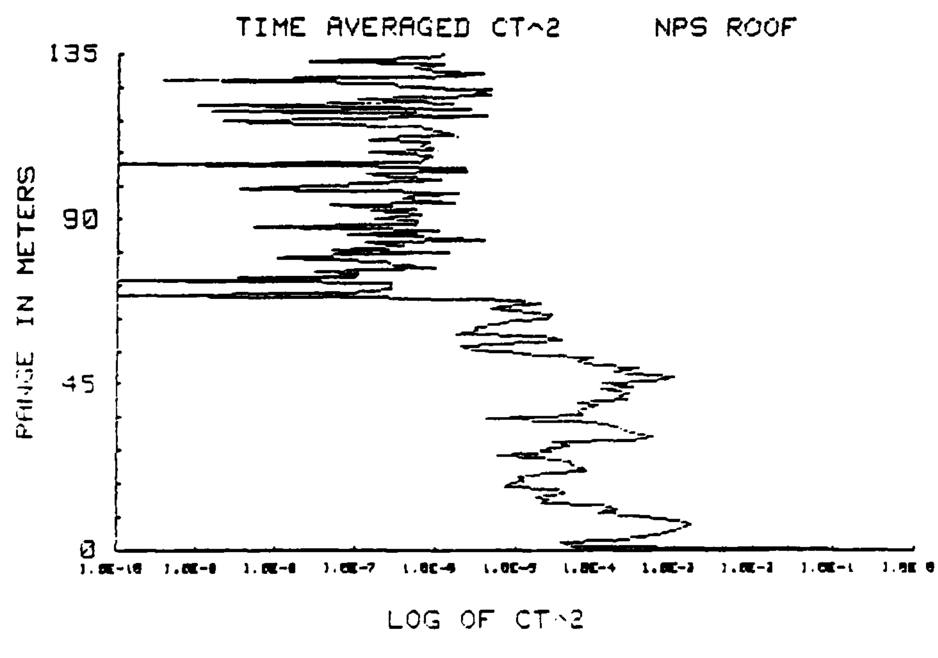
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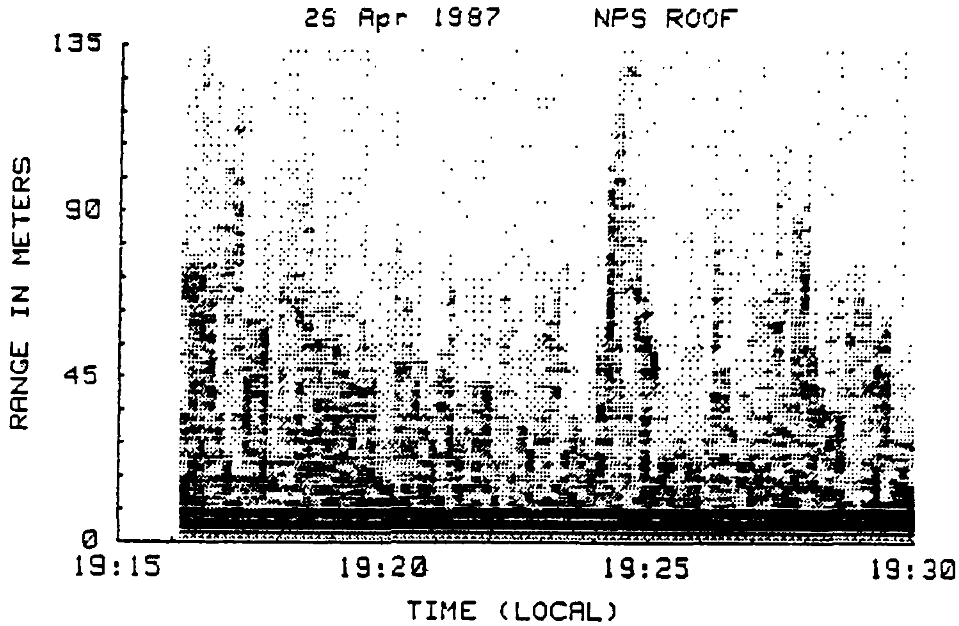
1.0E-7
1.0E-4
LOG OF CT^2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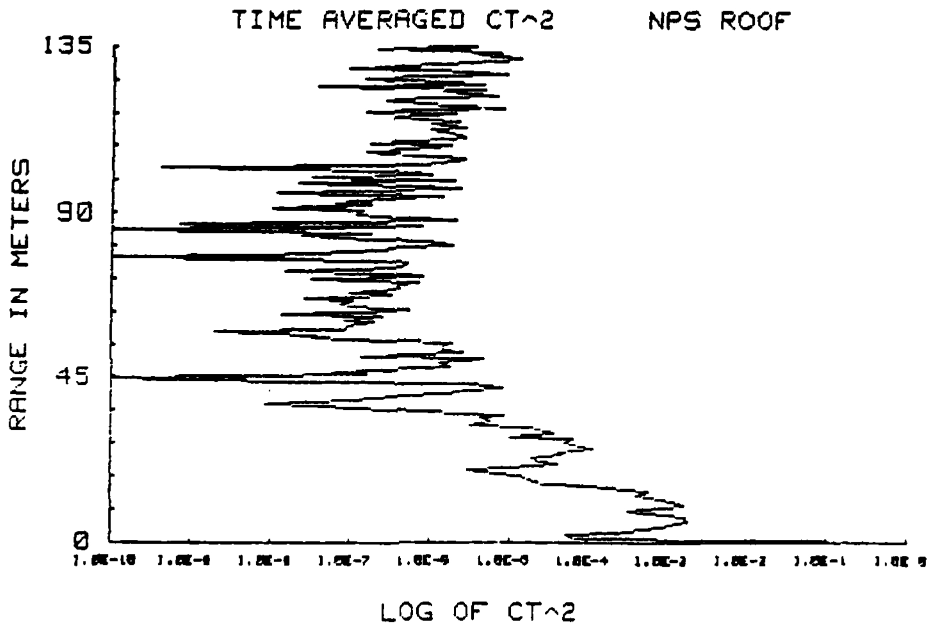
RANGE IN METERS
19:15
19:20
19:25
19:30
TIME (LOCAL)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90
45
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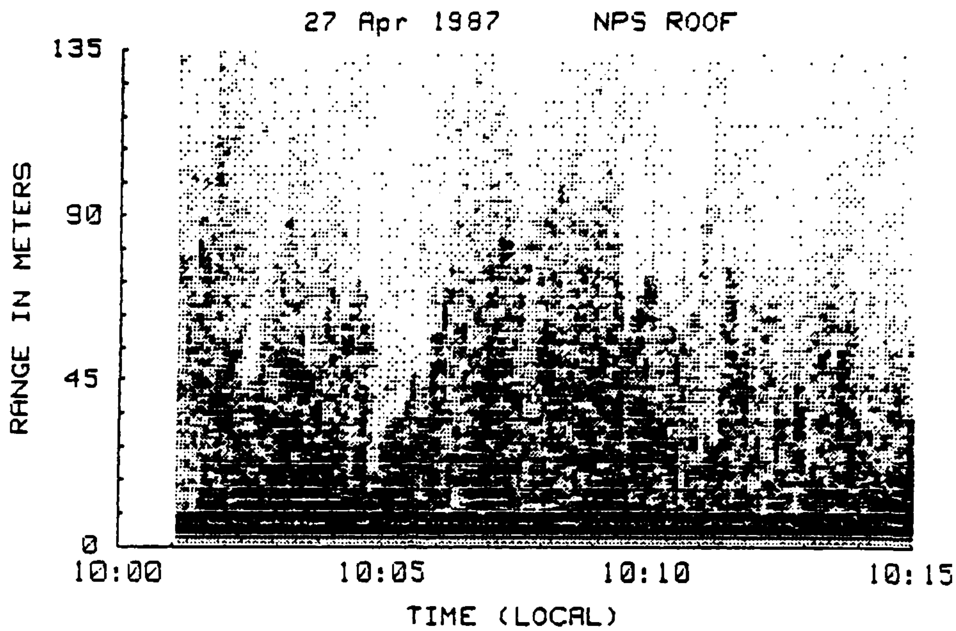
RANGE IN METERS
LOG OF CT^2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RANGE IN METERS
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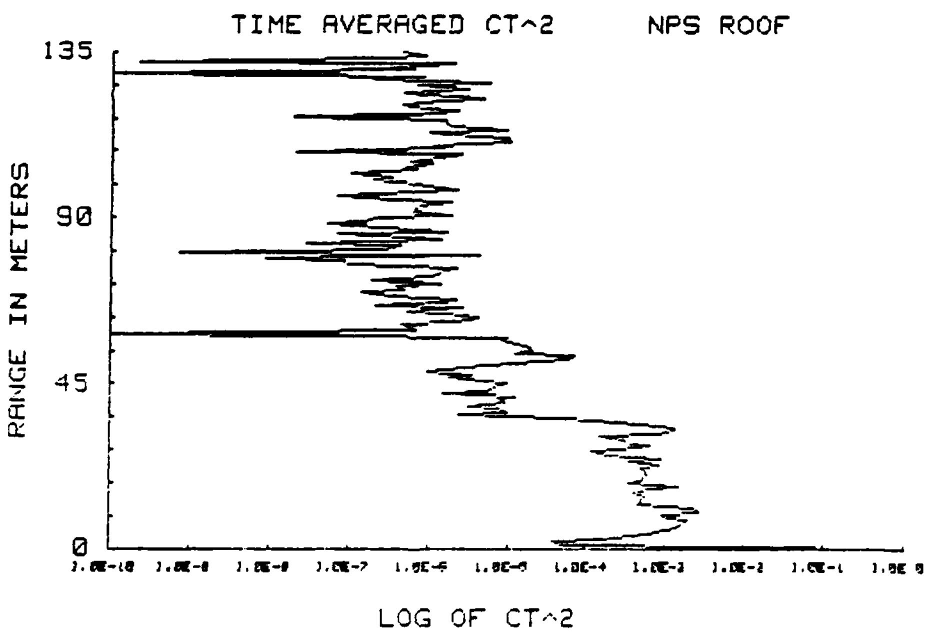
10:00
10:05
10:10
10:15
TIME (LOCAL)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RANGE IN METERS
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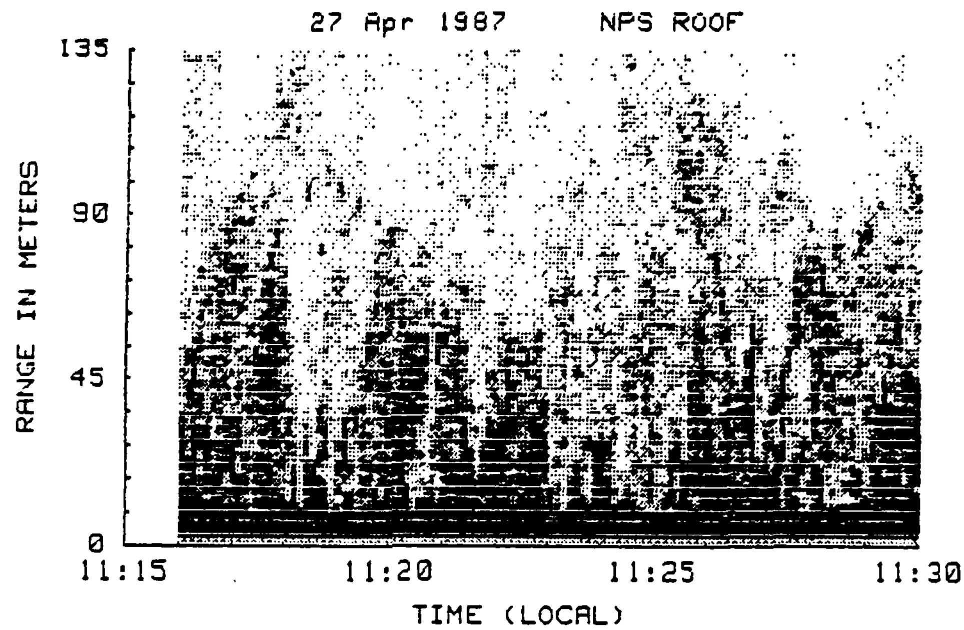
0
LOG OF CT^2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11:15
11:20
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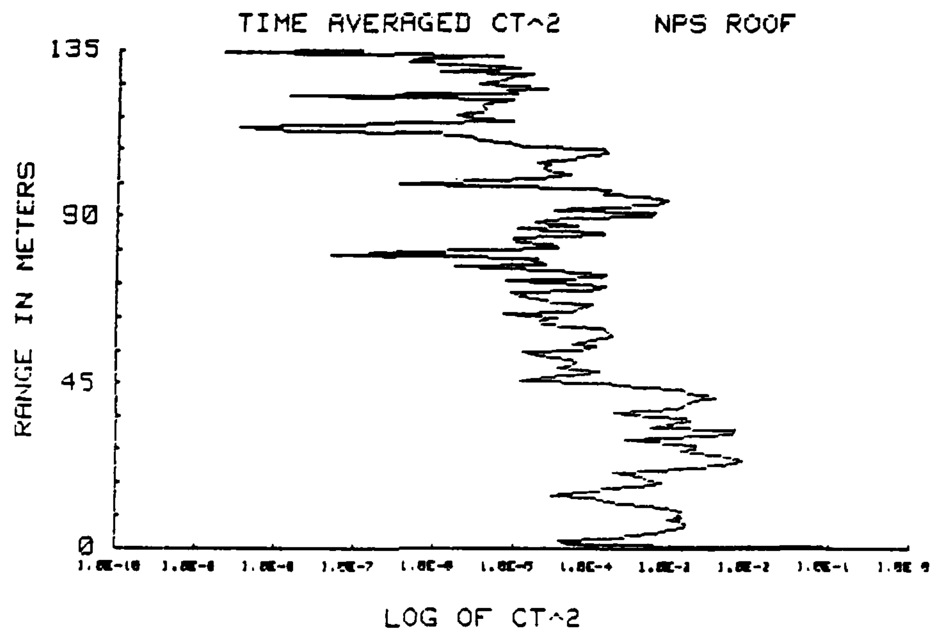
11:30
TIME (LOCAL)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NPS ROOF
RANGE IN METERS
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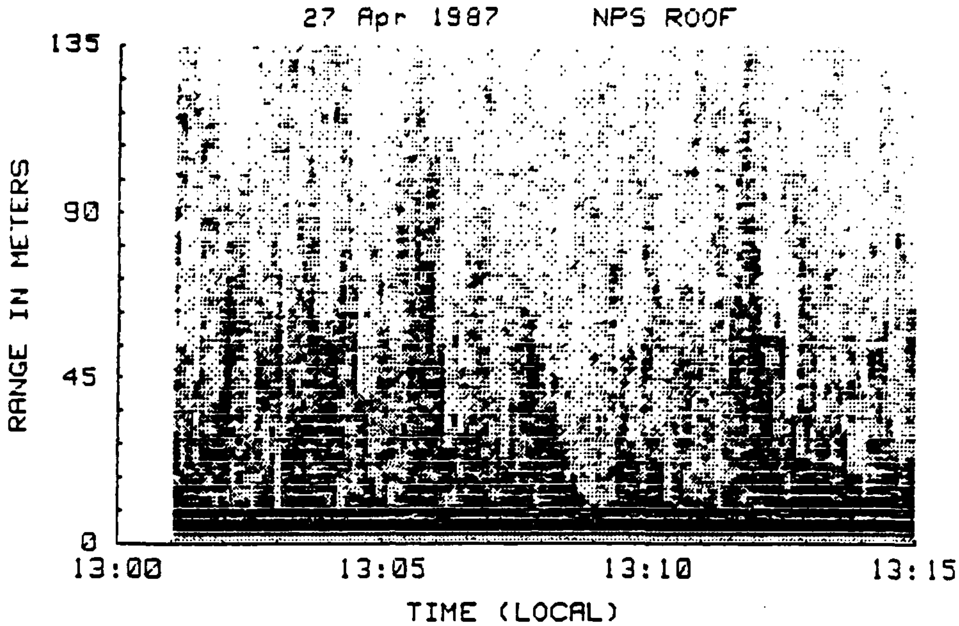
LOG OF CT^2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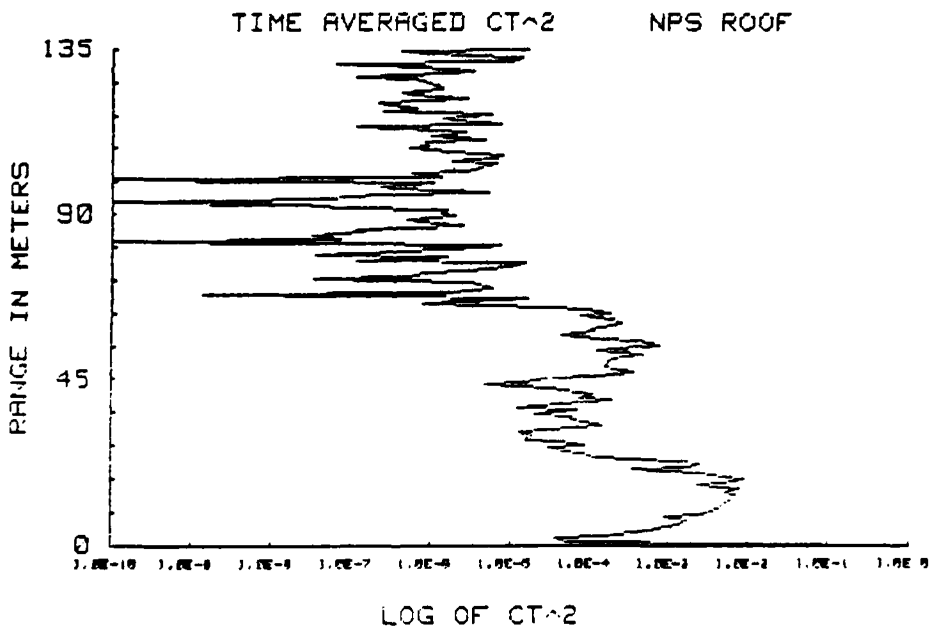
RANGE IN METERS
13:00
13:05
13:10
13:15
TIME (LOCAL)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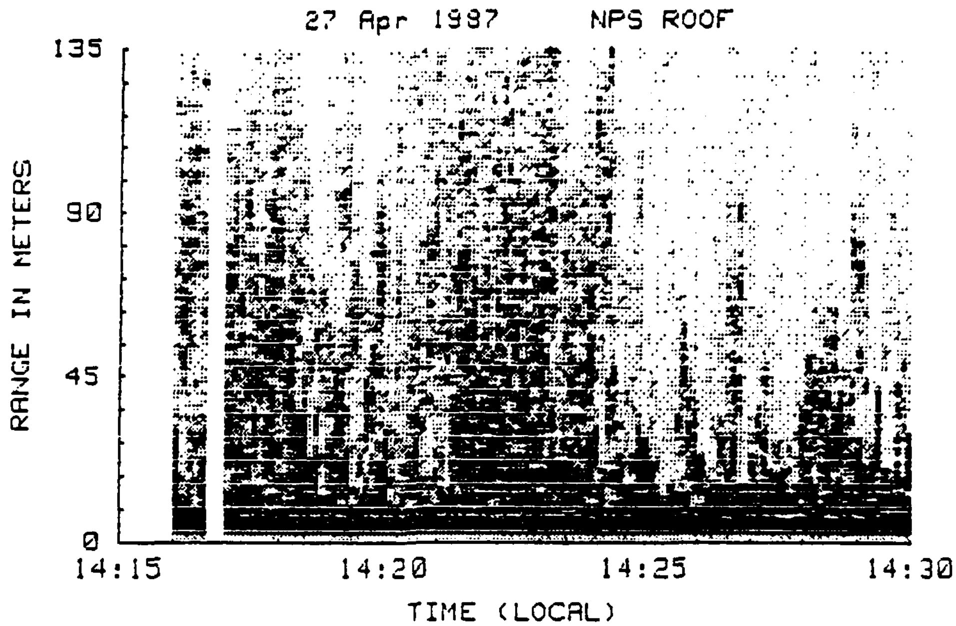
RANGE IN METERS
LOG OF CT^2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RANGE IN METERS
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14:20
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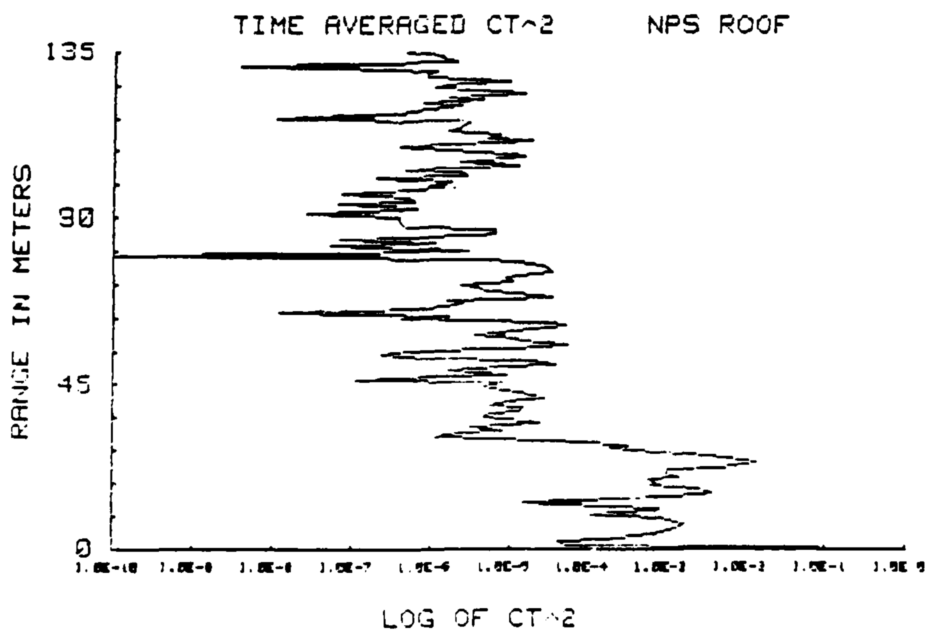
TIME (LOCAL)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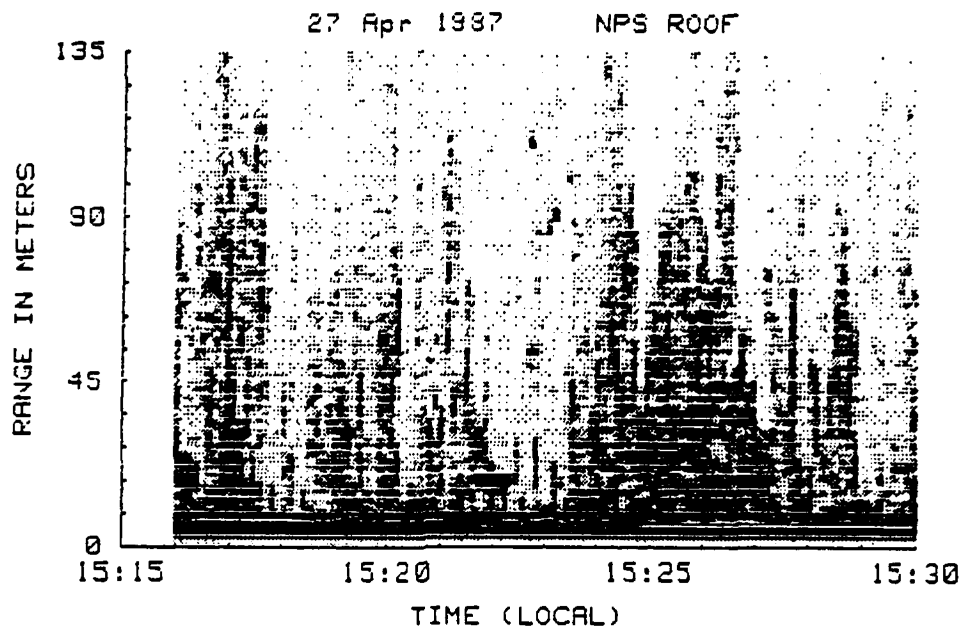
RANGE IN METERS
LOG OF CT^2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RANGE IN METERS
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15:15
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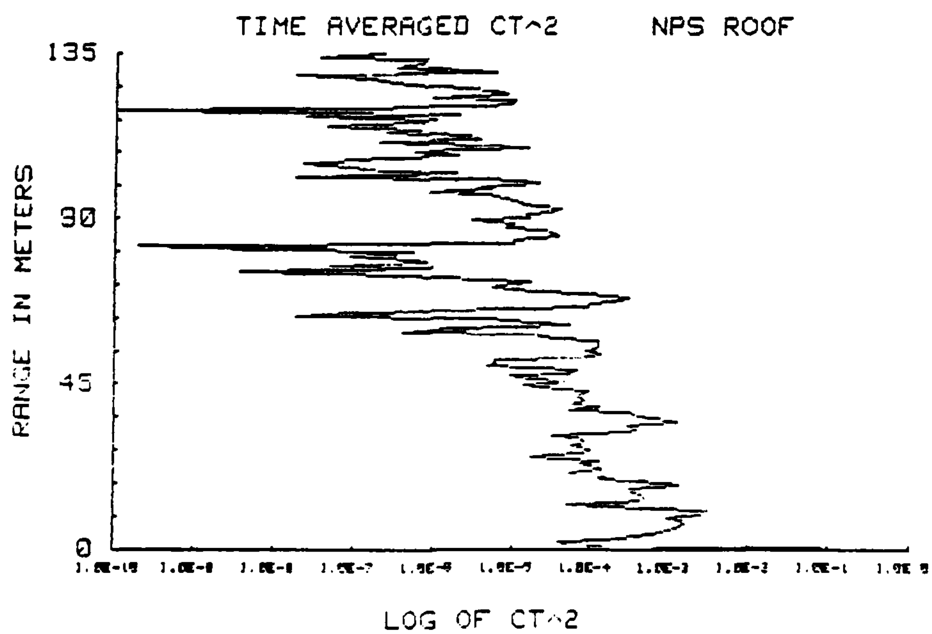
TIME (LOCAL)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RANGE IN METERS
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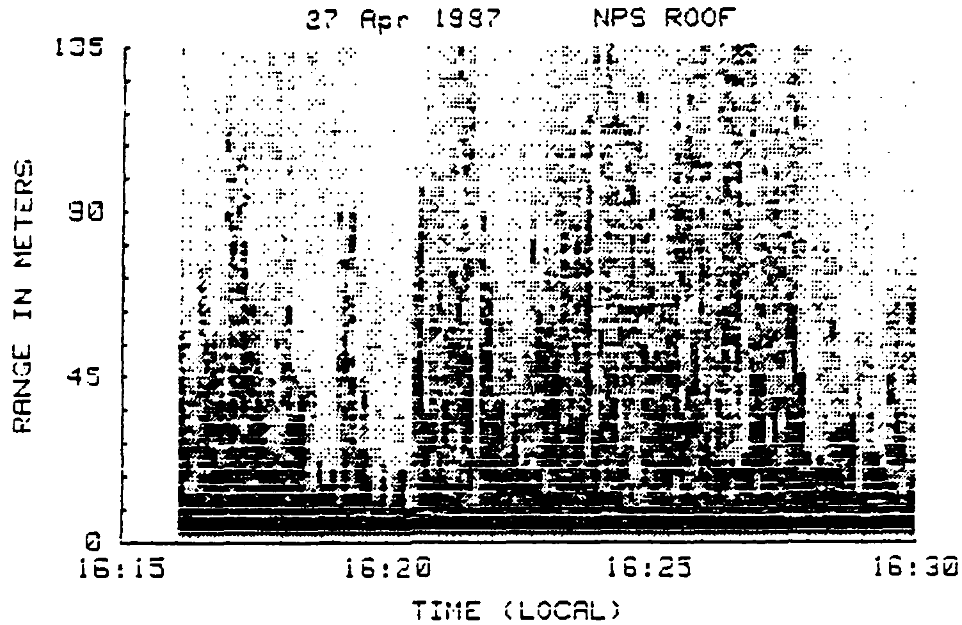
LOG OF CT^2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16:15
16:20
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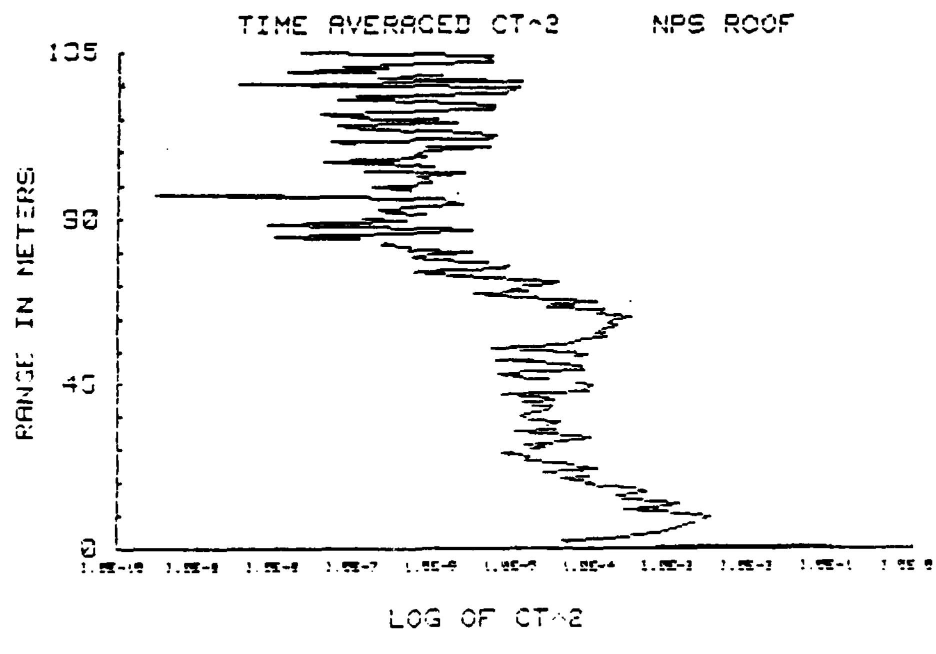
16:30
TIME (LOCAL)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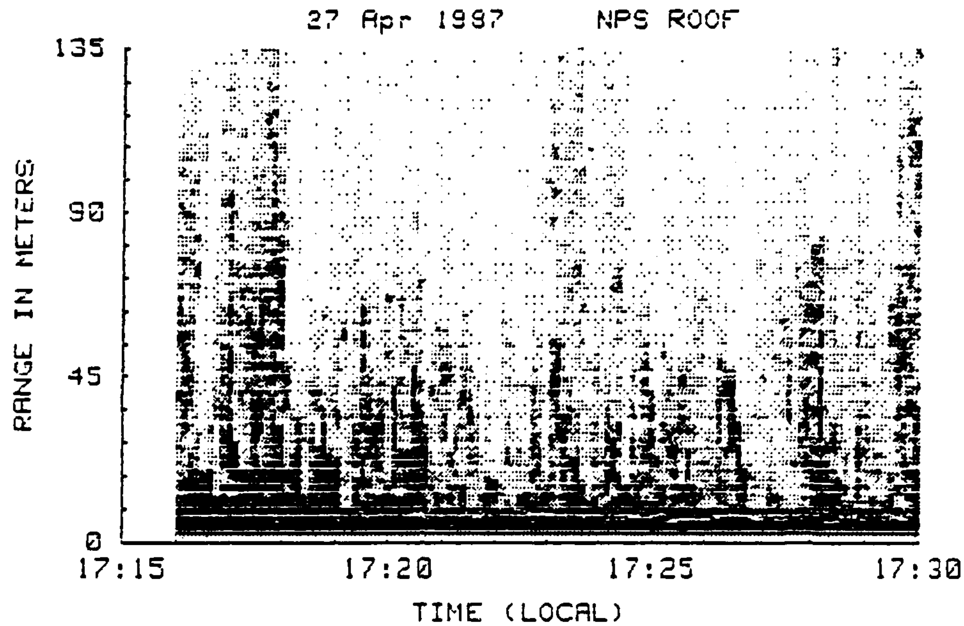
RANGE IN METERS
LOG OF CT^2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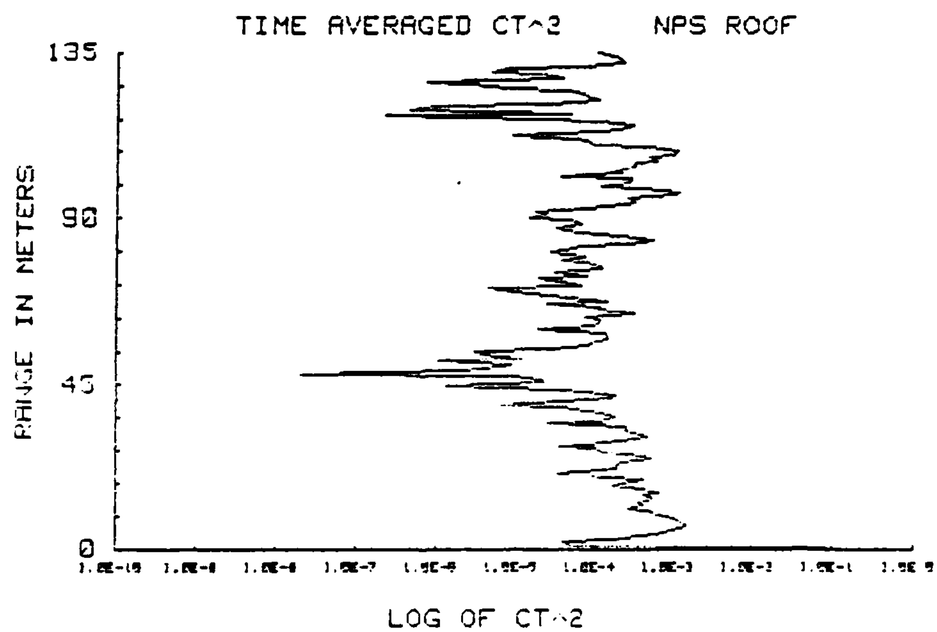
TIME (LOCAL)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RANGE IN METERS
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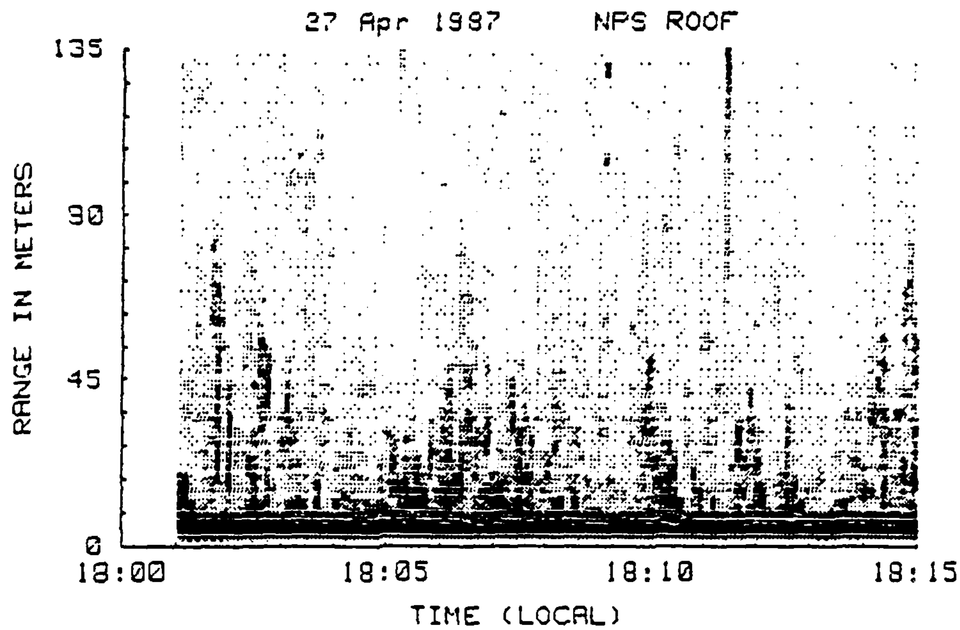
LOG OF CT^2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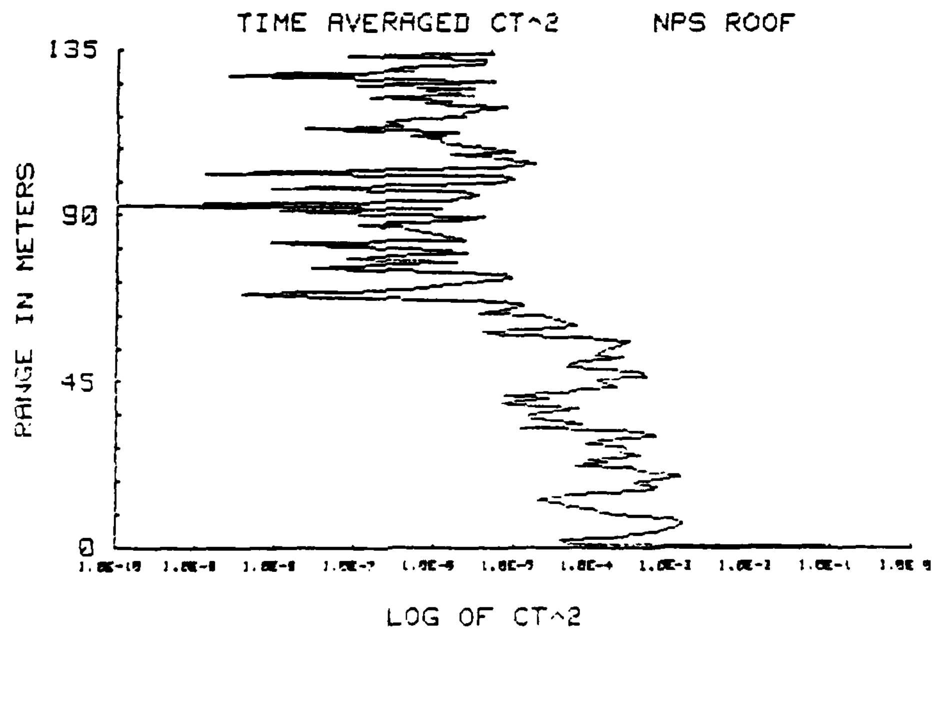
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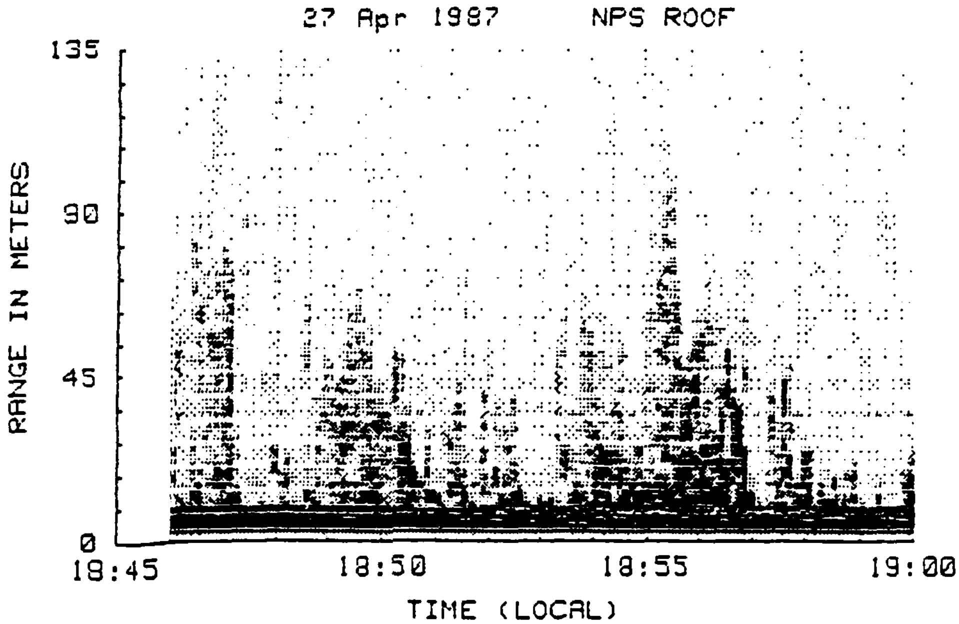
LOG OF CT^2



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RANGE IN METERS
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45
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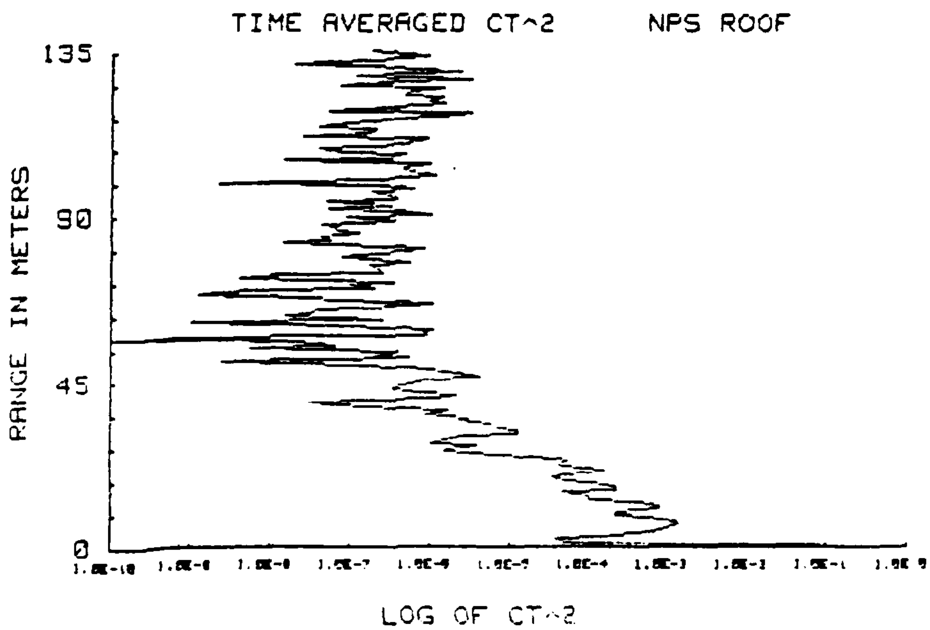
18:45
18:50
18:55
19:00
TIME (LOCAL)



TIME AVERAGED CT^2 NPS ROOF
RANGE IN METERS
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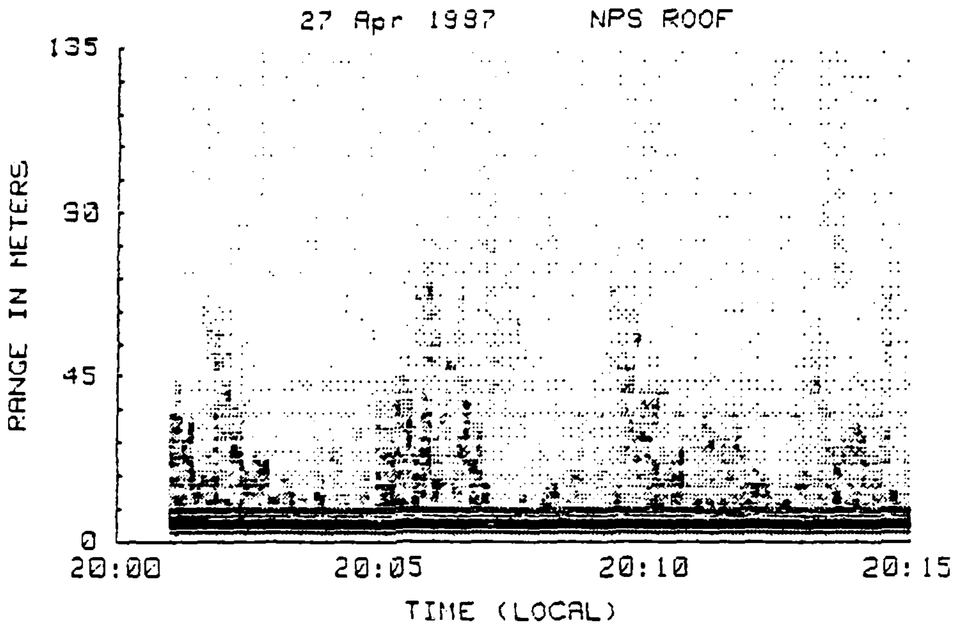
90
45
0
LOG OF CT^2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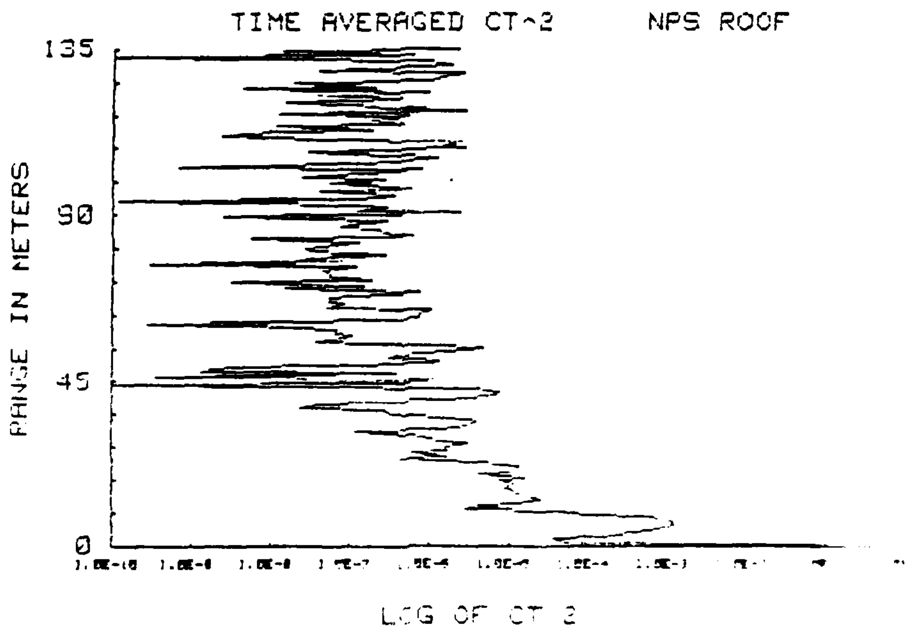
20:10
20:15
TIME (LOCAL)


TIME AVERAGED CT^2 NPS ROOF
135
90
45
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RANGE IN METERS
LOG OF CT 2

AD-A184 972 DEVELOPMENT OF A DATA ANALYSIS SYSTEM FOR THE DETECTION OF LOWER LEVEL AT (U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA M R WROBLEWSKI JUN 87 2/2

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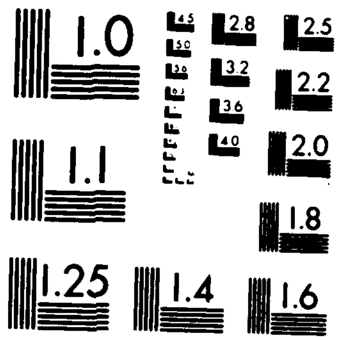
END



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