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RESEARCH AND DEVELOPMENT TECHNICAL REPORT
ECOM-0083-12

PROJECT THEMIS

A CENTER FOR THE DESCRIPTION
OF ENVIRONMENTAL CONDITIONS
WEATHER PHENOMENA

ANNUAL REPORT

By

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December 1970

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND • FORT MONMOUTH, N.J.

- Contract DAAB 07-68-C-0083
SCHOOL OF ELECTRICAL ENGINEERING
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A CENTER FOR THE DESCRIPTION
OF ENVIRONMENTAL CONDITIONS
WEATHER PHENOMENA

Third Annual Progress Report
October 1, 1969 through September 30, 1970

Contract No. DAAB07-68-C-0083
OSU Reference: WP70-I-12

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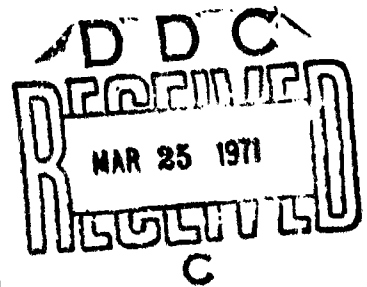
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ABSTRACT

The Oklahoma State University Themis Project has developed an algorithm for identifying cloud to ground strokes compared to cloud to cloud strokes. That identification is based upon the relative energies of the strokes in vertical polarization contrasted to horizontal polarization and at the frequencies of 10 KHz, 50 KHz, 150 KHz and 250 KHz.

The project has developed an on-board aircraft analog data reduction package which gives real-time readout of the sferic rate history at any one selected frequency. Close correlation of the sferic rate with vertical cloud development remains the rule and indicates that the sferics are an intimate part of the vertical wind profile.

A CPS-9 weather radar facility has been added to the project and was operated during the 1970 Oklahoma storm season. The first suitable photographs of cloud to ground lightning photographs were obtained late in the spring at Stillwater.

ACKNOWLEDGEMENT

The research work described in this report was sponsored by the Department of Defense under Project Themis. The Oklahoma State University Themis Weather Phenomena research is administered under Contract Number DAAB07-68-C-0083.

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1. INTRODUCTION

A. HISTORY OF PROGRAM

The College of Engineering, Oklahoma State University, submitted Proposal ER 67-T-21 entitled, "A Center for the Description of Environmental Conditions--Weather Phenomena (Themis No. 129)" to the Department of Defense on May 1, 1967, in response to the brochure, Project Themis, dated November, 1966. Authorization to implement the program, with limited funds, was given in the form of a letter contract. The effective date of the letter contract was October 1, 1967. The actual contract which authorized the initial three years of the program was signed by the contracting office on January 16, 1968.

On October 30, 1969 the contract between Oklahoma State University and the Department of Defense was amended to authorize full funds for three years - 2/3 funds for one year and 1/3 funds for one year of the contract covering the period October 5, 1969 through October 4, 1972. Word was received during late summer of 1970 that additional funding of this project would not be available. Therefore, the objectives and schedules of the project have not been materially changed from those already set forth.

B. OBJECTIVES OF PROGRAM

The proposals submitted have been based on the following objectives:

1. Immediate objective: the determination of the electromagnetic characteristics of severe weather.
2. Intermediate objective: the prediction of operationally restrictive and severe weather.
3. Long-term objective: the modification of operationally restrictive and severe weather.

C. RATIONALE

The recognition and definition of electromagnetic signature associated with specific severe weather occurrences and the development of instrumentation to detect, measure, and analyze the electromagnetic energy present will provide another technique for use in short range weather forecasting. This new method, along with existing meteorological techniques, will be of benefit to the Department of Defense in tactical operations of all the services.

The modification of weather, if possible, will be of benefit to long-range military planning. The ability to either predict or cause a rainstorm, for example in a particular area will provide a tremendous advantage in tactical operations planning.

D. IMPLEMENTATION PLANS

The program was initiated with a three-phased effort;

1. The development and use of instrumentation to measure the electromagnetic signature of certain weather phenomena (clear air turbulence, thunderstorms, tornadoes) in airborne and ground-based laboratories. (The correlation of electromagnetic data to existing meteorological information will be made on identifiable weather phenomena.)
2. The investigation of pattern recognition in the total data acquisition program (sferics, severe weather, existing meteorological information). (The mathematical modeling and information theory application to both the discrete and continuous data will attempt to provide keys for the third phase.)

3. The data analysis and application to identify indicators for probability of specific phenomena, to determine possible trigger mechanisms which induce the phenomena, and to define techniques for possible modification-abatement, diversion or intensification of the phenomena.
4. The development of one or more simple airborne instrument packages which can be put in any aircraft for short term measurement of the severity of weather immediately ahead.

II. DATA GATHERING.

A. CHRONOLOGY OF THE 1970 SEVERE STORM SEASON.

- 18 April 1970 -- A squall line associated with a cold front formed southeast of Stillwater and spawned a tornado East of Oklahoma City. The CDEC aircraft became airborne following the tornado event.
- 23 April 1970 -- A stationary front lay east-west across Oklahoma. The storm cells sampled were southeast of Stillwater near Shawnee, Oklahoma. Hail was reported during the sample period.
- 26 April 1970 -- A dewpoint discontinuity or so called "dry line" existed west and north of Stillwater, Photos were taken from the radar tower but were of poor quality.
- 10 May 1970 -- A wave formed in the Oklahoma panhandle along a stationary front. Thunderstorms formed along a squall line associated with the low. Hail and possible funnel clouds were reported near Wichita, Kansas during the sample period.
- 11 May 1970 -- Mild activity west of Stillwater, near Canton Reservoir, continued to be associated with the low center now in Western Kansas and Nebraska.
- 13 May 1970 -- Again some activity is associated with the front in Kansas and a dewpoint discontinuity west of Stillwater. The activity moved south of Stillwater into the Tulsa area, but only moderate

thunderstorms resulted.

- 14 May 1970 -- The front which was stationary in Kansas moved southward as a cold front. Flying was difficult ahead of this system and was terminated as the front passed over Stillwater.
- 29 May 1970 -- A front lay stationary and to the northwest of Stillwater. Meanwhile, a low was induced in southwestern Oklahoma causing storms near Oklahoma City and Shawnee. A tornado was sighted near Shawnee before the CDEC aircraft began sampling.
- 9 June 1970 -- A small group of cells formed directly north of Stillwater. Photos were taken from the radar tower at Stillwater and excellent film data was obtained.
- 10 June 1970 -- A cold front moved rapidly eastward and passed Stillwater in the evening. The CDEC aircraft landed shortly after takeoff due to the impending weather at the airport.
- 12 June 1970 -- A dewpoint discontinuity lay on to of Stillwater. Although at 18:30 CDT the sky was cloudless, at 19:00 there was a 45,000' Cb. about ten miles northwest of Stillwater. Later in the storm hail was reported at Ponca City. However, this was a case where few sferics were apparent. Three strokes in all were visible from the ground and the sampling aircraft reported little sferic activity.

In cooperation with the Institute of Atmospheric Sciences at the South Dakota School of Mining & Technology at Rapid City, South Dakota.

- 6 July 1970 -- Test case @16:43 M.D.T. with Ag I (silver iodide) seeding. Low to occasionally moderate sferics - considered a mild storm.
- 7 July 70 -- A cold front passed over the area but almost no activity resulted.
- 9 July 70 -- Test case called @12:05 M.D.T. activity was sudden and sporadic. Considered a mild to moderate storm day with no seeding done.
- 10 July 70 -- Test case called @13:30 M.D.T. moderate cumulus activity - sferics light. No seeding done.
- 13 July 70 -- No test cases called due to lack of activity.

In cooperation with the weather modification Branch of the Atmospheric Physics Laboratory at White Sands Missile Range, New Mexico:

- 23 July 70 -- Hughes and Overton on Organ Peak with WSMR personnel. Light cumulus activity over peak area in afternoon. Some activity at night. Photos were taken but were of poor quality.
- 24 July 70 -- Pybus and Byrne on Organ Peak. Early evening cell with moderate sferics. Observations from Organ Peak were poor.
- 27 July 70 -- Observers on the ground. Large area rainstorm northeast of Las Cruces. Moderate sferics with called shots.
- 28 July 70 -- Several large cells near Truth or Consequences,

New Mexico and north of Deming. Called observations from the airport. These cells showed synchronous sferic activity.

- 29 July 70 -- One large cell on the Mexican border at Columbus, New Mexico provided a splendid display of various kinds of sferics. Considered the best set of called data yet this season.

In cooperation with the Joint Hail Research Project (JHRP) of the National Center for Atmospheric Research (NCAR), the Colorado State University (CSU), and the University of Wyoming (WU) all operating over the Pawnee Grasslands at Greeley, Colorado and Raymer, Colorado.

- 4 August 70 -- The remnants of a stationary front lay east of the Greeley area. Cells on this day were small, sferics were mild.
- 5 August 70 -- The old frontal line was near Cheyenne and cells along the line grew moderately strong to produce hail. Sferics were moderate
- 6 August 70 -- Same line as yesterday's. Cells formed early to the north and moved southward. Hail reported on several occasions.
- 8 August 70 -- Moderate cell near Julesburg, Colorado produced hail. A later storm directly over Greeley was not sampled.

B. DATA GATHERING - GENERAL SYNOPTIC RESUME.

April 1970 began with a sharp transition from the previous zonal flow to a break up into meridional flow over Oklahoma. A weak trough over the Eastern Rockies (at 700 mb.) brought below normal temperatures and light precipitation to the western half of Oklahoma and above normal temperatures and moderate precipitation to the eastern half of the state.

The trend toward meridional flow continued with weakening of the flow pattern at 700 mb. for both May and June. Temperatures in Oklahoma were near normal in May but went below normal in June. Precipitation remained moderate in May becoming light in June.

The storm season was considered to be a light to moderate one with only a few severe storms. However, those few storms spawned several destructive tornadoes.

July in South Dakota was a light storm season. The zonal flow at 700 mb. was very weak and caused only light precipitation with normal temperatures.

Later that month and into early August a high centered in the southwest dominated the flow at White Sands and at Colorado. Thunderstorms were frequent at those locations, but only moderately severe. No tornadoes were observed at South Dakota, White Sands or Colorado.

III. DATA ANALYSIS.

A. PATTERN RECOGNITION.

1. Introduction:

The progress made in the past year by the Pattern Recognition group is reported in this section. Major efforts in this area have been directed towards developing a mathematical model for lightning discharges, developing a procedure for classifying lightning discharges, developing a statistical model for describing thunderstorm noise and theoretical investigation of the problem of learning to recognize patterns with an imperfect teacher. These efforts have resulted in three doctoral dissertations and four technical papers that are being submitted for publication in research journals:

Ph.D. Dissertations:

- 1) "Learning to Recognize Patterns With an Imperfect Teacher", by K. Shanmugam, completed in May, 1970
- 2) "A Study of the Second-Order Statistical Properties of Thunderstorm Noise", by Richard L. Johnson, completed in September, 1970.
- 3) "A Lightning Model for Pattern Recognition", by Guy O. Marney, completed in November, 1970.

Technical Papers:

- 1) "Learning With an Imperfect Teacher", by K. Shanmugam and A. M. Breipohl, Proceedings of the 1970 IEEE SSC Conference, pp. 32-38, Pittsburg, October 14-16, 1970.
- 2) "An Error Correcting Scheme for Learning With an Imperfect Teacher", by K. Shanmugam and A. M. Breipohl, accepted for publication by the IEEE transactions on Systems Science and Cybernetics.

- 3) "Discriminating Between Cloud to Ground and Cloud to Cloud Lightning Discharges, A Pattern Recognition Approach", by K. Shanmugam and A. M. Breipohl, accepted for publication in the Journal of Geophysical Research.
- 4) "A Study of the Second Order Statistical Properties of Thunder Storm Noise", by R. L. Johnson, being submitted to the Journal of Geophysical Research.

A brief summary of the above listed works will be presented in the following sections. For a detailed description, the interested reader is referred to Appendix A of this report, which contains abstracts of the listed dissertations and copies of the listed papers.

2. Modeling of Lightning Discharges:

The objective of this phase of research is to develop a Fortran program to implement a mathematical model of a lightning discharge of a given geometry on the digital computer. The general geometry of the discharge model, illustrated in Figure 1, consists of straight segments connecting points A and B, with branching segments extending from B. At this time, TOL, a time-varying current $IL(t)$

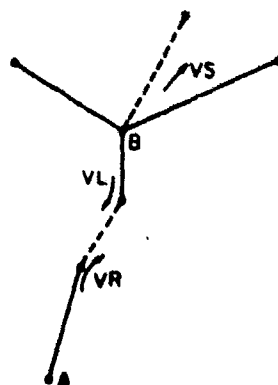


Figure 1. General Geometry of Discharge Model

is allowed to progress down the main channel from B to A with a velocity $VL(t)$ which may be of the form $VL(t) = VL_0 \text{EXP}(-GLt)$. At a later time TOR a return current $IR(t)$ is allowed to move up the channel from A to B with a velocity $VR(t)$. Still later in time, TOS, a third current $IS(t)$ moves from B towards the branch tips with a velocity $VS(t)$. The programs calculate the electromagnetic fields at any specified observation point by approximating each straight segment by a prescribed number of oscillating electric dipoles.

One program calculates the Fourier transform of the fields resulting from the above model. The other, which is essentially an extension of the first program, calculates the comb-filter outputs that would result from the assumed discharge model.

At present only the return stroke is being investigated ($IL(t) = IS(t) = 0$) for comparison with models existing in the literature. This requires that the channel between A and B be represented by a vertical segment and the observation point be located on the earth's surface 100 Km. from the channel.

An accepted waveform for the return stroke current is

$$IR(t) = I_0 (e^{-\alpha t} - e^{-\beta t}) + I_1 e^{-\gamma t}.$$

A standard velocity expression is

$$VR(t) = VR_0 e^{-GRt}.$$

Typical values for a first return stroke in a discharge are: $I = 3 \times 10^4$ amp., $I_1 = 2.5 \times 10^3$ amp., $\alpha = 2 \times 10^4 \text{ sec.}^{-1}$, $\beta = 2 \times 10^5 \text{ sec.}^{-1}$, $\gamma = 10^3 \text{ sec.}^{-1}$, $VR_0 = 8 \times 10^7 \text{ m/sec.}$, $FR = 3 \times 10^4 \text{ sec.}^{-1}$.

The maximum channel height allowed by the expression $VR(t)$ is VR_0/GR or $2\frac{2}{3}$ Km. for the constants given. Using the above current and velocity expressions, Figure 2 illustrates the magnitude of the Fourier transform of the vertical field at 100 Km. on the earth's surface for a 2.66 Km. vertical discharge approximated by 266 10 m. dipoles. This graph is in agreement with that found in the literature (1, 2).

If GR is set equal to zero, $VR(t) = 8 \times 10^7$ m./sec. and the length of the channel may be as long as desired. At the present time it is only noted that increasing the channel height reduces the frequency at which the main peak of the Fourier transform occurs, and this shifting on the frequency axis may be some indication of storm height.

This model is now being extended to include stepped leaders. Also modeling of cloud to cloud discharges will be attempted. The result of this study will be reported in a doctoral dissertation expected to be completed in November, 1970.

3 Classification of Lightning Discharges:

In this phase of the project a procedure has been developed for classifying lightning discharges into cloud to ground or cloud to cloud type based on sferic data. Using this procedure we hope to study the changes in the lightning structure of the storm in relation to the severe storm events occurring in the storm.

All the data used in this phase of the project were taken from the narrow-band recordings of the various comb-filter outputs. The edge tracks of the narrow-band recordings contain descriptions about the types of discharges that were visible to the observer in the aircraft. Sections of narrow-band data containing identified

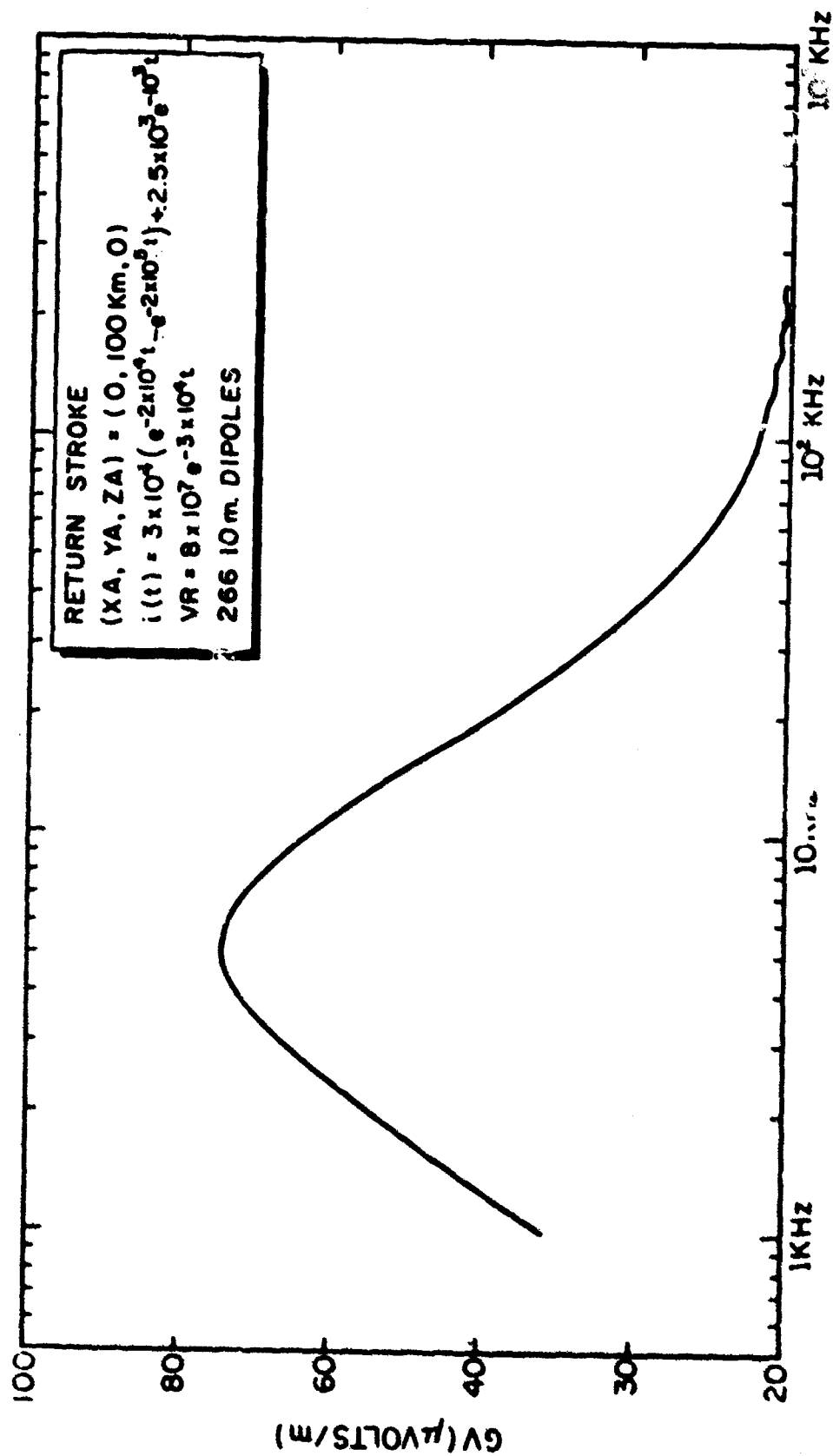


Figure 2. 2.66 Km. Return Stroke

discharges were selected and the data were digitized on eight channels (10KHz, 50KHz, 150KHz, 250KHz horizontal and vertical). From these data, a set of measurements representative of the relative amounts of energy in various comb-filter frequencies was computed. These measurements consist of the normalized average value of the signal in each comb-filter channel. The average value of the signal in each horizontal channel ($\bar{X}_{10H}$, $\bar{X}_{50H}$, $\bar{X}_{150H}$, $\bar{X}_{250H}$) were normalized with respect to the sum of averages in the four horizontal channels ($\bar{X}_H$). Similarly the average values in the vertical channels ($\bar{X}_{10V}$, $\bar{X}_{50V}$, $\bar{X}_{150V}$, $\bar{X}_{250V}$) were normalized with respect to the sum of the averages in the four vertical channels ($\bar{X}_V$). In addition to these measurements, the sum of averages in the horizontal channels ($\bar{X}_V$) normalized with respect to the total sum were also included to provide some information about the polarization of the received signal. This is the basic set of measurements used in this investigation.

The narrow-band data corresponding to a total of 86 discharges have been processed for these measurements. The following conclusions are drawn from the study of these 86 sample patterns:

- 1) Cloud to ground discharges have more energy in 10KHz Horizontal than in 50KHz Horizontal. In comparison, cloud to cloud discharges have more energy in 50 KHz Horizontal.
- 2) Cloud to cloud discharges have more horizontally polarized energy than cloud to ground discharges.
- 3) There is significant difference in the polarization of cloud to ground and cloud to cloud discharges in 50KHz range.

Using these 86 sample patterns, a computer was "trained" to classify discharges into cloud to ground or cloud to cloud types using three different methods. Using a "test set" of 50 discharges of known types, the performance of the classification scheme was evaluated. It was found that the procedures developed can be used to classify discharges with a reliability of up to 82%.

For details of this phase of the project, the interested reader is referred to the paper "Discriminating Between Cloud to Ground and Cloud to Cloud Discharges: A Pattern Recognition Approach", enclosed in Appendix A of this report.

4. Statistical Model for Thunderstorm Noise:

A study of the second order statistical properties of thunderstorm noise was undertaken in this phase of the project. A characterization of thunderstorm noise was obtained in terms of the time averaged autocorrelation and power spectral density functions. The data was first analyzed to determine whether or not a stationary assumption would be valid. It was found that the sferic triggering mechanism can be modeled by a Poisson impulse process. Based on this property of wide sense stationarity, estimates of the averaged autocorrelation and power spectral density functions were computed from three data segments of 0.75 second duration. Because of close resemblance of the three estimates, the mean of the time averaged autocorrelation and power spectral density estimates is believed to be a reasonable description of the process. This representation is useful in the design of filters for the purpose of minimizing thunderstorm noise inference in a mean square sense.

Details of this study and the results can be found in the paper

"A Study of the Second Order Statistical Properties of Thunderstorm Noise" included in this report.

5. Theoretical Research in Pattern Recognition:

In problems involving learning to recognize patterns, a set of sample patterns with known identifications is necessary. For example in classifying lightning discharges, data from a set of discharges along with the type of discharge from which these data came from is required to train a computer.

Usually a sample identification scheme furnishes the identification for the sample patterns. In many practical situations the sample identification scheme may incorrectly identify some of the training samples. For example in attempts to classify severe storm patterns using electromagnetic data from the storms, meteorological measurements such as reports of hail will be used as standards for identifying the sample patterns. Often these measurements such as reports of hail are unreliable and hence there is a possibility of some incorrectly identified sample patterns. Another example where there is a possibility of incorrect identification of sample patterns occurs in attempts to classify lightning discharges into cloud to cloud or cloud to ground type based on electromagnetic data. Here the sample identification is based on visual sightings of the discharges. In many occasions, the discharge is only partly visible and hence the possibility of incorrect identification. These examples give the motivation for investigating pattern recognition schemes where the teacher, or the sample identification scheme, is known to be imperfect.

This investigation resulted in the development of a nonparametric

scheme for learning to recognize patterns with an imperfect teacher. Under certain mild assumptions on the probabilistic structure of the patterns, it was found that the proposed learning scheme asymptotically bettered the performance of its own teacher. Taking this as a motivation, the proposed learning scheme was modified to correct the errors made by the imperfect teacher. This error correction scheme was found to improve the performance of the learning scheme. Details of this investigation can be found in two papers:

- 1) "Learning With an Imperfect Teacher"
- 2) "An Error Correcting Scheme for Learning With an Imperfect Teacher"

enclosed in Appendix A of this report.

The procedures developed for learning to recognize patterns involve the estimation of probability density functions. One way of estimating these density functions is in the form of a polynomial, whose coefficients can be updated recursively. Two problems encountered here are 1) determining how many terms should be included in the polynomial and 2) how many sample patterns are needed to get a given degree of accuracy.

Bounds on the sample size required to insure a desired degree of precision on the estimates have been obtained. Further research is needed to determine the number of terms that should be included in the polynomial.

6. Outline of Research for the Coming Year:

The pattern recognition scheme for classifying lightning discharges has shown that there is enough information in the narrow band data to discriminate between the different types of discharges.

Attempts will be made in the coming year towards relating changes in meteorological conditions of the storms to changes in the lightning structure of the storm. The meteorological conditions of the storms occurring in Oklahoma will be processed from the NSSL radar data. Accordingly the electromagnetic data from storms in Oklahoma will be analyzed first.

Studies on spheric count of narrow band data will be continued. Also studies will be made on the changes in polarization of the narrow band signal.

B. ANALOG DATA REDUCTION.

A scheme was devised and reported upon last year for using analog methods of data reduction to produce a storm's sferic-rate history. Since that time two developments have taken place. First, the data so obtained have been correlated with the storm meteorology and two cases of significance are shown here below. Second, a portable unit was installed in the CDEC sampling aircraft and enabled sferic-rates to be observed during real-time, i.e. during flight. The capability was first operational during August 1970 and will be shown below.

1. Sferic Rate History Correlations.

Following are excerpts from a paper presented by title at the A.M.S. Cloud Physics Conference at Fort Collins, Colorado, on 27 August 1970 and also presented and discussed at the 14th Radar Meteorology Conference in Tucson, Arizona on 19 November 1970.

Sferic Rate Calculations

To obtain sferic rate history for a storm, the procedure used is to choose one of the six frequencies of a vertical antenna system and count the number of lightning strokes using a running weighted average technique.

Analytically, each count is diminished in time (i.e. in weight) by a factor $(1-1/e)$ in one minute, i.e. time constant $= \tau = 60$ sec for $(1-1/e)X$ count. Electrically this is accomplished in real time by providing an RC time constant of one minute across an integrating operational amplifier.

Figure 3 shows the schematic of the data reduction procedure. In brief, the sferic signal from one trace of the taped data is A) amplified B) counted C) integrated D) recorded. Figure 4 shows

a typical record of such sferic rate histories at five frequencies, in this case for the storm at Rapid City, South Dakota, on 14 July 1969 (vertically polarized).

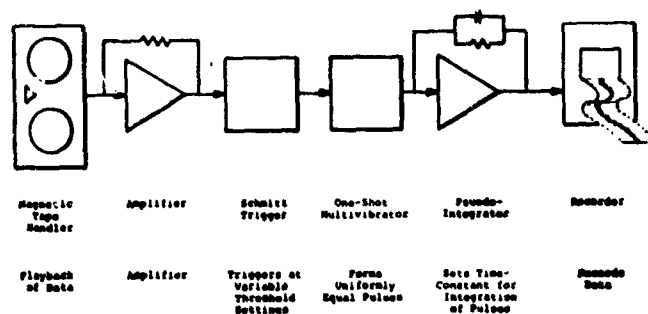


Figure 3. Schematic of Analog Data Reduction

Storm Cases

It is observed in the data to be presented here that A) sferic rates increase with increased vertical cloud building and B) sferic rates increase at the time of individual severe storm events such as hail and tornadoes. The implication is that hail and tornado events occur at the time of rapid vertical cloud development.

Each of two storm cases will be examined by itself in the following paragraphs.

a. 17 July 1969 - Rapid City, South Dakota

Four sources of information were used to analyze this storm:

- 1) O.S. U. sferic records obtained by the aircraft sferic data sampling system described earlier;
- 2) Institute of Atmospheric Sciences radar cloud profile records obtained with I.A.S. radar facility at Rapid City;
- 3) Recorded radio comments giving events and location of events such as hail and tornadoes;
- 4) O.S.U. observer's flight

log of meteorological events during the course of the flight.

Figure 4 presents the sferic rate history for five discrete frequencies recorded through the vertically polarized receiver and comb filter system described earlier (Section I).

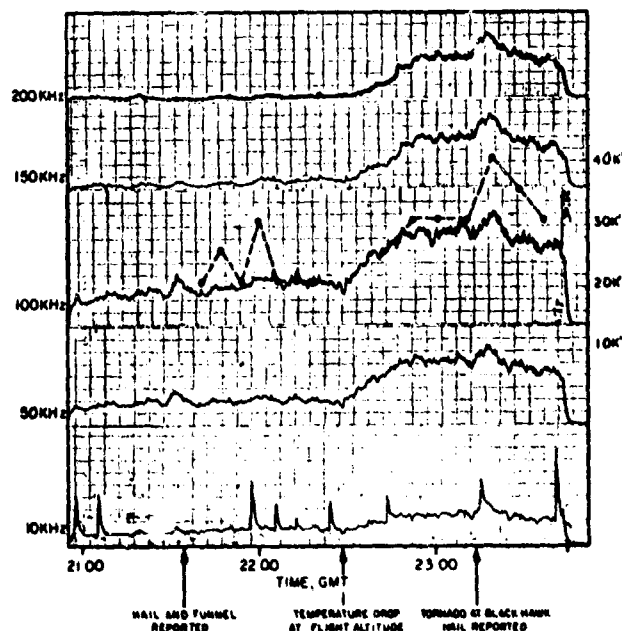


Figure 4. Sferic rate history, storm of 17 July 1969, Rapid City, South Dakota

Figure 4 also presents the I.A.S. radar data plotted on the 100 KHz data, in the form of maximum cloud heights, for the significant cells being sampled. A note of explanation is in order concerning the location of the significant cells.

A forecast is made by the I.A.S. Meteorologist as to the grid squares (of a previously determined grid network) where severe weather is likely to occur. Those forecast grid squares are then sampled by the radar to record existing conditions. The forecasts

are made for approximately half hour intervals in advance.

Occasionally it happens that the major storm activity does not coincide with the grid squares being sampled by the radar. That is, there may be more intense storm activity outside the grid squares being sampled than in those squares. However, that was not the case on this storm of 17 July 1969. Major storm activity was contained within the designated grid squares.

At the bottom of Figure 4 are noted the events recorded on magnetic tape during the storm as well as pertinent notes from the observer's flight log as seen from the 16,500 foot flight altitude.

It is quite clear from the comparison of the data of Figure 4 that cloud building in the early part of the storm, i.e. about 21:30 GMT was not accompanied by much sferic activity. Visual observations show that that part of the storm did not develop to any great extent. Notice, however, that hail and a vortex (not reaching ground) were generated by that time (21:35 GMT).

In contrast, note the increased sferic rate at 22:40 GMT which was accompanied by cloud tops growing above the 30,000 foot height. Hail and a tornado on the ground near Black Hawk, South Dakota were noted during this later cloud building.

It seems almost too coincidental to ignore the slight but unquestionable small-scale increases of sferics at the same times that funnel clouds and hail occur. However, there appear to be other minor increases of sferic rate without those events being observed.

b. 11 June 1969 - Stillwater, Oklahoma

Three sources of information were used to analyze this storm:

1) O.S.U. sferic records obtained by the aircraft sferic data sampling system, 2) National Severe Storms Laboratory (hereafter designated NSSL), Norman, Oklahoma, radar cloud height information, and 3) recorded radio comments concerning the storm and aircraft locations.

Figure 5 presents the sferic rate history at the six discrete frequencies for this storm, as recorded on the vertically polarized receiving system of the sampling aircraft. The aircraft was generally located east of the line of storm cells and was west of Oklahoma City when a tornado was reported near Fairview, Oklahoma, northwest of Oklahoma City.

Superimposed upon the plot of Figure 5 are the three available cloud top height reports of the NSSL radar.

The first event of interest during this storm of 11 June 1969 was a tornado near Fairview, Oklahoma. Time of occurrence of the tornado was 03:10 GMT as can best be determined from ground reports. However, it was probably associated with the very pronounced sferic peak at 03:08 GMT. That impulse of sferic activity (peak at 03:08 GMT) shows a rapid increase of sferic rate. Past experience leads one to suspect a sizeable updraft velocity existed.

The second event of interest during this storm resulted from NSSL radar information subsequent to the tornado event. Three cloud height reports are shown plotted with respect to the received sferic rate. One can only say that cloud tops seen by radar appear to correlate well with the sferic rate of the storm, as was the case in the South Dakota storm of part A. Note here, however, the abrupt decrease in sferics as the storm "topped out", i.e., ceased to grow.

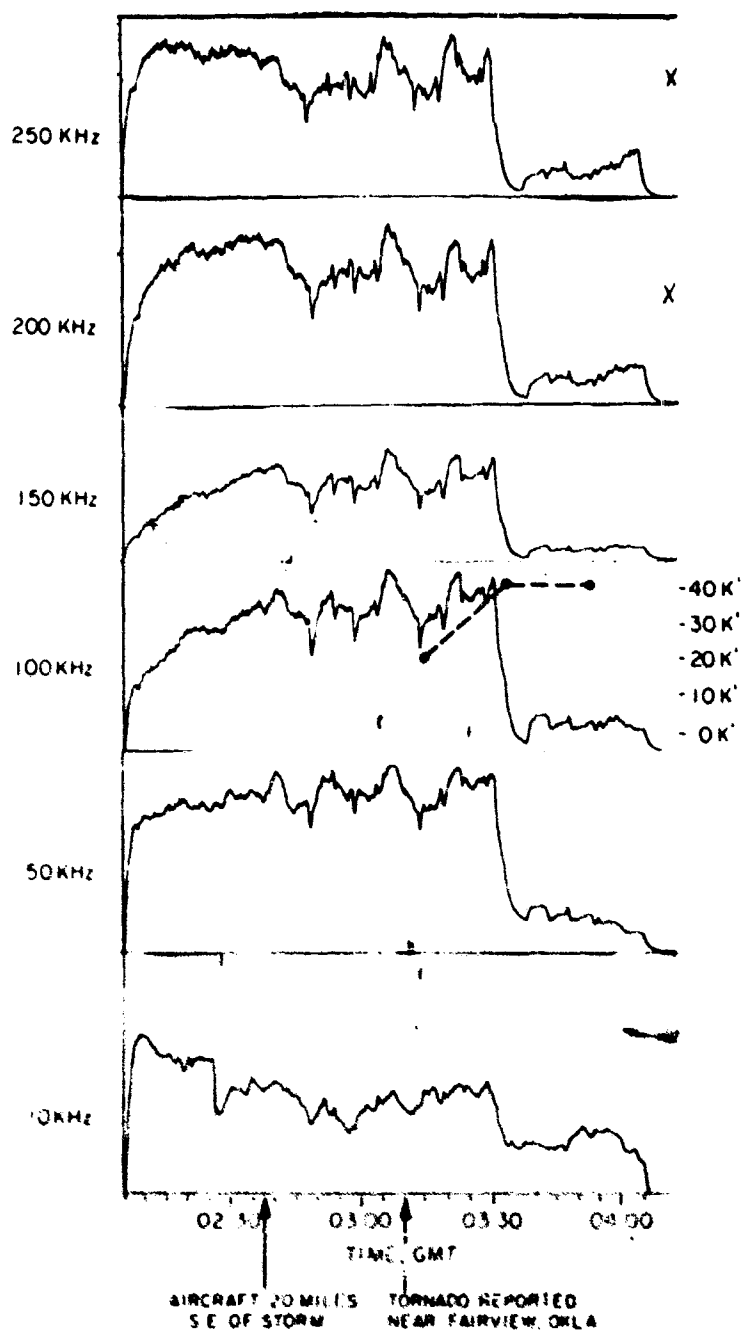


Figure 5.
Sferic Rate History for Storm of
11 June 1969, near Fairview, Oklahoma

The data remain suspect at the time, although there is no malfunction nor other abnormal condition that can be found during data gathering and during data reduction. If true, these data show a storm which almost literally blew itself apart.

Conclusions

The two well defined storm cases presented here show a correlation between rapid cloud growth and sferic rate. Other cases, not presented here, give examples of similar correlation. However, there are also cases of rapid visible and radar reported cloud growths not accompanied by the increase in sferic rate. Therefore, we must conclude that a rapid increase in sferic rate signals rapid cloud building, but rapid cloud building may also occur without a significant sferic rate increase.

It is also concluded that more meteorology must be in hand to determine why some storms are more electrically active than others. Nuclei and cloud particle concentrations must be known as well as freezing levels and temperature structure of the storms.

Further analysis of these and other storms is being done to quantify the sferic rate and updraft velocity. The data shown here are sufficient only to indicate what might be a reasonable correlation. This lead must now be followed by stronger and quantitative proof of the stated correlation.

2. CDEC Results From The Colorado Joint Hail Research Project (JHPP).

The airborne sferic-rate recorder is a solid state version of the laboratory device and differs only in the options allowed to change preamplifier gains and integration time constants.

The airborne device was installed during the latter part of

July and tested during the CDEC field trip to WSMR, New Mexico. However, the system was not considered operational until the August 1970 CDEC field trip to Greeley, Colorado, in conjunction with the joint Hail Research Project. The following data was obtained during that data gathering trip.

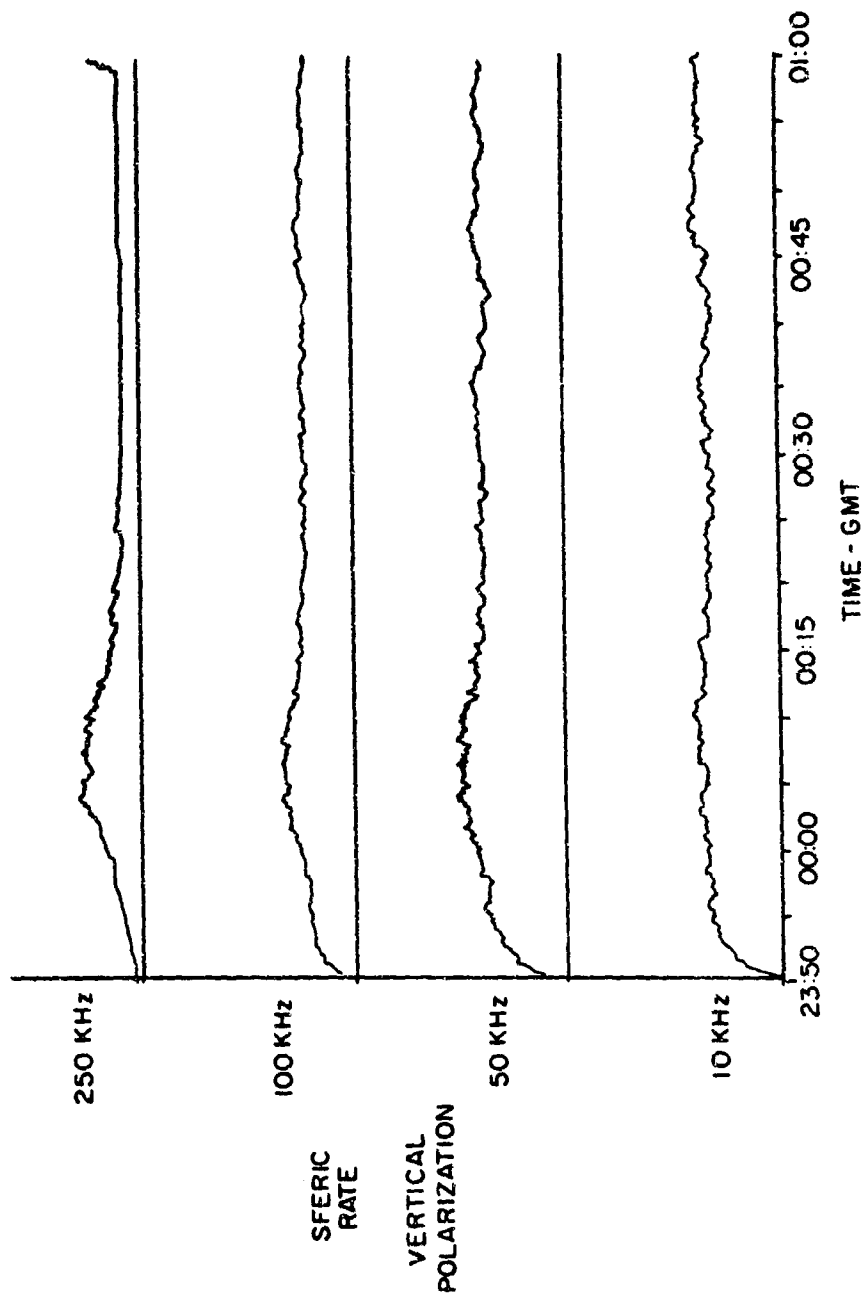
a. August 4, 1970 - Greeley, Colorado with JHRP

Figure 6 shows a sferic rate history at four frequencies for a small storm which failed to intensify on 4 August 1970. The time of occurrence of the main shower activity coincides with the maximum of sferic rate at 00:05 GMT and is most readily apparent on the 250 KHz trace.

b. August 5, 1970 - Greeley, Colorado with JHRP

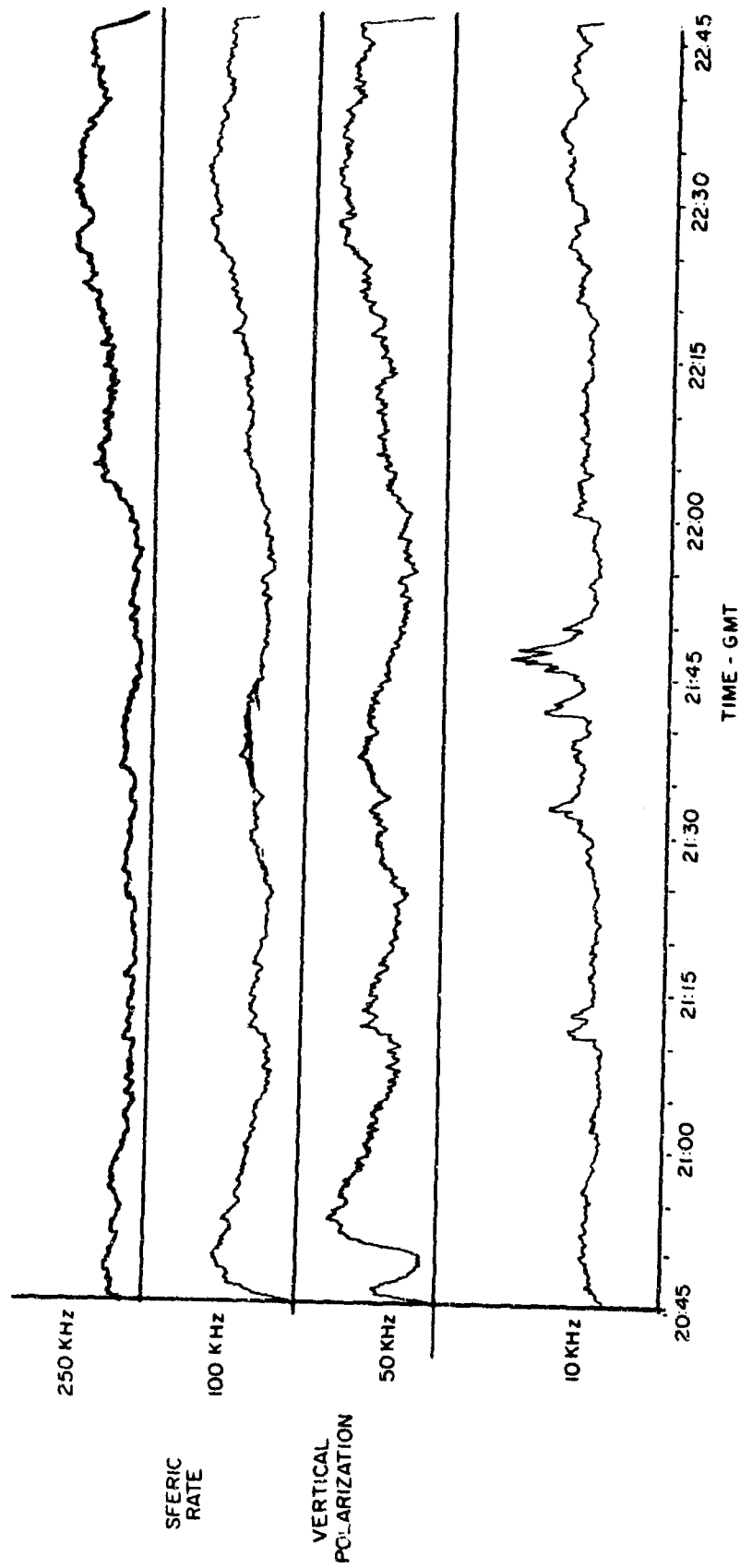
There existed a line of storm development from northeast of Cheyenne, Wyoming, to northeast of Greeley, Colorado. Development of activity was from the northern end (Cheyenne) southward. The initial buildups were mostly rainshowers of considerable duration and magnitude. However the main storm developed east of Greeley and became a cumulonimbus with hailstorm later in the afternoon.

The sferic record, Figure 7, shows several unexplained phenomena in the sferic rate as well as more common features. The abrupt peaks in the 10 KHz trace at 21:12, 21:32 and peaks near 21:45 GMT can not yet be explained. The decrease in sferic rate shown at 20:50 at 50 KHz, 100 KHz and 250 KHz is the decay of a large cell located near Cheyenne. Brief buildups in intensity on the south end of the storm line, i.e. between Cheyenne and Grover, Colorado show at 21:12 and at 21:37. A subsequent buildup at 22:05 continued to develop into a hailstorm with hail reported about 22:30 GMT.



JOINT HAIL RESEARCH PROJECT
GREELEY, COLORADO
4 AUGUST 1970

Figure 6.



JOINT HAIL RESEARCH PROJECT
GREELEY, COLORADO
5 AUGUST 1970

Figure 7.

The brief drop in sferic rate at 20:50 on the 50 KHz trace is an anomaly which can not be explained at this time. The period between growth impulses on this storm is taken to be about 25 minutes.

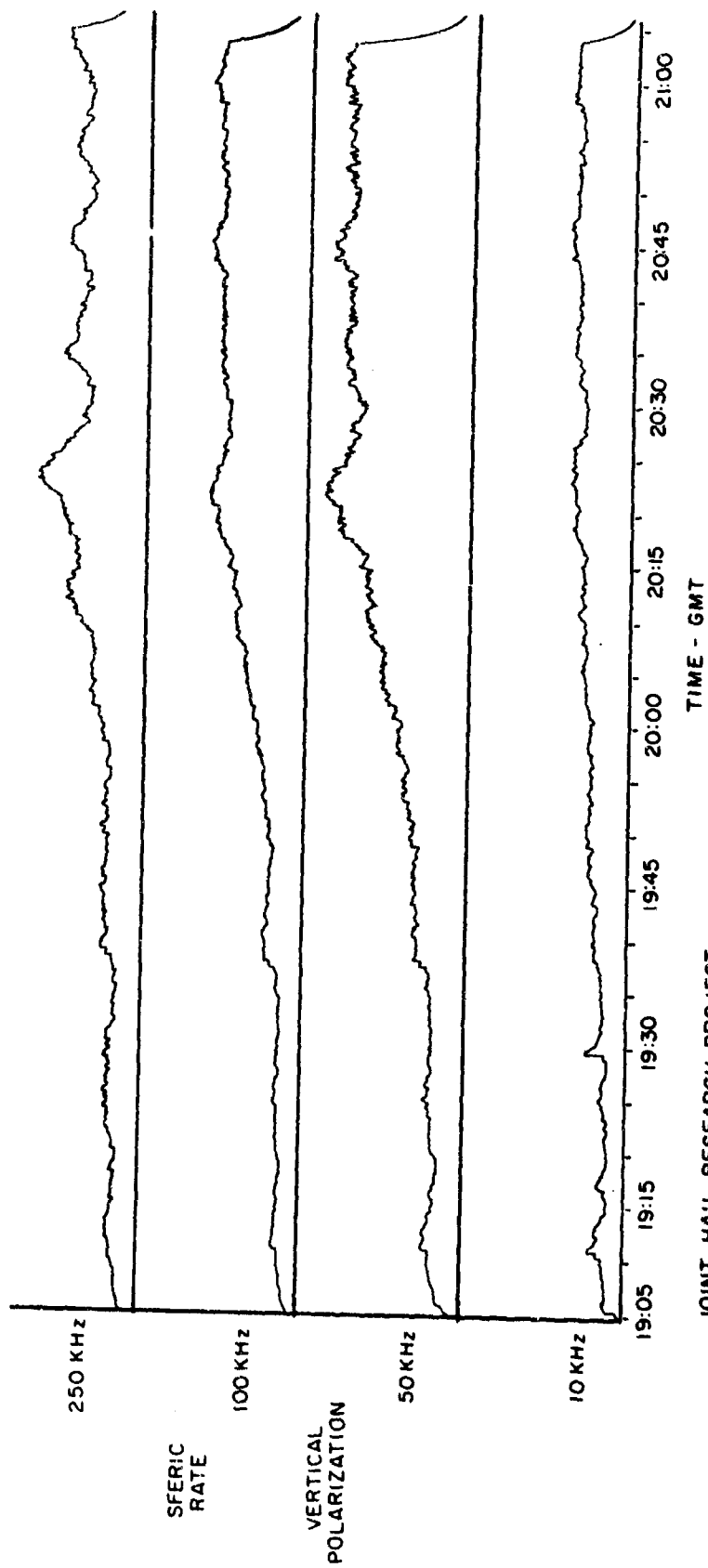
c. August 6, 1970 - Greeley, Colorado with JHRP

The situation on August 6, 1970, was similar to that of August 5th. A line of activity extended from east of Cheyenne, Wyoming southward to east of Greeley, Colorado with the northern part of the line developing early storms and subsequent development southward. However, the storm cells on August 6 developed earlier and contained hail earlier than on the previous day. The periods of development, i.e. the growth impulses, show clearly at 250 KHz in Figure 8. 20:15 GMT shows the first of a series of significant growth impulses. The period between impulses for this storm was ten minutes. Hail to 1 1/2" was reported from the later parts of the storm.

3. Conclusions from the Data

From the data shown here and in previous reports it is evident that the sferic rate is intimately related to the vertical development of a thunderstorm. Furthermore, the spacing of growth impulses during any one storm seems to be regular and fairly constant on any one day. The growth impulses on August 5 did not vary from 25 minutes by more than seven minutes. Those on August 6 did not vary from ten minutes by more than two minutes. There were standard deviations of .6 and .35 respectively for the periods between impulses of the two storms. Those small deviations seem to be the general rule for the storms so far examined by the use of sferics.

10KHz sferics seem to correspond more closely to the general



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Figure 8.

area activity rather than to the activity in a particular cell. The higher frequencies, especially 250 KHz, provide the most sensitive indicator of local cell development

IV. DATA PROCESSING EQUIPMENT, PROGRAMS AND PROCEDURES.

During the period covered by this report, a number of new digital programs and procedures were developed. Additionally, a 12-channel multiplexer was designed and constructed as was a spheric activity meter.

For the benefit of project members, as a reference and guide, some of the earlier developed programs will be included herein in order that a complete package will be available. These older programs are named ADC1, ADC2 and ADC3.

Much of the data processing work associated with the project hinges around the procedure of playing back analog data tapes, converting the data to digital form-on tape-and then doing the main computation on an IBM 360/65 computer.

The experience with this procedure thus far has shown that nothing can be left to chance in the process. To insure the integrity of the data at each step, the procedure and results must be checked and re-checked.

The analog data tape is 1 inch tape recorded with a total of fourteen channels. When desired twelve, or fewer, of these channels may be digitized through the use of the multiplexer. When digitizing only one channel the conversion rate can be as high as 24,000 samples per second.

The resulting digital tape is standard 9-track IBM standard. If the digital data tape was being created on the IBM 360 computing system, then either IBM labelled or unlabelled tapes could be created easily. However, when the data is being written on the tape by another processor (HP2115A), as is being done on the subject project, then in order that these tapes can be read back by the IBM 360/65, certain preparations must be observed. If the digitized data is to be written onto an

unlabelled tape, then the HP2115A program need only to write a tape-mark (end-of-file) prior to the first data set. While unlabelled tapes are somewhat easier to create, there is a danger that a tape with good data on it be inadvertently used improperly on the 360/65.

The use of labelled tapes circumvents the problem of tapes being used improperly; however, creating a labelled tape is a more involved procedure. First, the reel of tape must be submitted to the 360/65 facility as a special run solely for the purpose of putting a unique label on the tape. At this time, the user specified the volume and serial name to be used. After the tape is returned, the user will need to load a data set name on the tape. This may be accomplished by running a normal FORTRAN job-with dummy data-to place a data set on the tape. This will complete the standard label such that it will be read properly by FORTRAN in the future. When the blank labelled tape is loaded on the HP2115A system to receive digitized data, the HP2115A program must initially cause the first four records to be skipped. Then the data is written. These four records constitute the label.

PROGRAMS

The program entitled ADC1 and listed as Figure B-1, is for the purpose of converting data at speeds up to 24,000 samples per second and writing the result on an unlabelled digital tape. The digital data is in raw binary form. A program is available for the IBM 360/65 computer for converting this data to 32-bit floating-point form compatible to FORTRAN IV (360).

ADC2 given in Figure B-2 is also for converting data at speeds up to 24,000 SPS. Only one record is converted at a time, and some flexibility

in use is provided. The procedure is included as part of Figure B-2.

ADC2A presented in Figure B-3 is similar to ADC2 except that a labelled tape is used and the digitized data is written on the tape directly in 32-bit floating point form ready to be read by 360 FORTRAN IV. This necessitates a maximum convert rate of 13,000 SPS.

ADC3, Figure B-4, can be used for reading a record of data from the digital tape back into the processor. This is for the purpose of checking the nature of the data on a digital tape.

ADC4 depicted in Figure B-5, is similar to ADC1. Data is converted continuously for a specified number of records and written on a standard labelled tape in 32-bit floating point form. This limits the maximum sampling to 13,000 SPS but the output tapes are ready to be read by a 360/65 FORTRAN IV program.

ADC5 shown as Figure B-6, is the same as ADC4 except it outputs on an unlabelled tape.

DIAG1, Figure B-7, is designed to transfer data from the analog-to-digital converter into the B-register of the HP2115A processor. This is for the purpose of checking for proper operation of the A/D converter and the I/O interface.

DIAG2, Figure B-8, is a magnetic tape reading program. It allows the operator to go forward or backwards on the tape in steps of records. Data on any record may be observed and tape marks are clearly indicated.

DIAG3 of Figure B-9, consists of two independent programs. These are for testing and adjusting the multiplexer.

ADC1 Program

Purpose: To digitize analog data continuously.

Speed: Up to 24,000 samples per second.

Output tape: Unlabelled 9-track. Data in raw 16 bit binary form.
2,000₁₀ words per record. (This number can be changed.)
Mount tape.

Procedure: Load program using HP2115A Basic Binary Loader. (BBL)
Program origin is at 100 octal.
Halt No. 1 - Load switches with number of records to be
written. (octal) Push run.
Halt No. 2 - Wait to ready the system. Push run to start
system.
Halt No. 3 - Records complete. Push run to write EOF and
rewind tape.
Halt No. 4 - End. Mount another tape, push run to repeat
entire program.

ADC2 Program

Purpose: To digitize one record at a time.

Speed: Up to 24,000 samples per second.

Output tape: Unlabelled 9-track. Data in raw 16-bit binary form.
2048₁₀ words per record. This can be changed.

Special: Forward spacing of records can be accomplished, so a tape may be taken down and then remounted later and continued.

Procedure: Mount tape

Load program tape using BBL.

Program entry is 100 octal. Push run.

Halt No. 1 - Set Switches to the number of records to be skipped. Push run.

Halt No. 2 - Waiting. Push run to convert.

Halt No. 3 - Set Switches one of three options. Then push run.

000 - To convert another record.
Goes back to Halt No. 2.

001 - Backspace one record. Push run
Goes back to Halt No. 2.

010 - Rewinds tape. Push run.
There is no EOF mark.

Halt after rewind is end.

Branch manually to address 100 (octal) to repeat, if desired.

ADC2A Program

Purpose: To digitize one or more records at a time.

Speed: Up to 13,000 samples per second.

Output tape: Labelled 9-track. Data is in 32-bit 360/65 floating point form. 1944 words per record (can be changed).

Procedure: Mount a labelled tape.

Load program using the BBL.

Program entry is 100 octal. Do not push run yet.

If it is desired to space forward on tape then turn on bit switch 15. Then push run.

Otherwise, push run.

Halt 14 - Load switches with number of records to be skipped. Push run.

Halt 0 - Enter number of records desired into switch register. Push run.

Halt 1 - Program ready and waiting to start converting data. Push run to start.

Halt 66 - A data convert run is finished.

(a) To proceed with another run, turn on bit switch 0 and push run. The program will return to Halt 0. Turn off SW 0.

(b) To backspace a desired number of records, set bit SW 15 and push run. Program will backspace the tape and then return to Halt 0. Turn off SW 15.

Halt 6 and 7 - Error halts. Clock rate too fast

Halt 25 - Tape not accepted (not proper label).

ADC3 Program

Purpose: To read a digital tape record in HP2115A memory.

Features: Can Forward space past records. Examine words in a record using front panel lights.

Procedure: Mount tape.

Load program with BBL

Program entry is 16100 octal. Push run.

Halt No. 1 - Load switch register with number of records to be skipped. Push run.

Halt No. 2 - Ready to read tape.

Push run to read.

Returns to Halt No. 1.

Data may be viewed on T-register lights.

Tape data is loaded into memory address 02000 octal.

2048 words per record (can be changed).

Halt No. 1 - If desired to rewind tape - set bit SW 15, push run.

ADC4 Program

Purpose: To digitize analog data continuously

Speed: Up to 13,000 samples per second.

Output Tape: Labelled 9-track. Data is in 32-bit floating point form.
1944 words per record (can be changed).
Can have multiple files (data sets).

Procedure: Mount tape.

Load program with BBL.

Entry address is 100 octal. Push run.

Halt 0 - Enter number of records to be written in switch register. Octal. Push run.

Halt 1 - Ready to convert. Push run to start converting

Halt 66 and Halt 77 - Normal end. Data loaded. Push run to write EOF. Then stops on Halt 70

Halt 70 - Push run sends program back to Halt 0 for a second file (data set).

If set SW15, then push run, a second EOF is written (End of volume).

Tape is rewound-stops on Halt 65 or Halt 76.

Halt 6 and Halt 7 - Error halts. Slow clock rate.

ADC5 Program

Purpose: To digitize analog data continuously.

Speed: Up to 13,000 samples per second.

Output tape: Unlabelled 9-track. Data is in 32-bit floating point form.
1944 words per record (can be changed).
Can have multiple files (data sets).

Procedure: Same as ADC4.

DIAG1 Program

Purpose: To check A/D converter and I/O interface of processor.

Procedure: Load program with BBL.
Entry address is 100 octal. Push run.
Halt 77 - Ready. Push run to start.

Connect a d-c power supply ($0 \rightarrow \pm 10\text{v}$) to the analog input and turn on the clock signal to the A/D converter. By slowly varying the input voltage the user can watch the B-register count up and down. The binary reading may be compared to the input voltage reading.

If bit SW 15 is set at any time, the program will halt back on Halt 77.

DIAG2 Program

Purpose: A magnetic tape reading program. Allows the operator to go forward or backwards on the tape in steps of records. Data on any record may be observed and tape marks are clearly indicated.

Procedure: Mount tape. Load program using BBL. Program entry is 100 octal. The first halt, Halt 76, is the starting point in the program. The "A" and "B" registers hold the number of the record of data presently directly behind the magnetic read head. Two operator options are possible at this point. Setting bit switches 14 and 15 causes the tape to backspace one record. Otherwise the next record is read in and Halt 0 is executed. The "A" register will contain the record length (up to 7400₈) and the "B" register will hold the record number. If the record read in is a tape mark, Halt 25 will be executed and 177777₈ will appear in the "A" register and "B" will hold the record number. Push run to read the next record.

Pushing run after Halt 0 allows the operator several options. One may look at the nth word on the tape record by entering n-1 into the switch register. That is, to look at the first word of the tape record, set the switch register to zero. To look at the second word, set the switch register to 1, etc. By setting switch bit "14" Halt 0 is executed with the registers holding the same information as before. Setting bit "15" returns the program to Halt 76 so the next record may be read, or the tape may be backspaced. The memory block area starts at 4000₈.

DIAG3 Program

Purpose: DIAG3 consists of two independent programs. The first is intended to aid in setting the offset voltage of the multiplexer. The second determines the peak input voltage to the A/D converter. The programs are located in memory such that they may be loaded and executed without destroying either the Magnetic Tape Operating System or the magnetic tape loading programs of the ADC series.

Procedure: Load the program tape using the BBL.
Entry 7000₈: Program acts as an integrator on the data from the A/D converter. Intended use is to set the offset voltage of the multiplexer.
Entry 7100: Program reads data from the A/D converter, removes sign and compares magnitude with largest magnitude received previously. If latest input is larger, the value is displayed in the "A" register. Intended use is to allow operator to adjust input voltages to the A/D converter such that it is not saturated on the peaks of the input waveforms.

The first program with starting address of 7000₈ reads data from the A/D converter and sums all the inputs together. That is, the program simulates an integrator. The integral is displayed in the "A" register at all times. The "A" register may be zeroed at any time by setting bit SW "15" of the switch register. To use the program, all inputs to the multiplexer should be removed, the multiplexer output connected to the A/D signal input, and a clock signal connected to the A/D trigger input. By watching the "A" register, the operator can determine if the average offset voltage is positive or negative. He can then turn the potentiometer to adjust the offset voltage the proper direction such that the integral tends to stay close to zero. The potentiometer is under the chassis of the multiplexer. However, it is located such that it may be adjusted while the multiplexer is in the relay rack. Experience has shown that it is usually best to have a slow clock rate when running this program.

The second program has an entry address of 7100₈. It reads data from the A/D converter, strips off the sign bit and compares the magnitude of the last data point with the largest data point received previously. If the last input is larger, it is displayed in the "A" register. Thus, the program tells the operator the peak input voltage to the A/D converter. Setting bit "15" of the switch register will reinitialize the program at any time.

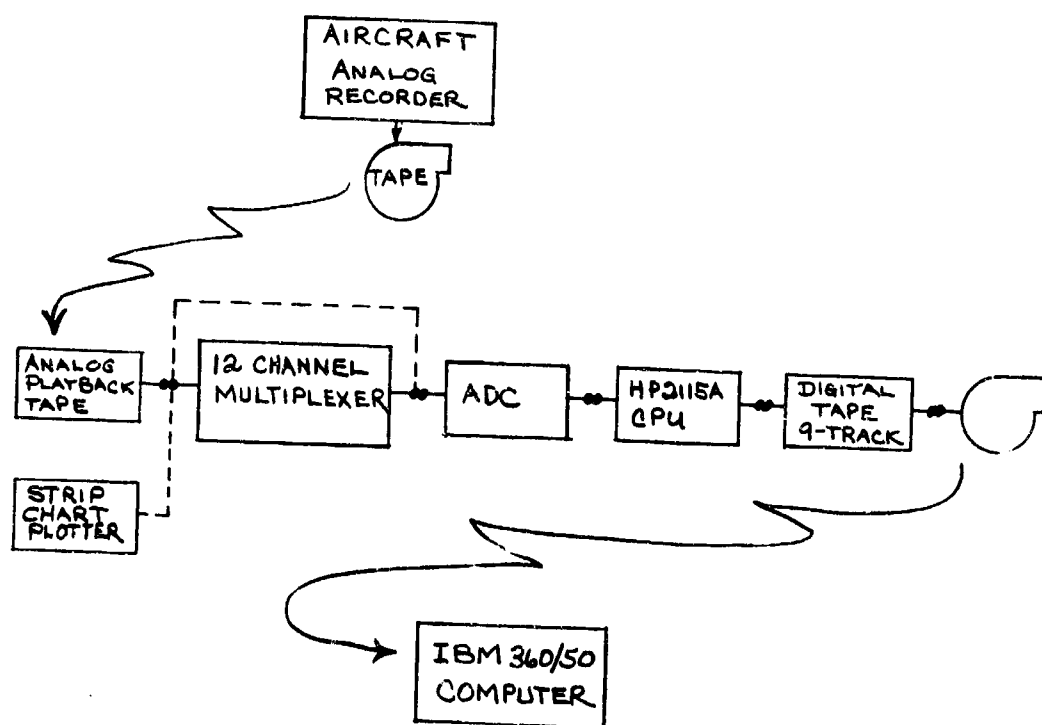


Figure 9. The Data Handling and Conversion System

Multiplexer. A multiplexer was designed and constructed which allows as many as 12 channels to be digitized simultaneously.

The analog portion of the multiplexer is depicted in Figure 10. The analog signals, which feed into terminals A1 through A12, originate from the playback Sangamo analog tape machine. These signals have levels that are normally in the 0 to 10 volt range. The preamplifiers in the multiplexer, PA1 to PA12, are designed to keep the signal levels at a maximum of ± 10 volts.

When a sample command is received on terminal SC, the sample-hold integrators, SH1 through SH12, all go into HOLD at the same time. Then, in the interim period between this sample command and the next one, the data samples are fed, one at a time, to the analog-to-digital convertor (761A). This is accomplished by opening the electronic switches, SW1 through SW12, sequentially in turn. The commutating control signals for this purpose are applied to terminals S1 through S12 in Figure 10.

The maximum sampling rate of the system, with 12 channels operating, is limited first by the digital tape machine. The maximum sampling rate, per channel, is 1940 samples per second. This figure is arrived at by dividing the overall maximum speed of 25,250 samples per second by 13 (the number of intervals in the read-out process). Naturally if fewer channels were in operation, the maximum speed, per channel, would be faster.

The necessary timing signals to accomplish the desired sequencing of the HOLD and READ-OUT operations are shown in Figure 11. In Figure 12 is pictured the digital control system for producing the timing signals.

With reference to Figure 12, the process is started by enabling the GO line. This can be done manually with a switch, or it may be desirable at times to synchronize this with the analog playback tape machine. The output of the AND gate, AND1, will start the clock whenever the 2115A processor delivers a SET-CONTROL signal (approximately 2 μ s max from GO). The one-shot, OS1, provides shaping of the clock pulses as well as providing a 10 μ s delay for the ADC convert signal.

The first change of the ring-counter sets the HOLD flip-flop which, in turn, causes the sample-hold integrators to HOLD. Then, as subsequent clock pulses occur, the ring-counter steps through 13 intervals. The outputs of 12 of the ring-counter flip-flops are used to gate the electronic switches SW1 - SW12. The 13th interval allows the sample-hold integrators to go back to the track or sample states and to stay in that state long enough to assume stable tracking operation. The entire cycle is then repeated when the ring-counter starts its cycle again.

TABLE I
Identification of Analog and Digital Modules

PA	Type 3112/12C, Burr-Brown
BA	Type 3130/15 , Burr-Brown
SH	Type 4035/15 , Burr-Brown
SW	Type 9859/15 , Burr-Brown
Clock	Type R401 , Digital Equipment Corporation
OS	Type R302 , Digital Equipment Corporation
Inv	Type R107 , Digital Equipment Corporation
FF	Type R202 , Digital Equipment Corporation
NC1	Type W600 , Digital Equipment Corporation
NC2	Type W601 , Digital Equipment Corporation
AND1	Type R111 , Digital Equipment Corporation

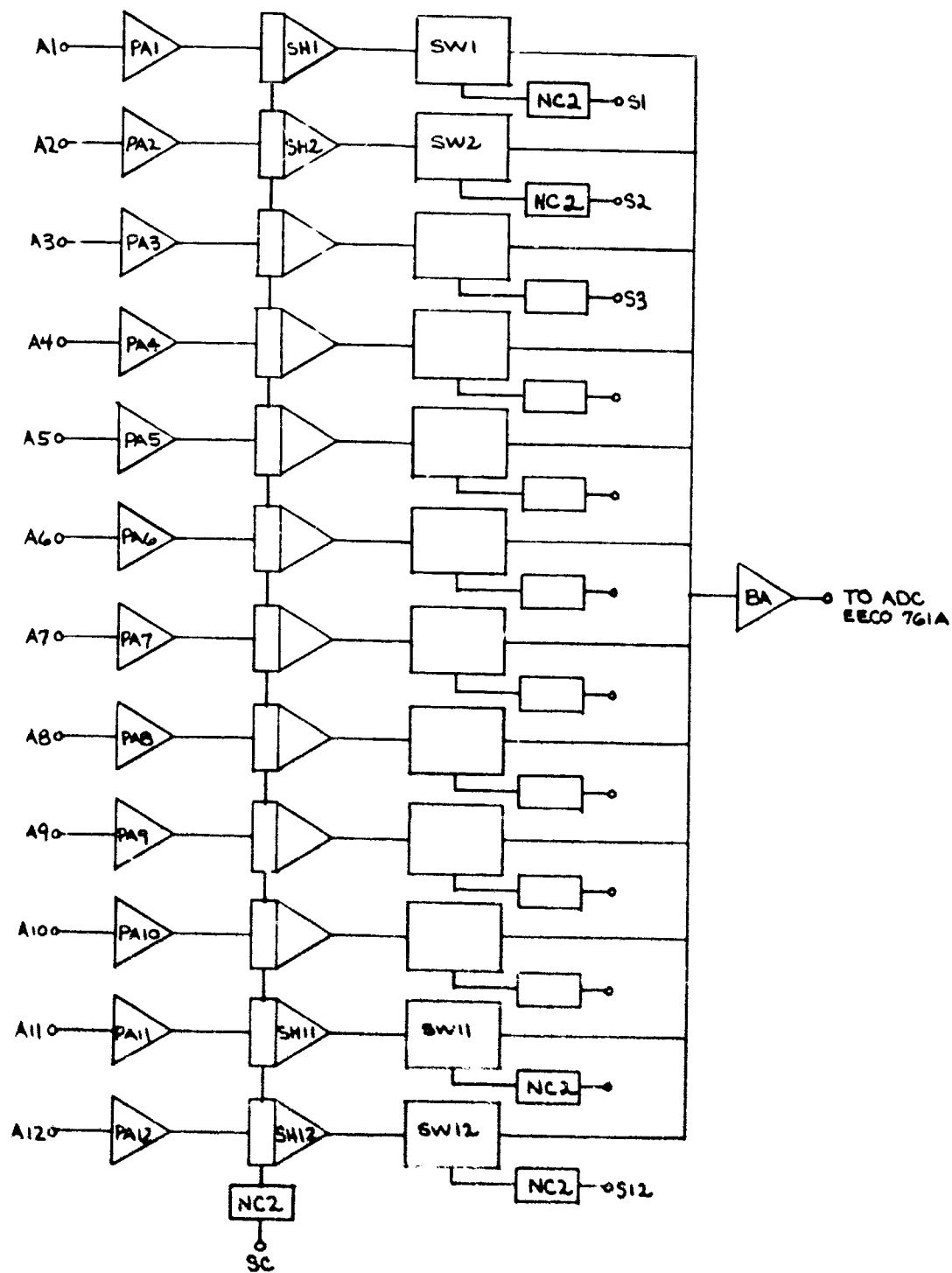


Figure 10. Analog Portion of Multiplexer

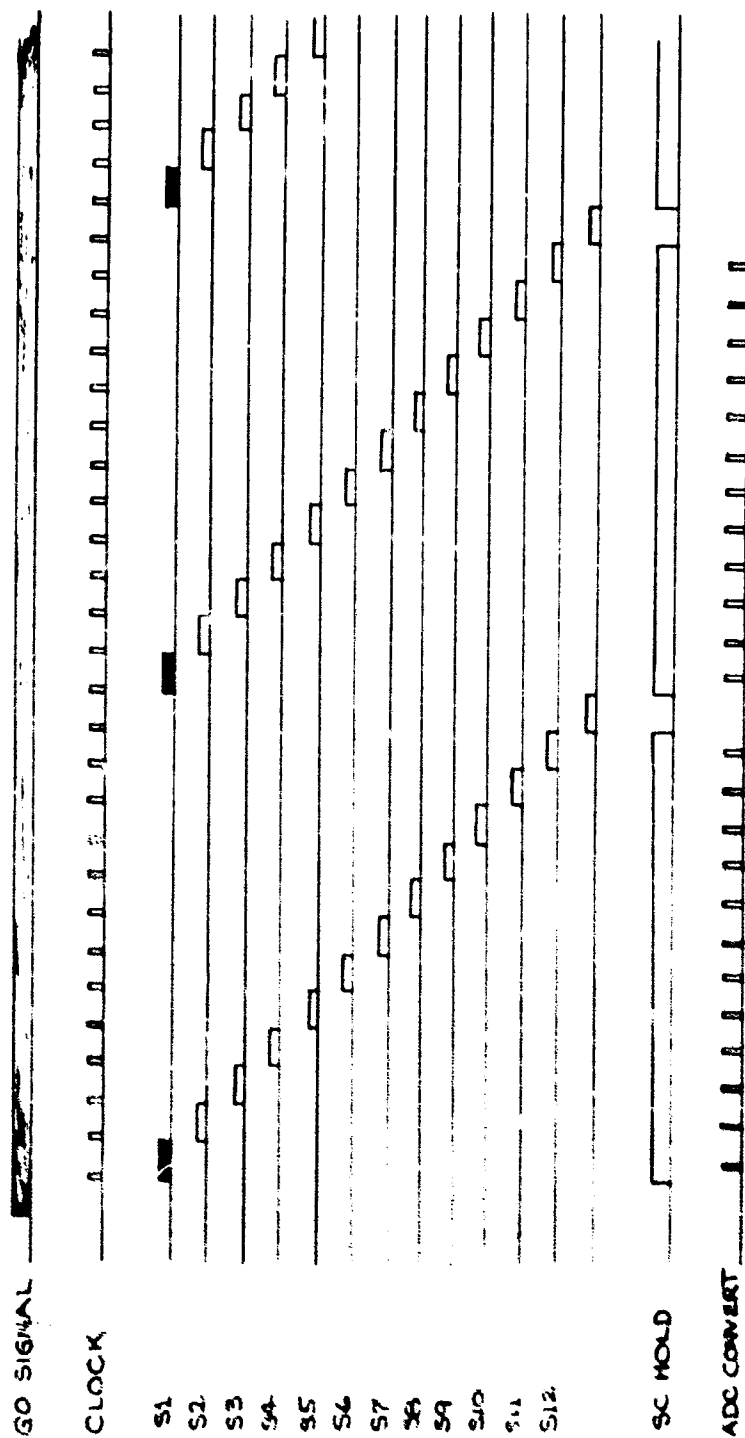


Figure 11 Digital Timing Signal Sequence

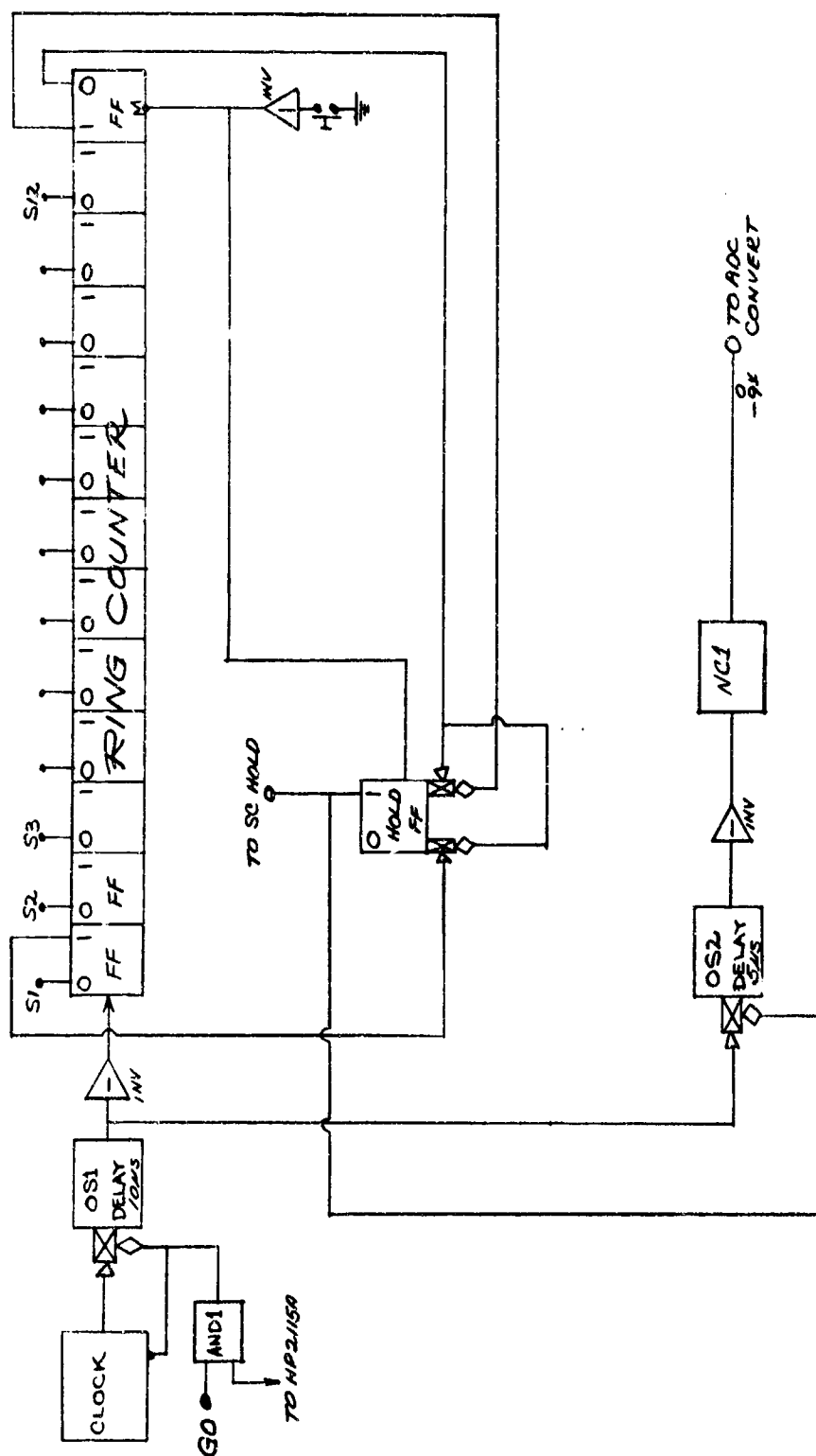


Figure 12. Digital Control System for the Multiplexer

Sferic Activity Meter. During the year, work has been done toward the development of a more universal sferic activity meter. This device is one embodying principles similar to that used in producing the Sferic Rate Histories presented as Figure 2, page 9, of the Quarterly Report dated March 31, 1970.

The diagram of Figure 13 represents the present form of the sferic instrument and the general nature of its operation is as follows. The input signal at terminal, T1, is the sferic signal from either a playback of an analog record or it can be originating in real-time from a detector output. In any event, it must be composed of positive signal bursts. Waveform, S1, of Figure 14 is representative of this signal.

The circuit is designed to accommodate an input signal, S1, with a minimum level of about 0.1 volt peak. The gain control P1, allows adjustment for larger signals.

The inverting amplifier, A1, has gain of 100. This builds up the maximum value of the signal to approximately 10 volts (negative peak). Control P2 sets the maximum negative limiting level of the amplifier to prevent overloading.

The Schmitt Trigger works as a discriminator against undesirable noise levels. The logic output levels of the trigger are 0 and -3 volts. The threshold levels at which the circuit switches are nominally -2.2 and -0.8 volts; however, these can be adjusted by pots P4 and P5 for changing the discriminating characteristics. The typical output of the Schmitt Trigger appears in Figure 14 as waveform S3.

The next stage, the one-shot multivibrator, OS, is for standardizing the widths of the pulses which coincide with sferic bursts. The adjustment of the pulse width is quite critical and the necessary width

is related to the nature of the sferic bursts. Waveform S4 of Figure 14 is representative of the output of the OS.

The special integrator, I1, serves as a short-time analog memory. In terms of the LaPlace Transform operator, S, this stage has a transfer function of

$$\frac{C_o}{C_1} = \frac{R_9}{R_8} \left[\frac{1}{1 + R_8 CS} \right]$$

which shows the state to be a first-order lag function. The time constant of the special integrator has three selections controlled by switch SW1. They are 70, 45 and 15 seconds, respectively. S5 waveform in Figure 14 serves to show the action of this stage.

The amplifier A2 serves merely to interface the resulting signal from the integrator to a recording meter M1. The present recorder, a RUSTRAK, requires 1 ma for full-scale deflection. Amplifier A2 has normal gain of 2.

In order that the sferic activity meter be suitably responsive to varied storm conditions, the threshold levels of the Schmitt Trigger, the plus width of the one-shot and the time-constant (and gain) of the 1st-order lag integrator must be coordinated suitably. Studies and experiments along this vein are continuing.



Figure 13. Diagram of the Sferic Activity Meter

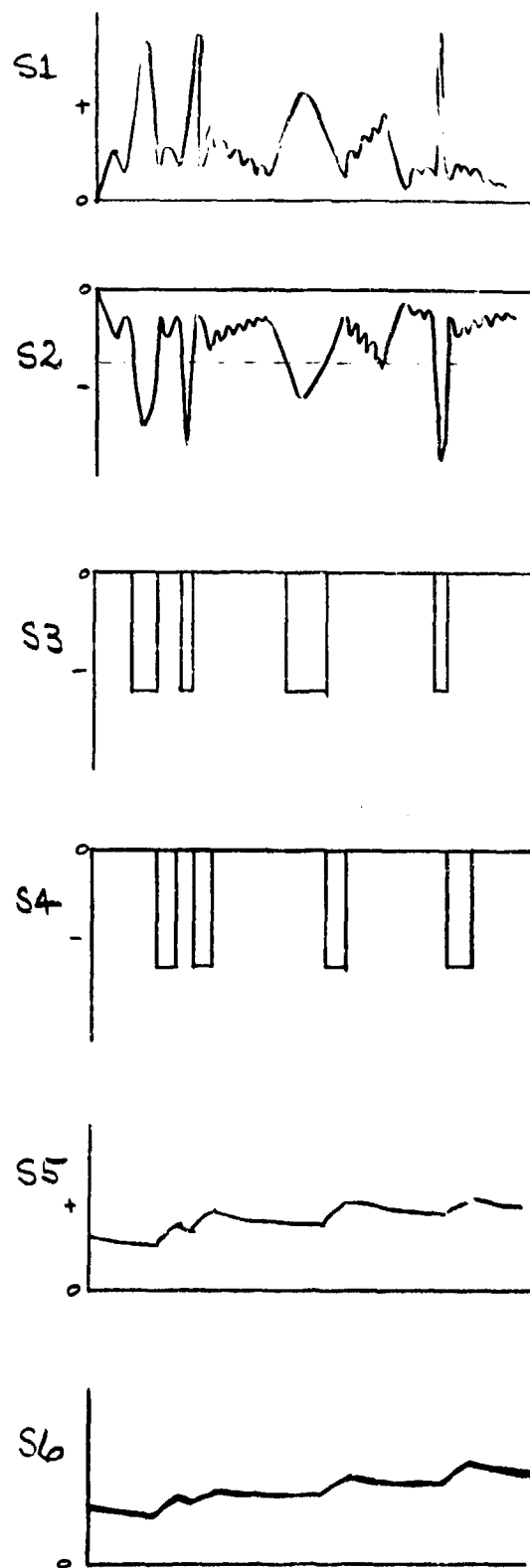


Figure 14. Signal Waveforms

APPENDIX A

Name: Kumarasamy Shanmugam

Date of Degree: May 25, 1970

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: LEARNING TO RECOGNIZE PATTERNS WITH AN IMPERFECT
TEACHER

Pages in Study: 104

Candidate for Degree of Doctor of Philosophy

Major Field: Electrical Engineering

Scope and Method of Study: Most of the earlier research efforts in pattern recognition have been directed towards developing procedures for learning to recognize patterns with a perfect teacher. In recent years considerable attention has been given to the problem of learning without a teacher. In between these two vastly different classes of problems is the problem of learning to recognize patterns with an imperfect teacher. This dissertation develops procedures for learning to recognize patterns with an imperfect teacher. The result is a nonparametric learning procedure. Theorems concerning the derivation of the learning procedure and analysis of performance are presented. The concept of feedback in the proposed learning scheme is investigated and a feedback learning scheme is proposed. The proposed feedback learning scheme is simulated on the computer and the results on the performance of the learning schemes are given. A comparison of the performances of the learning scheme with feedback and learning scheme without feedback is presented.

Findings and Conclusions: The proposed learning scheme is asymptotically optimal in the sense that it has an average risk equal to Bayes' (minimum) risk. If the density functions do not overlap then the average asymptotic performance of the learning scheme is better than the nearest neighbor rule and the imperfect teacher. The above results are true with a finite sample size also. For overlapping densities if the Bayes' risk is less than $(1-\beta)$, β being the probability that the teacher classifies a sample correctly, then the proposed learning scheme is still better than the nearest neighbor rule and the imperfect teacher. Also the proposed learning scheme does not require a knowledge of the exact value of β .

The thresholded feedback scheme proposed provides a deterministic method for combining the knowledge acquired by the learning scheme with that provided by the imperfect teacher. Threshold also provides control over the amount of feedback and facilitates a gradual phasing out of the teacher. If the density functions do not overlap then feedback results in an improvement in the average performance of the learning scheme. With overlapping densities such an improvement is possible only for low values of β . Further research needs to be done on using feedback with overlapping densities, on using a probabilistic feedback.

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Title of Study: A STUDY OF THE SECOND-ORDER STATISTICAL PROPERTIES OF THUNDERSTORM NOISE

Pages in Study: 143

Candidate for Degree of Doctor of Philosophy

Major Field: Electrical Engineering

Scope and Method of Study: This investigation was undertaken to develop a second-order statistical description of the thunderstorm signature as a source of noise interference. A characterization was obtained under three constraining conditions: (1) the data were gathered at a distance of thirty kilometers from the storm; (2) measurements of the storm signature were taken over the VLF portion of the radiated spectrum; and (3) the study was specialized to the segments of data which exhibited intense sferic activity. The data were, first, analyzed to determine whether or not a stationary assumption would be valid. It is shown that the sferic triggering mechanism can be modeled by a Poisson impulse process. Based on the assumption of wide sense stationarity, estimates of the time averaged autocorrelation and power spectral density functions are computed from three data segments of 0.75 second duration. These estimates are then, averaged to form an improved estimate.

Findings and Conclusions: The assumption of stationarity in the wide sense appears valid for data segments evidencing extremely intense sferic activity. Using a wide sense stationary model, estimates of the time averaged autocorrelation and power spectral density functions, computed from three member functions of the ensemble, were found to be strikingly similar after being normalized to the average measured power. Because of the close resemblance, it is concluded that the mean of the time averaged autocorrelation and power spectral density estimates is a reasonable description of the process in an ensemble sense. Specifically, it appears likely that this is a representative description of data segments evidencing extremely intense sferic activity. It is believed that this description may be useful in the design of filters for the purpose of minimizing thunderstorm noise interference in a mean square sense.

DISCRIMINATING BETWEEN CLOUD-TO-GROUND
AND CLOUD-TO-CLOUD LIGHTNING DISCHARGES:
A PATTERN RECOGNITION APPROACH

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ABSTRACT

A procedure for classifying lightning discharges into cloud-to-ground or cloud-to-cloud type is developed. This classification procedure is based on a set of measurements indicative of the frequency content of both horizontally and vertically polarized sferic signals from lightning discharges. The data corresponding to 84 visually identified discharges from one storm were used to develop the classification procedure. Additional data corresponding to 50 identified discharges from another storm were used to test the resulting classification scheme. Up to 82 percent agreement was found, on the test samples, between visual identification of the discharge and the type given by the classification scheme.

We found that significant difference exists in the frequency content of the horizontally polarized sferic signal from cloud-to-ground and cloud-to-cloud discharges. Also, the polarization ratio of the signal in the 50 kHz range was found to be considerably different for the two types of discharges.

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INTRODUCTION.

Considerable progress has been made during the past 30 years in the study of sferics from lightning discharges. Most of the earlier research attempts in this area have been directed towards understanding the nature of cloud-to-ground discharges. In recent years, efforts have been made towards the investigation of the nature of cloud-to-cloud discharges (Ogawa, T., and M. Brook, 1964) and towards finding out and explaining the differences in the sferic signals from different types of discharges (N. Kitagaw and M. Brook, 1960). This paper examines the differences in the frequency content of the sferic signal from cloud-to-cloud and cloud-to-ground discharges.

The frequency content of the sferic signal from lightning discharges have been studied by many investigators (Arnold and Pierce, 1964; Dennis and Pierce, 1964; Taylor, 1963). Most of the studies in this area are based on measurement of vertically polarized sferic signals recorded on the surface of the earth. By means of airborne instrumentation, both horizontally and vertically polarized sferic signals from lightning discharges were recorded and analyzed. Significant differences in the frequency content of the sferic signal from cloud-to-ground and cloud-

to-cloud discharges are pointed out and a procedure is given for discriminating between these two types of discharges in the absence of visual identification.

INSTRUMENTATION AND DATA GATHERING.

From the boundary conditions imposed on Maxwell's equations it follows that the horizontal polarization of the sferic signal cannot be measured effectively on the ground at low frequencies. Hence, airborne instrumentation was used in this investigation. Also, the airborne instrumentation made it possible to stay close to a moving storm and collect data for a reasonably long time. The antenna complement of the instrumentation consists of a vertical whip antenna mounted on top of the fuselage of the research aircraft (D-18S Beechcraft) and a horizontal tow-type antenna attached to a cable which unreels from the tail of the aircraft. The signal flow path, which is identical for both horizontal and vertical antennas, is shown in Figure 1.

The signal gathered at the antenna is routed through a cathode follower, pre-amp, cathode follower assembly to a set of comb filters. The filters used have center frequencies of 10kHz, 50kHz, 150kHz and 250kHz and a bandwidth of 1 kHz. The output of each comb filter is then envelope detected with a detection time constant of 1 millisecond. The detected signal is then recorded in FM mode on one of the 12 data channels of a magnetic tape recorder. In addition to the sferic data, one of the edge tracks of the tape contains an audio recording of the comments of an observer in the aircraft. These comments, recorded in real time along with the sferic data, contain information about the type of discharges that were visually identified by the observer in the aircraft. When the sferic data is played back, the voice recording

serves to identify a burst of data as coming from a cloud-to-ground or cloud-to-cloud discharge.

The data used in this investigation were taken during two thunderstorms in Oklahoma during June, 1969. Both the storms were of frontal type and had a large number of well defined lightning discharges. The aircraft was flying elliptical paths on one side of the storms at a distance of approximately 30 kilometers and an altitude of 5 kilometers. The data corresponding to 50 discharges from the storm on June 11, 1969 and 84 discharges from the storm on June 22, 1969 were processed for a set of measurements as described below.

DATA REDUCTION.

The first step in data reduction was converting the analog data into digital form suitable for processing on the digital computer. Sections of recorded data corresponding to visually identified, well defined discharges were selected and the analog data was converted into digital form. The average duration of the signal from the discharges was about 3/4 second and the digital data for the duration of the individual discharges were processed for a set of measurements which served as inputs to the pattern recognition scheme.

The measurements derived from the data consists of the relative amounts of energy in the various comb filter frequencies. Even though one would normally require exact values for these measurements for a quantitative analysis, a relative measure of these values will be adequate for pattern recognition purposes.

The energy received from a discharge at the input of a particular comb filter channel is the product of the average power, N , at the input

and the duration T of the discharge. Since T is the same for all frequencies for a given discharge, the average value of power at the input to the filter is sufficient for comparing the relative amounts of energy in various comb filter bands. For small amplitudes, the envelope of the comb filter output has been shown (Horner, F., 1964) to have a Raleigh distribution with a mean equal to $\sqrt{N\pi/2}$. Hence the average value of the comb filter output is a relative measure of N , the average power at the input and hence a measure of energy.

Since the received energy is a function of the distance between the aircraft and the discharge and since this varies from discharge to discharge, the average value of the signal in various comb filter channels were normalized as follows: The average value of the signal in each of the four horizontal channels was normalized with respect to the sum of averages in all horizontal channels. This gives a relative measure of the fraction of horizontally polarized energy that appears in a given comb filter band of frequencies. Similarly, the averages in the vertical channels were normalized with respect to the sum of averages in all the vertical channels. The sum of averages in horizontal and vertical channels were normalized with respect to the total sum to obtain fractions of total energy that are horizontally and vertically polarized. In addition to these 10 measurements the average values of signal in 50 kHz horizontal and vertical channels, normalized with respect to their sum were taken to represent the polarization ratio in 50 kHz range. This set of twelve measurements are listed below.

- x_1 - Normalized average value of signal in 10 kHz Horizontal
- x_2 - Normalized average value of signal in 50 kHz Horizontal
- x_3 - Normalized average value of signal in 150 kHz Horizontal

- x_4 - Normalized average value of signal in 250 kHz Horizontal
- x_5 - Normalized average value of signal in 10 kHz Vertical
- x_6 - Normalized average value of signal in 50 kHz Vertical
- x_7 - Normalized average value of signal in 150 kHz Vertical
- x_8 - Normalized average value of signal in 250 kHz Vertical
- x_9 - Normalized sum of average value of signal in horizontal channels
- x_{10} - Normalized sum of average value of signal in vertical channels
- x_{11} - Normalized horizontal signal in 50 kHz channel
- x_{12} - Normalized vertical signal in 50 kHz channel

Since x_4 , x_8 , x_{10} and x_{12} can be calculated if the other measurements are known, these were eliminated as inputs to the pattern recognition scheme. The remaining 8 measurements were used to form a "pattern vector" X from the data corresponding to each identified discharge, where

$$X = [x_1, x_2, x_3, x_5, x_6, x_7, x_9, x_{11}]^T$$

For sample patterns used to train the pattern classifier, information about the type of discharge to which a particular pattern X_i corresponds is needed as an input to the classifier. This identification information, denoted by θ^i , comes from visual sightings of the discharge by the observer in the aircraft. If θ_1 and θ_2 denote cloud-to-ground and cloud-to-cloud discharges respectively, then θ^i takes the form θ_1 or θ_2 depending on if X_i corresponds to a discharge identified as cloud-to-ground or cloud-to-cloud type. Combining this information with X_i , the data presented the pattern recognition scheme consists of a set of measurement pairs $(X_1, \theta^1), \dots, (X_n, \theta^n)$.

PATTERN RECOGNITION.

The pattern recognition problem in this investigation consists of developing procedures for identifying cloud-to-ground and cloud-to-cloud discharges based upon the sferic signals. The classification procedure is developed from a given set of measurement pairs $(X_1, \theta^1), \dots, (X_n, \theta^n)$. After the development of a classification procedure, only the measurement X is available and an estimate is desired of the type of discharge from which X was derived. Three methods described below were used for developing such procedures based on a set of n measurement pairs.

1. Polynomial Discriminant Function Method: For probabilistic pattern sets, a Bayes' procedure for classifying patterns into $\hat{\theta}_1$ or $\hat{\theta}_2$ with minimum probability of misclassification uses a discriminant function of the form,

$$D(X) = P(\hat{\theta}_1) f_{X|\hat{\theta}_1} - P(\hat{\theta}_2) f_{X|\hat{\theta}_2}, \quad (3)$$

where $P(\hat{\theta}_1)$ is the probability that a measurement X has a visual identification $\hat{\theta}_1$, and $f_{X|\hat{\theta}_1}$ is the conditional probability density function of X given that X is visually identified as $\hat{\theta}_1$. A given pattern X is assigned to $\hat{\theta}_1$ if $D(X) > 0$ and to $\hat{\theta}_2$ if $D(X) < 0$. Since no knowledge about $P(\hat{\theta}_1)$ and $f_{X|\hat{\theta}_1}$ is assumed, these quantities have to be estimated from the given sample patterns.

The quantity $P(\hat{\theta}_1)$ was estimated by

$$\hat{P}(\theta_1) = \frac{n_1}{n},$$

where n_1 is the number of sample patterns with the identification $\hat{\theta}_1$ and n is the total number of samples. The unknown densities $f_{X|\hat{\theta}_1}$ were

estimated in the form of a second order polynomial in the components of X , as proposed by Specht (1967). Using the estimated probabilities and density functions in Equation (3), the estimated discriminant function

$$\hat{D}(X) = \hat{P}(\hat{\theta}_1) D_1(X) - \hat{P}(\hat{\theta}_2) D_2(X) \quad (4)$$

was used to classify X into $\hat{\theta}_1$ or $\hat{\theta}_2$ depending on if $\hat{D}(X) > 0$ or $\hat{D}(X) < 0$. In Equation (4), for $i = 1$ or 2 $D_i(X)$ is the polynomial estimator of $f_{X|\hat{\theta}_i}$ whose coefficients were computed from the sample patterns identified as $\hat{\theta}_i$. Expressions for computing and updating these coefficients were given by Sprecht (1967).

2. Threshold Logic Unit: In the threshold logic unit method, a linear discriminant function of the form

$$D(X) = w_1 x_1 + w_2 x_2 + \dots + w_d x_d + w_{d+1} \quad (5)$$

was used to classify X into $\hat{\theta}_1$ or $\hat{\theta}_2$ depending on whether $D(X) > 0$ or $D(X) < 0$. In Equation (5), d is the number of measurements used, $x_1, \dots, x_d$ are the components of the pattern vector X and $w_1, w_2, \dots, w_{d+1}$ are a set of weights determined through an error correcting procedure (Nillson, 1965). The correction factor in this procedure was made to decrease as $1/(m+1)$ where m denotes the number of training cycles completed. The weight vector that resulted at the end of 1,000 training cycles was used in Equation (5) for classifying the test patterns.

3. Linear Least Square Method: A linear discriminant function of the form given in Equation (5) was used in this method also. However, the weight vectors were chosen such that the sum $\sum_{i=1}^n (Y_i - w_{d+1} - W^T X_i)^2$ is minimized, where

$$Y_i = +1 \text{ if } X_i \text{ has an identification } \hat{\theta}_1$$

$$Y_i = -1 \text{ if } X_i \text{ has an identification } \hat{\theta}_2$$

and

$$W = (w_1, w_2, \dots, w_d)^T.$$

RESULTS.

Data corresponding to 84 discharges from one storm, consisting of 42 cloud-to-ground discharges and 42 cloud-to-cloud discharges were used to "train" the pattern classifier. Fifty additional samples from a different storm were used to test the performance of the trained classifier. The index of performance was the percentage agreement between the identification provided by the classifier and the visual identification of the test samples.

The classifier was first trained with all the eight measurements as inputs to the classifier. At the end of training, it was observed that the weights attached to measurements x_1 , x_2 and x_{11} were large in magnitude compared to the other measurements. This suggested that x_1 , x_2 and x_{11} are more significant than the remaining measurements. So the classifier was trained again with x_1 and x_2 and also with x_1 , x_2 and x_{11} . The summary of performance of the classifier for the three different methods of training with three different input measurement sets is given in Table I. The entries in the table represent the percentage agreement between the classification provided by the pattern recognition scheme and visual identification on the 50 test samples.

It can be seen from Table I, that the best classification scheme is the one using x_1 , x_2 and x_{11} as input measurements. A scatter diagram of the training patterns with respect to these measurements is shown in Figures 2 and 3. The following observations can be made from these Figures.

- (1) Cloud-to-cloud discharges tended to have more horizontally polarized energy in 50 kHz range while cloud-to-ground discharges tended to have more horizontally polarized energy in 10 kHz range.
- (2) Cloud-to-ground discharges tended to have more vertically polarized energy in 50 kHz range while cloud-to-cloud discharges tended to have more horizontally polarized energy.

The differences in frequency content of the two types of discharges can be explained in terms of the physical lengths of the discharge paths, the magnitude of currents and the rates at which they change. In a cloud-to-ground discharge, two main sources of radiation are the step leader and the return strokes. Return strokes, which are strong and contain large slowly changing currents, radiate maximum energy in 5-10 kHz range (Uman, 1969; Dennis and Pierce, 1964). Return strokes may also have continuing current with energy in the ELF range. The cloud-to-cloud discharges do not have return strokes of the same form as those in a cloud-to-ground discharge. They may radiate low frequency energy comparable with but usually smaller than that from return strokes (Hornev, 1964), hence cloud-to-cloud discharges have comparatively smaller energy in the lower frequencies.

The difference in polarization can be attributed to the physical orientation of the discharge, the cloud-to-ground discharges having more of a vertical orientation. The average value of the percentage of horizontally polarized energy in 50 kHz range for the cloud-to-ground discharge was found to be 39.85% and was 49.10% for cloud-to-cloud discharges. This 39.85% horizontal polarization for cloud-to-ground discharges suggests that the horizontal component of the in-cloud

channel on the average is comparable to the vertical component. Based on a study of electric field changes involving 539 return strokes involving 84 flashes, T. Ogawa and M. Brook (1969) concluded that the horizontal component of the in-cloud channel is significant and on the average exceeds the vertical component. Our results support the conclusions of T. Ogawa and M. Brook to the extent that there is significant horizontal component in cloud-to-ground discharges. Since four channels that we used did not encompass the entire range of frequencies containing energy, further interpretation of our results is not possible.

The performance of the classification procedure evaluated by checking for agreement with visual identification does not give a measure of the true performance of the classifier. If β^* is the probability that the computer gives correct identification, and if β is the corresponding probability for visual identification, then the probability of agreement between the two is $\beta\beta^* + (1-\beta)(1-\beta^*)$. If β and $\beta^* > 1/2$, then the probability of agreement given in table one will be less than β^* that the probability classification scheme gives correct performance, i.e., the true performance index of the pattern recognition scheme will be higher than the probability of agreement given in table one. (Shanmugam and Breipohl, 1970).

CONCLUSIONS

It has been shown that measurements from sferic data can be used to identify cloud-to-cloud and cloud-to-ground discharges. There are significant differences in the frequency spectrum of the horizontally polarized sferic signal and the differences are significant in the horizontal vs vertical polarization ratio of the sferic signal in 50 kHz range. Combining these two measures we found that the identification provided

by the pattern recognition scheme agreed up to 82% with visual observations.

ACKNOWLEDGEMENT.

The authors wish to acknowledge the financial support provided by the Electronics Command of the Department of the Army under contract number DAAB07-68-C-0083.

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Table 1. Summary of Performance

Input Measurements	Percentage Agreement with Visual Identification		
	Polynomial Discriminant Function Method	Threshold Logic Unit	Linear Least Sq. Method
All	70%	74%	80%
x_1, x_2	72%	78%	74%
x_1, x_2, x_{11}	76%	80%	82%

LEGEND FOR FIGURES

- Figure 1. Block Diagram of Instrumentation.
- Figure 2. Horizontally polarized Energy in 10 kHz Vs 50 kHz.
- Figure 3. Horizontal Vs Vertical Polarization in 50 kHz band. All the points in this diagram lie along the line $x_{11} + x_{12} = 100$, but for the sake of clarity they are shown with an offset.

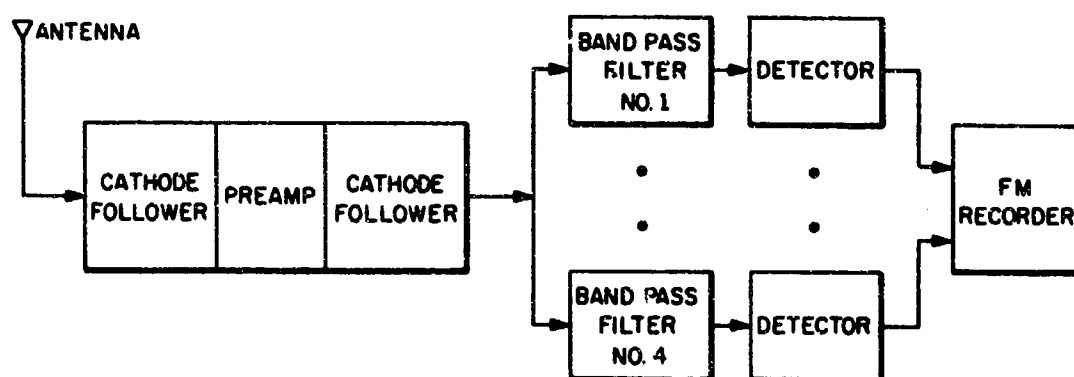


Figure 1.

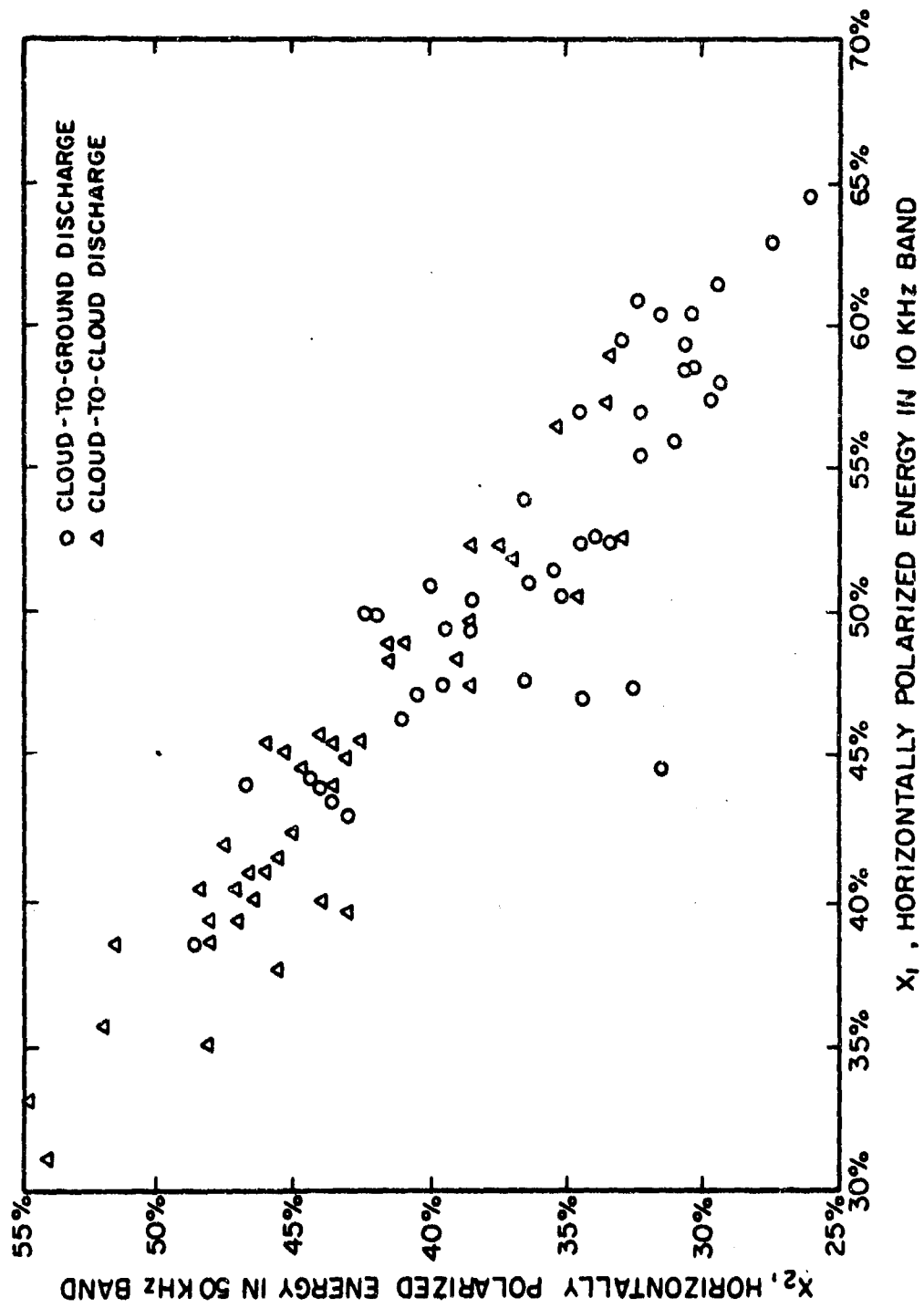


Figure 2.

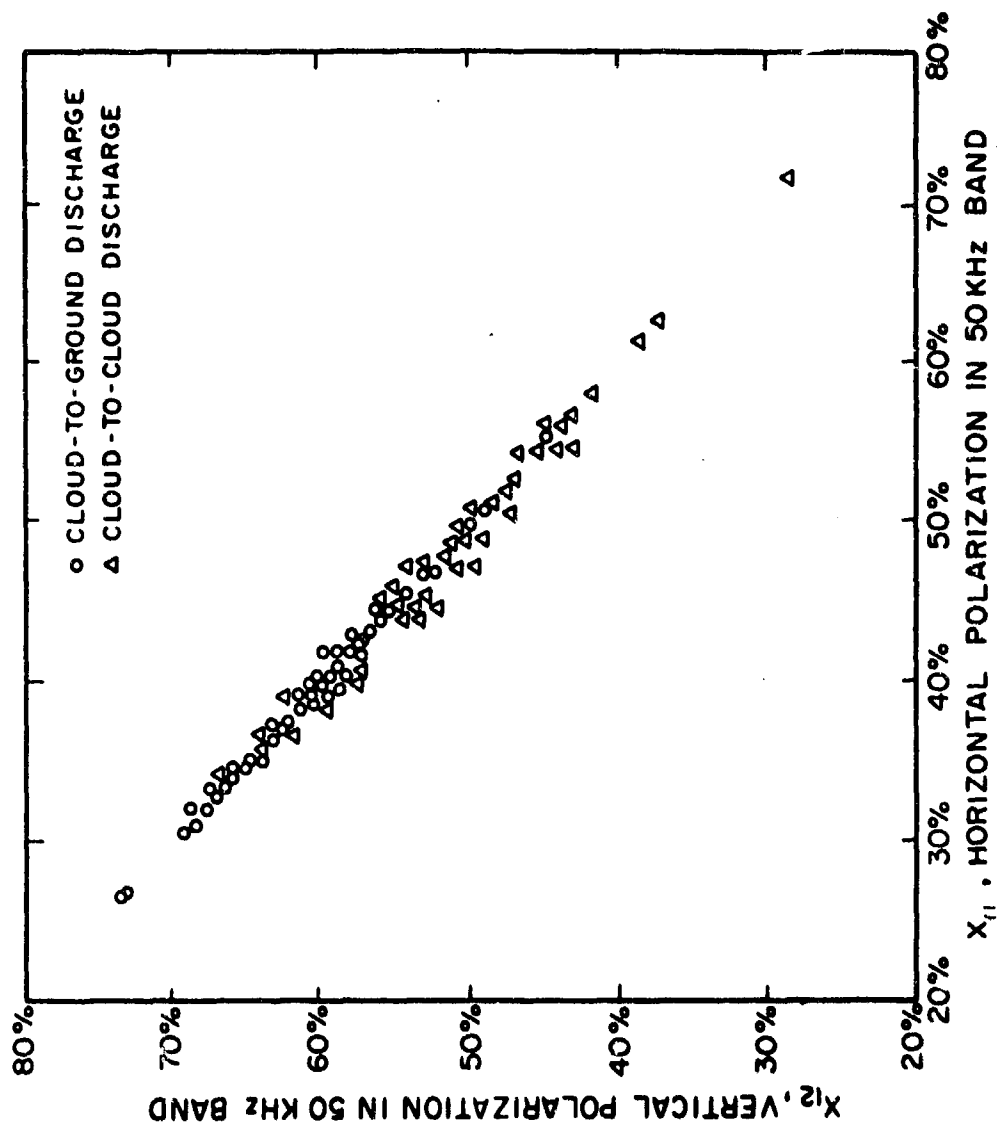


Figure 3.

A STUDY OF THE SECOND-ORDER STATISTICAL
PROPERTIES OF THUNDERSTORM NOISE

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Measurements were taken of the electromagnetic field radiated from two thunderstorms which were separated in time by three days. Analysis of two data segments from the first storm and one segment from the second storm revealed that the signature fit a wide sense stationary model; moreover, estimates of the autocorrelation and power spectral density functions indicate that the process satisfies a condition of local ergodicity. The study culminates in a second-order statistical description which appears to be valid in an ensemble sense.

As a part of the weather phenomena research work sponsored by the Department of Defense under Project Themis (A Center for Description of Environmental Conditions, Themis Project No. 129), atmospheric noise measurements were made in the presence of thunderstorm activity occurring in the vicinity of Rapid City, South Dakota in July 1969. The vertically polarized electromagnetic field radiated from the storm was sensed by a 1.525 meter vertical whip antenna mounted atop the fuselage of a D-18 twin engine Beechcraft airplane. The data were collected and recorded by magnetic tape on board the airplane while the aircraft flew in an elliptical path at an altitude of approximately 5 km. The flight path was centered approximately 30 km from the storm and was executed by

flying parallel to the storm for 10 min., making a 180° turn, and flying in the opposite direction for 10 min. The objective was one of maintaining the path as near constant as possible with respect to the storm.

Three representative data segments of 0.75 sec. duration were selected for detailed analysis. These segments were characterized by a relatively high density of large amplitude K-change pulses, but were otherwise arbitrarily chosen (for a discussion of K-change pulses see Uman [1969]). Two of the data segments were taken from the data collected on July 14 and the third segment was taken from the recorded data of July 17.

The objective of the data analysis was to produce a credible estimate of the autocorrelation and power spectral density functions by serially reducing each data segment. In order to effect this analysis, the process was first investigated to determine the degree of stationarity. To test for stationarity in the wide sense, we hypothesized that the sferic triggering mechanism could be modeled by a Poisson impulse process. The condition of wide sense stationarity would be determined by whether or not the Poisson parameter were constant and the sferic pulses bore reasonable similarity. For illustration, let $h(t)$ characterize a single K-change pulse and let λ denote the Poisson parameter. The process described is shot noise, and for a zero mean value, Papoulis [1965] shows that the autocorrelation function is represented by

$$\phi(t_1, t_2) = [\lambda(t_2) h(t_1 - t_2)] * h(t_2)$$

where $*$ denotes convolution. If λ is constant, then Papoulis [1965] shows that the autocorrelation depends only on the parameter $\tau = |t_1 - t_2|$ and is given by

$$\phi(\tau) = \lambda \int_{-\infty}^{\infty} h(\tau + \beta) h(\beta) d\beta$$

Furthermore, when the triggering mechanism is characterized by a constant λ , Hogg and Craig [1965] show that the waiting time between pulses has a probability distribution function represented by

$$F_W(\omega) = \begin{cases} 0 & \omega < 0 \\ 1 - e^{-\lambda\omega} & \omega \geq 0 \end{cases}$$

This implies that

$$\lambda\omega = -\ln[1 - F_W(\omega)] \quad \omega > 0$$

and if $-\ln[1 - F_W(\omega)]$ is plotted as a function of ω , the constancy of λ can be tested by whether or not the result is a straight line.

Measurements of the waiting times between pulses were taken from each of the data segments separately, and an empirical distribution function was computed. A plot of $-\ln[1 - F_W(\omega)]$ versus ω , then, revealed that a straight line approximation to the data points provided a reasonable fit. Hence, we concluded that a Poisson model with a constant parameter was a reasonable description of these segments of the storm signature. Further, we concluded that the data could be reduced using the methods of stationary analysis.

The autocorrelation and power spectral density functions were estimated from each of the three records. These estimates were strikingly similar after being normalized to the average measured power on each data segment. Because of the close resemblance in the estimates, we concluded that the process can be credibly represented by computing a sample mean based on the individual curves. The computed mean of the three autocorrelation functions is shown in Figure 1, while the mean of the power spectral densities is shown in Figure 2. Inspection of the power spectral density plot reveals a peak at 9 kHz which was expected

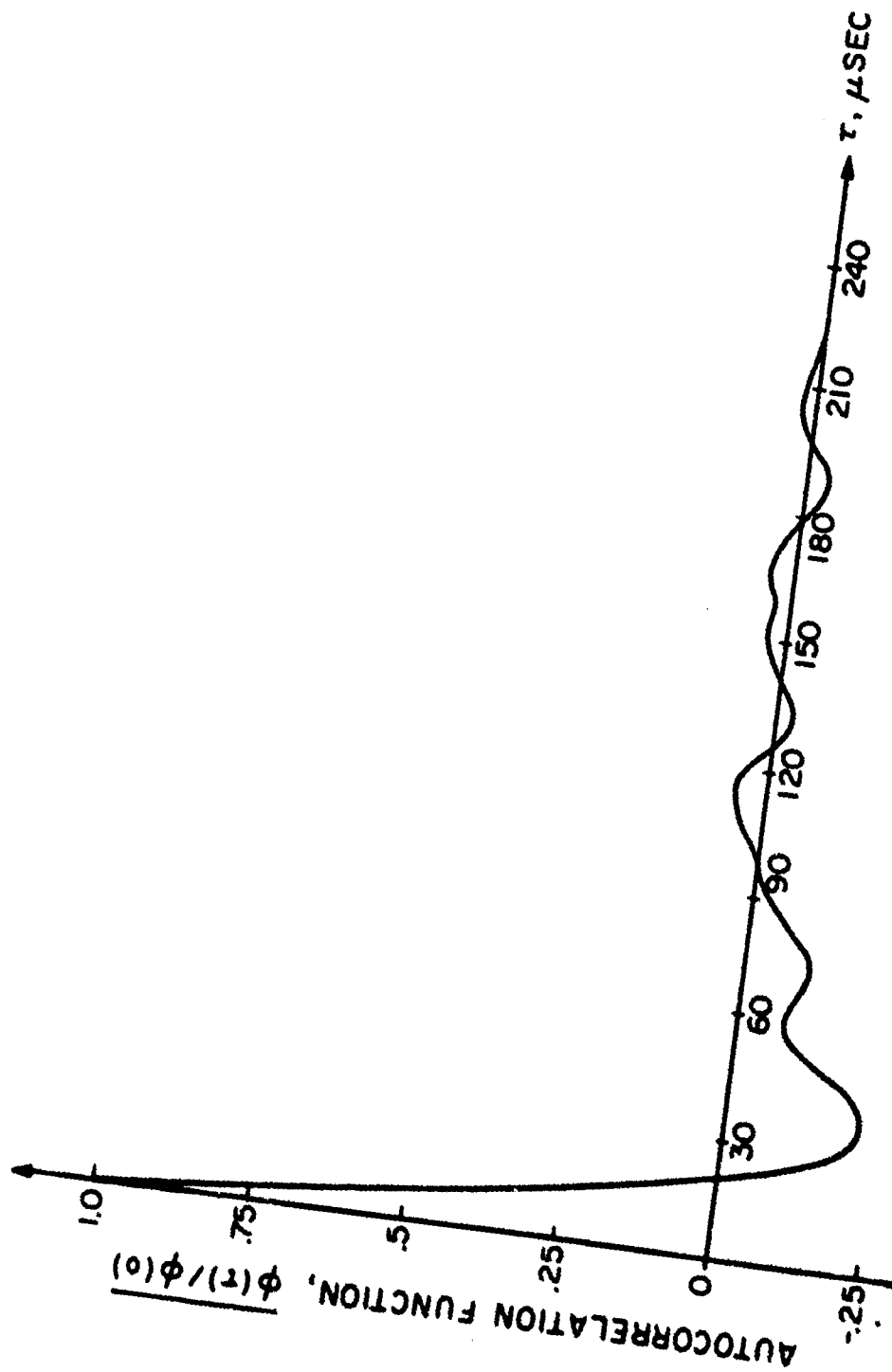


Figure 1. Averaged Autocorrelation Estimate.

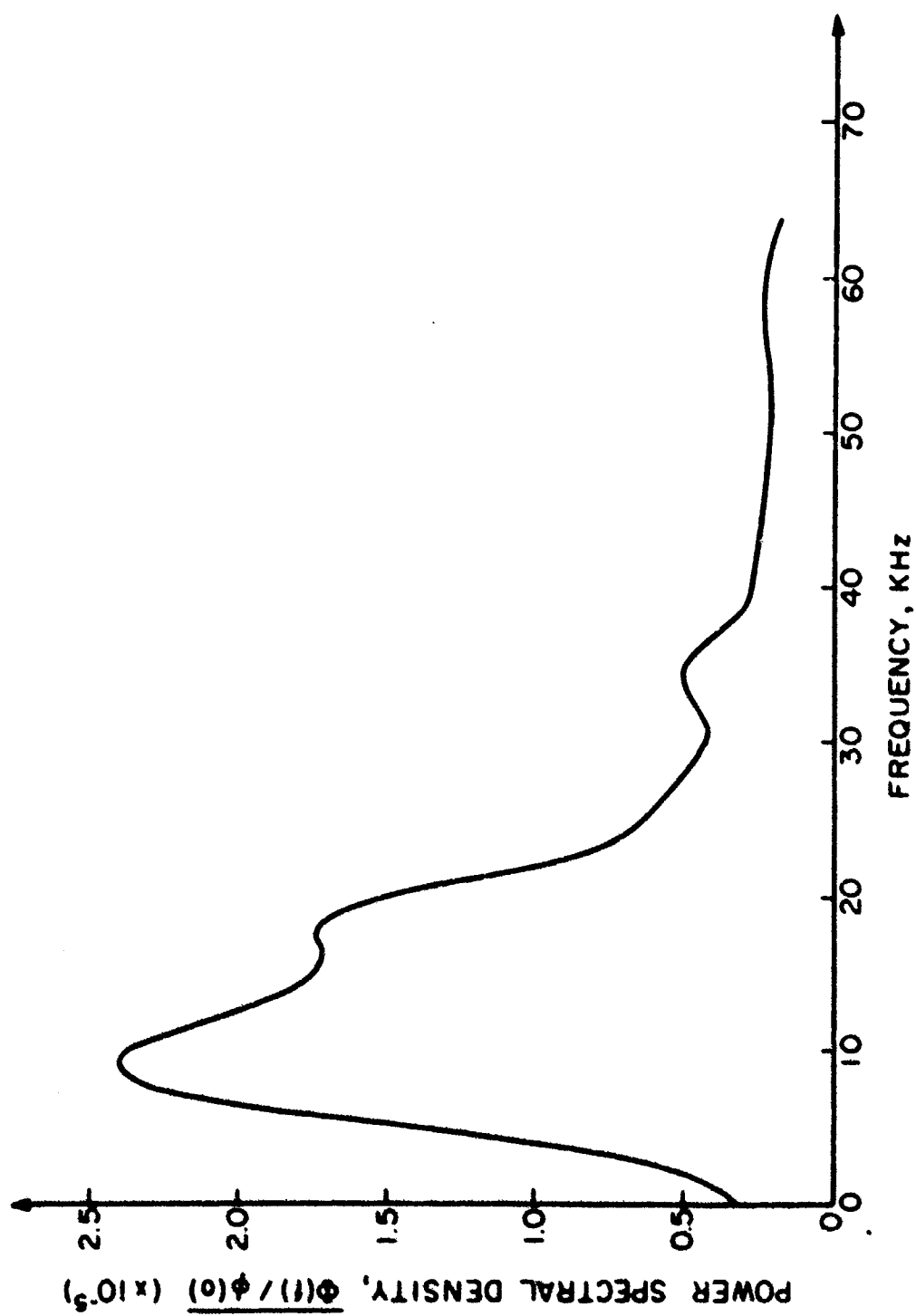


Figure 2. Averaged Power Spectral Density Estimate.

The hump at 18.75 kHz results from an interfering signal in the aircraft electrical system. The hump at 34.5 kHz was thought at first to be constructive interference from ground reflection or from the ionosphere; however, this component did not appear in the power spectral density of the first data segment. Because there were several sustained discharges of 30 msec duration or greater in the second and third data segments, but there were no discharges of this type in the first data segment, we speculated that the sustained discharges promote the radiation of this component although the cause for this phenomenon is unknown.

Summarizing, the assumption of stationarity in the wide sense appears justified for data segments evidencing relatively uniform intense sferic activity. Using the wide sense stationary model, estimates of the autocorrelation and power spectral density functions exhibit the ergodic property after being normalized to the average measured power. Because the data segments analyzed are believed to be representative, it appears reasonable to assume that the descriptions presented are valid in an ensemble sense for data segments of relatively uniform intense sferic activity.

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LEARNING WITH AN IMPERFECT TEACHER

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Summary

Most of the earlier research efforts in pattern recognition have been directed towards developing procedures for learning to recognize patterns with a perfect teacher. In recent years considerable attention has been given to the problem of learning without a teacher. In between these two vastly different classes of problems is the problem of learning to recognize patterns with an imperfect teacher. This paper is concerned with developing and analyzing a procedure for learning to recognize patterns with an imperfect teacher.

A decision rule for classifying patterns with an imperfect teacher is derived. Using nonparametric estimators for the unknown densities appearing in the decision rule, a procedure for learning to recognize patterns with an imperfect teacher is given. It is shown that the proposed learning scheme has an asymptotic average risk equal to the Bayes' minimum risk. For non-overlapping densities, the average asymptotic performance of the learning scheme is better than the teacher and nearest neighbor rule trained by the same imperfect teacher. The same is true for overlapping densities if the amount of overlap is less than $1 - \beta$, β being the probability that the teacher is correct. Also it is shown that for non-overlapping densities the proposed learning scheme performs better than the teacher, on the average, after looking a finite but large number of samples. The proposed learning scheme is simulated on the Computer for some simple density functions and the results are presented.

Introduction

A major step common to all pattern recognition problems consists of developing procedures which classify observations such that a particular strategy is optimized. This step can be formulated as follows. A set of n measurement pairs $(X_1, \theta^1), \dots, (X_n, \theta^n)$ are given as sample (training) patterns. $X_i (i=1, \dots, n)$ is a vector measurement drawn from one of the R possible categories $\theta_1, \dots, \theta_R$. θ^i takes the form θ_k , when X_i is identified by the teacher as being from category θ_k . After development of a classification procedure, only the measurement X is available and an estimate is desired of the category from which X was drawn.

Depending on the nature of information available in the form of θ^i 's, the problem of learning to recognize patterns can be subdivided into three classes. If θ^i contains identification of the true category of X_i then learning is said to take place with a "perfect teacher". If no information about the true category of X_i is available, then this class of problems is referred to as "learning without a teacher".

Between these two problems is the problem of "learning with an imperfect teacher". This problem has received much less attention; nevertheless, many situations fall into this category. For example, medical diagnoses which are used to determine the categories into which electrocardiogram records are to be classified are not perfect. The authors of this paper were led into an investigation of learning with an imperfect teacher by trying to classify spheres into cloud-to-cloud or cloud-to-ground discharges on the basis of measurements of electromagnetic signature. The categories for the training samples were identified by visual observations which apparently contained some errors.

This paper is concerned with developing procedures for learning to classify patterns with an imperfect teacher characterized by

$$P(\hat{\theta}_i | \theta_i) = \beta > \frac{1}{R}; \quad i = 1, \dots, R$$

$$P(\hat{\theta}_j | \theta_i) = \left(\frac{1-\beta}{R-1} \right); \quad i, j = 1, \dots, R; i \neq j. \quad (1.a)$$

The patterns are assumed to be probabilistic in nature with unknown conditional probability density functions $f_{X|\theta_i}$, with the property that

$$f_{X|\theta_i, \hat{\theta}_j} = f_{X|\theta_i} \quad i, j = 1, \dots, R. \quad (1.b)$$

A decision rule for classifying patterns with an imperfect teacher using discriminant functions of the form $P(\hat{\theta}_i) f_{X|\hat{\theta}_i}$ is given. This decision rule is shown to be equivalent to a Bayes' decision rule using discriminant functions of the form $P(\theta_i) f_{X|\theta_i}$. Nonparametric estimators $\hat{f}_{X|\hat{\theta}_i; n}$ of the unknown density $f_{X|\hat{\theta}_i}$ are proposed for learning to recognize patterns with an imperfect teacher. Using one such estimator it is shown that the proposed learning scheme has an average asymptotic risk equal to the average Bayes' (minimum) risk. For non-overlapping densities and for densities with overlap less than $(1-\beta)$ it is shown that the average asymptotic performance of the learning scheme is better than that of the imperfect teacher and the nearest neighbor rule trained by the same imperfect teacher.

The performance of the learning scheme with a finite, but large number of samples is also derived for non-overlapping densities and it is shown that the learning scheme better in probability the performance of the teacher after looking at a finite number of samples. A somewhat more surprising result is that more samples will be required to better the performance of either of the mediocre teacher. The proposed scheme was simulated on a computer to obtain the average risk for some simple density functions.

The Decision Rule

For probabilistic patterns with known probability distributions, a Bayes' procedure can be used to arrive at a decision rule that optimizes the given strategy. The strategy to be optimized is specified in terms of a loss function L_{ij} , defined for $i, j = 1, \dots, R$. The loss function L_{ij} represents the loss incurred when a pattern actually belonging to category θ_j is misplaced into category θ_i . For a zero-one loss function $L_{ij} =$

1- δ_{ij} , where δ_{ij} is the Kronecker delta function, it has been shown¹ that the Bayes' procedure leads to discriminant functions of the form

$$D_{\theta_1} = P(\theta_1) f_{X|\theta_1} \quad (2)$$

$P(\theta_1)$ is the prior probability of category θ_1 and $f_{X|\theta_1}$ is the probability density function of pattern X given that it belongs to θ_1 . A given pattern x is classified into category θ_1 if

$$D_{\theta_1}(x) > D_{\theta_j}(x) \quad j = 1, \dots, R; j \neq 1 \quad (3)$$

It is assumed in Equation 2 that all information relevant to $P(\theta_1)$ and $f_{X|\theta_1}$, ($i = 1, \dots, R$), were known. In practice, often this information is only partially known. The unknown information must be learned from the given set of labelled sample patterns, the information associated with D_{θ_1} being estimated from samples belonging to category θ_1 . But due to the imperfect teacher, the true categories of the sample patterns are not available to the learning scheme. The only labeling information available to the student is one of $\hat{\theta}_1, \dots, \hat{\theta}_R$ provided by the imperfect teacher. Hence in order to learn from these incorrectly labeled samples, it is necessary to derive a decision rule in terms of $P(\hat{\theta}_1)$ and $f_{X|\hat{\theta}_1}$; $i = 1, \dots, R$.

Theorem 1. With an imperfect teacher characterized by Equations (1.a) and (1.b), a decision rule using discriminant functions of the form $D_{\hat{\theta}_1} = P(\hat{\theta}_1) f_{X|\hat{\theta}_1}$ is equivalent to a Bayes' decision rule using discriminant functions of the form $D_{\theta_1} = P(\theta_1) f_{X|\theta_1}$.

Proof. The above theorem can be proved by showing that $D_{\hat{\theta}_1}(x) > D_{\hat{\theta}_j}(x)$ if and only if $D_{\theta_1}(x) > D_{\theta_j}(x)$; thus establishing that the two decision rules are equivalent.

Using Bayes' theorem it follows that the distribution function of X given that X is labelled as $\hat{\theta}_1$ is

$$f_{X|\hat{\theta}_1}(x|\hat{\theta}_1) = \sum_{k=1}^R f_{X|\hat{\theta}_1, \theta_k}(x|\hat{\theta}_1, \theta_k) P(\theta_k|\hat{\theta}_1)$$

Using the condition given in Equation (1.b) it follows that

$$\begin{aligned} f_{X|\hat{\theta}_1}(x|\hat{\theta}_1) &= \sum_{k=1}^R f_{X|\theta_k}(x|\theta_k) P(\theta_k|\hat{\theta}_1) \\ &= \sum_{k=1}^R f_{X|\theta_k}(x|\theta_k) \frac{P(\hat{\theta}_1|\theta_k) P(\theta_k)}{P(\hat{\theta}_1)} \end{aligned}$$

$$\begin{aligned} f_{X|\hat{\theta}_1}(x|\hat{\theta}_1) &= \frac{1}{P(\hat{\theta}_1)} \{ P(\theta_1) \beta f_{X|\theta_1}(x|\theta_1) \\ &+ \sum_{\substack{k=1 \\ k \neq 1}}^R P(\theta_k) \left(\frac{1-\beta}{R-1} \right) f_{X|\theta_k}(x|\theta_k) \} \end{aligned}$$

and

$$\begin{aligned} f_{X|\hat{\theta}_j}(x|\hat{\theta}_j) &= \frac{1}{P(\hat{\theta}_j)} \{ P(\theta_1) \beta f_{X|\theta_1}(x|\theta_1) \\ &+ \sum_{\substack{k=1 \\ k \neq j}}^R P(\theta_k) \left(\frac{1-\beta}{R-1} \right) f_{X|\theta_k}(x|\theta_k) \} \end{aligned}$$

Hence

$$\begin{aligned} D_{\hat{\theta}_1}(x) &= P(\hat{\theta}_1) \beta f_{X|\theta_1}(x|\theta_1) \\ &+ \sum_{\substack{k=1 \\ k \neq 1}}^R P(\theta_k) \left(\frac{1-\beta}{R-1} \right) f_{X|\theta_k}(x|\theta_k) \end{aligned}$$

A similar expression can be obtained for $D_{\hat{\theta}_j}(x)$ and from these two equations it follows that

$$\begin{aligned} D_{\hat{\theta}_1}(x) - D_{\hat{\theta}_j}(x) &= P(\hat{\theta}_1) \beta f_{X|\theta_1}(x|\theta_1) \\ &- P(\hat{\theta}_j) \beta f_{X|\theta_j}(x|\theta_j) \\ &+ P(\hat{\theta}_j) \left(\frac{1-\beta}{R-1} \right) f_{X|\theta_j}(x|\theta_j) \\ &- P(\hat{\theta}_1) \left(\frac{1-\beta}{R-1} \right) f_{X|\theta_1}(x|\theta_1) \\ &= \left(\frac{\beta R - 1}{R - 1} \right) \{ D_{\theta_1}(x) - D_{\theta_j}(x) \} \end{aligned}$$

Since $\beta > \frac{1}{R}$ by assumption, it follows from the above equation that

$$D_{\hat{\theta}_1}(x) \geq D_{\hat{\theta}_j}(x) \iff D_{\theta_1}(x) \geq D_{\theta_j}(x)$$

as was to be shown.

If there are only two categories of patterns θ_1 and θ_2 and if $\beta > 1/2$, then classification can be done by evaluating a single discriminant function

$$\begin{aligned} D_{\hat{\theta}}(x) &= P(\hat{\theta}_1) f_{X|\hat{\theta}_1}(x) - P(\hat{\theta}_2) f_{X|\hat{\theta}_2}(x) \\ &= (2\beta - 1) [P(\theta_1) f_{X|\theta_1}(x) - P(\theta_2) f_{X|\theta_2}(x)] \end{aligned} \quad (4)$$

A given pattern x is assigned to θ_1 if $D_{\hat{\theta}}(x) > 0$ and θ_2 if $D_{\hat{\theta}}(x) < 0$. From Equation (4) it can be seen that if $\beta < 1/2$, then changing the sign of $D_{\hat{\theta}}(x)$ will lead to an optimum classification procedure. Also it can be seen that when $\beta = 1/2$, no classification will result from the above discriminant function.

If the density functions $f_{X|\theta_1}$ and if $f_{X|\theta_2}$ do not overlap, then a discriminant function of the form

$$D'_{\hat{\theta}}(x) = f_{X|\hat{\theta}_1}(x) - f_{X|\hat{\theta}_2}(x) \quad (5)$$

is optimum for dichotomizing patterns. In fact,

$$\begin{aligned} f_{X|\hat{\theta}_1}(x|\hat{\theta}_1) - f_{X|\hat{\theta}_2}(x|\hat{\theta}_2) &= \frac{1}{P(\hat{\theta}_1)} \{ \beta P(\theta_1) f_{X|\theta_1}(x|\theta_1) \\ &+ (1-\beta) P(\theta_2) f_{X|\theta_2}(x|\theta_2) \\ &- \frac{1}{P(\hat{\theta}_2)} \{ (1-\beta) P(\theta_1) f_{X|\theta_1}(x|\theta_1) \\ &+ \beta P(\theta_2) f_{X|\theta_2}(x|\theta_2) \} \\ &= \frac{1}{P(\hat{\theta}_1) P(\hat{\theta}_2)} \{ P(\theta_1) f_{X|\theta_1}(x|\theta_1) \\ &[\beta P(\hat{\theta}_2) - (1-\beta) P(\hat{\theta}_1)] \\ &- P(\theta_2) f_{X|\theta_2}(x|\theta_2) \\ &[\beta P(\hat{\theta}_1) - (1-\beta) P(\hat{\theta}_2)] \} \\ &= \frac{1}{P(\hat{\theta}_1) P(\hat{\theta}_2)} \{ P(\theta_1) f_{X|\theta_1}(x|\theta_1) [(2\beta - 1) P(\theta_2)] \\ &- P(\theta_2) f_{X|\theta_2}(x|\theta_2) [(2\beta - 1) P(\theta_1)] \} \end{aligned}$$

$$= \frac{P(\theta_1)P(\theta_2)}{P(\hat{\theta}_1)P(\hat{\theta}_2)} (2\beta - 1) [f_{X|\theta_1}(x|\theta_1) - f_{X|\theta_2}(x|\theta_2)].$$

Hence

$$D'_{\hat{\theta}}(x) = \frac{P(\theta_1)P(\theta_2)}{P(\hat{\theta}_1)P(\hat{\theta}_2)} (2\beta - 1) [f_{X|\theta_1}(x|\theta_1) - f_{X|\theta_2}(x|\theta_2)].$$

As in Equation (4) if $\beta < 1/2$, then $-D'_{\hat{\theta}}(x)$ instead of $D'_{\hat{\theta}}(x)$ can be used for classifying patterns.

Also, it can be seen from Equation (5) that $D'_{\hat{\theta}}(x)$ does not involve the exact value of β . The only information required is whether $\beta > 1/2$ or $\beta < 1/2$. The same is true of $D_{\hat{\theta}}(x)$, for overlapping densities.

Learning With An Imperfect Teacher

The decision rule derived in Theorem 1 involves $P(\hat{\theta}_i)$ and $f_{X|\hat{\theta}_i}$; $i = 1, \dots, R$. The samples are given with labels $\hat{\theta}_1, \dots, \hat{\theta}_R$. Hence any unknown information associated with $D_{\hat{\theta}_i}$ can now be estimated (learned) through the samples carrying the label $\hat{\theta}_i$. In the remainder of this paper it will be assumed that $R = 2$, and that the prior probabilities $P(\theta_1)$ and $P(\theta_2)$ are known. (If unknown, $P(\theta_1)$ and $P(\theta_2)$ can be estimated by the number of times the labels $\hat{\theta}_1$ and $\hat{\theta}_2$ occur relative to the total number of samples used.)

The unknown densities $f_{X|\hat{\theta}_1}$ and $f_{X|\hat{\theta}_2}$ can be estimated from a set of incorrectly labeled independent sample patterns $X_1, \dots, X_{n_1}; Y_1, \dots, Y_{n_2}$. The X_i 's are sample patterns with labels $\hat{\theta}_1$ and are identically distributed random vectors with a common probability density function $f_{X|\hat{\theta}_1}$. Similarly the Y_i 's are patterns with labels $\hat{\theta}_2$ and identically distributed with a common probability density function $f_{X|\hat{\theta}_2}$.

Using nonparametric estimators proposed and analyzed by Parzen² and Murthy³, an estimate of $f_{X|\hat{\theta}_1}(x|\hat{\theta}_1)$ based on the sample patterns $X_1, \dots, X_{n_1}$ is

$$\hat{f}_{X|\hat{\theta}_1;n_1}(x|\hat{\theta}_1) = \frac{1}{\sqrt{n_1}} \sum_{k=1}^{n_1} \frac{1}{p} \left[\frac{1}{(2\pi)^{p/2}} \exp\left\{-\frac{[x - X_k]^T [x - X_k](n_1)^p}{2}\right\} \right] \quad (6)$$

and an estimate of $f_{X|\hat{\theta}_2}(x|\hat{\theta}_2)$ based on $Y_1, \dots, Y_{n_2}$ is

$$\hat{f}_{X|\hat{\theta}_2;n_2}(x|\hat{\theta}_2) = \frac{1}{\sqrt{n_2}} \sum_{k=1}^{n_2} \frac{1}{p} \left[\frac{1}{(2\pi)^{p/2}} \exp\left\{-\frac{[x - Y_k]^T [x - Y_k](n_2)^p}{2}\right\} \right] \quad (7)$$

In Equations (6) and (7) p is the dimension of the pattern space.

One of the disadvantages of this form of estimation is that all the sample patterns need to be stored. This difficulty can be overcome by using the polynomial approximation suggested by Specht (4) of the form.

$$\hat{f}_{X|\hat{\theta}_1;n_1}(x|\hat{\theta}_1) = \frac{1}{\sigma^p (2\pi)^{p/2}} \left[\exp\left(-\frac{(x-x)^T (x-x)}{2\sigma^2}\right) \right] D^1(x). \quad (8)$$

In the above estimator, $D^1(x)$ is a polynomial with a finite number of terms whose coefficients are computed using the n_1 sample patterns labelled as $\hat{\theta}_1$. As addi-

tional samples become available, these coefficients can be updated through a recursive equation. Hence the sample patterns need not be stored permanently. One of the unsolved problems associated with Specht's method of estimation is the number of terms that one needs to include in the polynomial. For a desired accuracy, it may be feasible to derive a relationship involving the number of sample patterns the dimension of the pattern space and the unknown density function.

Under certain regularity conditions, the above mentioned estimators have been shown^{2, 3, 4} to be consistent and asymptotically normally distributed. Using the estimated densities in the discriminant function given in Equation (4), the proposed learning scheme is:

- (1) Using the incorrectly identified sample patterns,

$$X_1, \dots, X_{n_1}; Y_1, \dots, Y_{n_2}, \text{ estimate } f_{X|\hat{\theta}_1} \text{ and } f_{X|\hat{\theta}_2};$$

- (2) Using estimators $\hat{f}_{X|\hat{\theta}_1;n_1}(x|\hat{\theta}_1)$ and $\hat{f}_{X|\hat{\theta}_2;n_2}(x|\hat{\theta}_2)$ compute

$$\hat{D}_{\hat{\theta}}(x) = P(\hat{\theta}_1) \hat{f}_{X|\hat{\theta}_1;n_1}(x|\hat{\theta}_1) - P(\hat{\theta}_2) \hat{f}_{X|\hat{\theta}_2;n_2}(x|\hat{\theta}_2);$$

- (3) Assign x to

$$\theta_1 \text{ if } \hat{D}_{\hat{\theta}}(x) > 0,$$

and

$$\theta_2 \text{ if } \hat{D}_{\hat{\theta}}(x) < 0. \quad (9)$$

Performance of the Proposed Learning Scheme

Asymptotic Performance. The asymptotic performance of the proposed learning scheme can be analyzed using the consistency properties of the estimators $\hat{f}_{X|\hat{\theta}_1;n_1}$ and $\hat{f}_{X|\hat{\theta}_2;n_2}$.

Theorem 2. The proposed learning scheme has an average asymptotic risk equal to the average Bayes risk.

Proof. It has been shown by Murthy³ that $\hat{f}_{X|\hat{\theta}_1;n_1} \xrightarrow{p} f_{X|\hat{\theta}_1}$ as $n_1 \rightarrow \infty$ with Probability 1 and $\hat{f}_{X|\hat{\theta}_2;n_2} \xrightarrow{p} f_{X|\hat{\theta}_2}$ as $n_2 \rightarrow \infty$ with Probability 1. Hence with Probability one $\hat{D}_{\hat{\theta}} \xrightarrow{p} D_{\theta}$ as $n_1, n_2 \rightarrow \infty$. Therefore with Probability one, the proposed learning scheme classifies a given pattern x into the same category into which a Bayes machine would place x . Hence the conditional risk $r_s(x; n_1, n_2)$ associated with classifying x according to (9), converges to the Bayes' conditional risk, $r^*(x)$, with Probability one, i.e. $r_s(x; n_1, n_2) \xrightarrow{p} r^*(x)$ as $n_1, n_2 \rightarrow \infty$ with Probability one. Hence

$$E(r_s(x; n_1, n_2)) = r^*(x) \text{ as } n_1, n_2 \rightarrow \infty. \quad (10)$$

For a symmetrical loss function the Bayes' conditional risk is given by

$$r^*(x) = \min\{P(\theta_1|x), P(\theta_2|x)\} \quad (11)$$

Taking the average on both sides of Equation (10) with respect to $f_X(x)$, the average risk associated with learning with an imperfect teacher is

$$\begin{aligned} R_s &= \int r^*(x) f_X(x) dx \\ &= P(\theta_1) \int_{D_2} f_{X|\theta_1}(x|\theta_1) dx \\ &\quad + P(\theta_2) \int_{D_1} f_{X|\theta_2}(x|\theta_2) dx \end{aligned} \quad (12)$$

where

$$D_1 = \{x : P(\theta_1)f_{X|\theta_1}(x|\theta_1) > P(\theta_2)f_{X|\theta_2}(x|\theta_2)\}, \text{ and}$$

$$D_2 = \{x : P(\theta_2)f_{X|\theta_2}(x|\theta_2) > P(\theta_1)f_{X|\theta_1}(x|\theta_1)\}.$$

The right hand side of Equation (12) is the Bayes' risk R^* , hence, as was to be shown,

$$R_s = R^* \quad (13)$$

The average risk for the teacher denoted by R_t is

$$R_t = 1 - \beta \quad (14)$$

and the average asymptotic risk for the nearest neighbor rule, R_n , has been shown ⁵ to be bounded by

$$(1 - \beta) + (2\beta - 1) R^* \leq R_n \leq (1 - \beta) + (2\beta - 1)[2R^*(1 - R^*)] \quad (15)$$

For non-overlapping densities $R^* = 0$ and from Equations (13), (14) and (15) it can be seen that the proposed learning scheme has a lower average risk and hence on the average performs better than the teacher and the nearest neighbor rule. Also if the overlap in densities is small, i.e. if $R^* < 1 - \beta$, then again the proposed learning scheme is better than the teacher and the nearest neighbor rule. In both cases the learning scheme (student) becomes smarter than the teacher.

Large Sample Performance of the Learning Scheme. In the previous sections of the asymptotic performance of the proposed learning scheme was analyzed and it was shown that if the density functions do not overlap then, on the average, the learning scheme performs better than the teacher. In this section it will be shown that the learning scheme performs better than the teacher, on the average, after being presented with a finite but large number of sample patterns $X_1, \dots, X_{n_1}; Y_1, \dots, Y_{n_2}$.

From Equation (5), the learning scheme for classifying patterns when the density functions do not overlap is:

$$\text{Assign } x \text{ to } \theta_1 \text{ if } \hat{f}_{X|\hat{\theta}_1;n_1}(x|\hat{\theta}_1) > \hat{f}_{X|\hat{\theta}_2;n_2}(x|\hat{\theta}_2) \quad (16)$$

$$\text{Assign } x \text{ to } \theta_2 \text{ if } \hat{f}_{X|\hat{\theta}_2;n_2}(x|\hat{\theta}_2) > \hat{f}_{X|\hat{\theta}_1;n_1}(x|\hat{\theta}_1). \quad (17)$$

A given pattern x from category θ_1 is therefore classified correctly if (16) is satisfied and will be incorrectly if (17) holds. Assigning a value of +1 for correct classification and 0 for incorrect classification, the gain associated with classifying a pattern x from a category θ_1 is

$$g_s(x|\theta_1; n_1, n_2) = P(\hat{f}_{X|\hat{\theta}_1;n_1}(x|\hat{\theta}_1) > \hat{f}_{X|\hat{\theta}_2;n_2}(x|\hat{\theta}_2) | x \in \theta_1) \quad (18)$$

For estimators of the form given in Equations (6) and (7), Murthy⁶ has shown that as $n_1, n_2 \rightarrow \infty$

$$E(|\hat{f}_{X|\hat{\theta}_1;n_1} - f_{X|\theta_1}|^2) = \frac{1}{\sqrt{n_1}(2\sqrt{\pi})^P} f_{X|\theta_1} \quad (19)$$

and

$$E(|\hat{f}_{X|\hat{\theta}_2;n_2} - f_{X|\theta_2}|^2) = \frac{1}{\sqrt{n_2}(2\sqrt{\pi})^P} f_{X|\theta_2} \quad (20)$$

These results can be used to derive a lower bound for $g_s(x|\theta_1; n_1, n_2)$.

Theorem 3. If (19) and (20) holds, then as n_1 and $n_2 \rightarrow \infty$, for x from category θ_1

$$P(\hat{f}_{X|\hat{\theta}_1;n_1}(x|\hat{\theta}_1) > \hat{f}_{X|\hat{\theta}_2;n_2}(x|\hat{\theta}_2) | x \in \theta_1) \geq L(\beta, n_1, n_2, x)$$

where

$$L(\beta, n_1, n_2, x) = [1 - \frac{C_1 \beta}{\sqrt{n_1} f_{X|\theta_1}(x|\theta_1)}] \times [1 - \frac{C_2(1 - \beta)}{\sqrt{n_2} f_{X|\theta_2}(x|\theta_2)}] \quad (21)$$

and

$$C_1 = \frac{P(\theta_1)}{P(\hat{\theta}_1)} \left[\frac{P(\hat{\theta}_1)P(\hat{\theta}_2)}{P(\theta_1)P(\theta_2)(2\beta - 1)} \right]^2 \frac{4}{(2\sqrt{\pi})^P}$$

$$C_2 = \frac{P(\theta_1)}{P(\hat{\theta}_2)} \left[\frac{P(\hat{\theta}_1)P(\hat{\theta}_2)}{P(\theta_1)P(\theta_2)(2\beta - 1)} \right]^2 \frac{4}{(2\sqrt{\pi})^P} \quad (22)$$

Proof. Let

$$D = f_{X|\theta_1}(x|\theta_1) - f_{X|\theta_2}(x|\theta_2) > 0$$

and let

$$D_1 = \{x: f_{X|\theta_1}(x|\theta_1) > 0\}$$

$$P(\hat{f}_{X|\hat{\theta}_1;n_1}(x|\hat{\theta}_1) > \hat{f}_{X|\hat{\theta}_2;n_2}(x|\hat{\theta}_2) | x \in \theta_1) \geq P(|\hat{f}_{X|\hat{\theta}_1;n_1}(x|\hat{\theta}_1) - f_{X|\theta_1}(x|\theta_1)| > \frac{D}{2} \cap |\hat{f}_{X|\hat{\theta}_2;n_2}(x|\hat{\theta}_2) - f_{X|\theta_2}(x|\theta_2)| < \frac{D}{2} | x \in \theta_1).$$

Since the estimators $\hat{f}_{X|\hat{\theta}_1;n_1}$ and $\hat{f}_{X|\hat{\theta}_2;n_2}$ are independent, the right hand side of the inequality becomes

$$\geq P(|\hat{f}_{X|\hat{\theta}_1;n_1}(x|\hat{\theta}_1) - f_{X|\theta_1}(x|\theta_1)| < \frac{D}{2} | x \in \theta_1) \times P(|\hat{f}_{X|\hat{\theta}_2;n_2}(x|\hat{\theta}_2) - f_{X|\theta_2}(x|\theta_2)| < \frac{D}{2} | x \in \theta_1) \geq P(|\hat{f}_{X|\hat{\theta}_1;n_1}(x|\hat{\theta}_1) - f_{X|\theta_1}(x|\theta_1)|^2 < \frac{D^2}{4} | x \in \theta_1) \times P(|\hat{f}_{X|\hat{\theta}_2;n_2}(x|\hat{\theta}_2) - f_{X|\theta_2}(x|\theta_2)|^2 < \frac{D^2}{4} | x \in \theta_1). \quad (23)$$

Let us consider

$$P(|\hat{f}_{X|\hat{\theta}_1;n_1}(x|\hat{\theta}_1) - f_{X|\theta_1}(x|\theta_1)|^2 < \frac{D^2}{4}) = 1 - P(|\hat{f}_{X|\hat{\theta}_1;n_1}(x|\hat{\theta}_1) - f_{X|\theta_1}(x|\theta_1)|^2 > \frac{D^2}{4}) = 1 - \frac{E(|\hat{f}_{X|\hat{\theta}_1;n_1}(x|\hat{\theta}_1) - f_{X|\theta_1}(x|\theta_1)|^2)}{\frac{D^2}{4}} \quad (24)$$

By Chebyshev's inequality. From Equation (19)

$$E\{|\hat{f}_{X|\hat{\theta}_1; n_1}(\underline{x}|\hat{\theta}_1) - f_{X|\hat{\theta}_1}(\underline{x}|\hat{\theta}_1)|^2\} \\ = \frac{1}{\sqrt{n_1}(2\sqrt{\pi})^p} f_{X|\hat{\theta}_1}(\underline{x}|\hat{\theta}_1) \quad (25)$$

Substituting (25) in (24), the right hand side of (24) becomes

$$\geq [1 - \frac{f_{X|\hat{\theta}_1}(\underline{x}|\hat{\theta}_1)}{\sqrt{n_1}(2\sqrt{\pi})^p} \cdot \frac{4}{D^2}] \quad (26)$$

Similarly

$$P\{|\hat{f}_{X|\hat{\theta}_2; n_2}(\underline{x}|\hat{\theta}_2) - f_{X|\hat{\theta}_2}(\underline{x}|\hat{\theta}_2)|^2 < \frac{D^2}{4}\} \\ \geq [1 - \frac{f_{X|\hat{\theta}_2}(\underline{x}|\hat{\theta}_2)}{\sqrt{n_2}(2\sqrt{\pi})^p} \cdot \frac{4}{D^2}] \quad (27)$$

If $\theta \in \theta_1$ then $\underline{x} \in D_1$, and on D_1

$$f_{X|\hat{\theta}_1}(\underline{x}|\hat{\theta}_1) = \beta \frac{P(\theta_1)}{P(\hat{\theta}_1)} f_{X|\theta_1}(\underline{x}|\theta_1)$$

$$f_{X|\hat{\theta}_2}(\underline{x}|\hat{\theta}_2) = (1 - \beta) \frac{P(\theta_1)}{P(\hat{\theta}_2)} f_{X|\theta_1}(\underline{x}|\theta_1)$$

and

$$D = \frac{P(\theta_1)P(\theta_2)}{P(\hat{\theta}_1)P(\hat{\theta}_2)} (2\beta - 1) f_{X|\theta_1}(\underline{x}|\theta_1) \quad (28)$$

Substituting (26), (27) and (28) in (23), one obtains

$$P\{\hat{f}_{X|\hat{\theta}_1; n_1}(\underline{x}|\hat{\theta}_1) > \hat{f}_{X|\hat{\theta}_2; n_2}(\underline{x}|\hat{\theta}_2) | \theta \in \theta_1\} \geq \\ [1 - \frac{C_1 \beta}{\sqrt{n_1} f_{X|\theta_1}(\underline{x}|\theta_1)}][1 - \frac{C_2(1 - \beta)}{\sqrt{n_2} f_{X|\theta_1}(\underline{x}|\theta_1)}]$$

where

$$C_1 = \frac{P(\theta_1)}{P(\hat{\theta}_1)} \left[\frac{P(\hat{\theta}_1)P(\hat{\theta}_2)}{P(\theta_1)P(\theta_2)(2\beta - 1)} \right]^2 \frac{4}{(2\sqrt{\pi})^p}$$

$$C_2 = \frac{P(\theta_1)}{P(\hat{\theta}_2)} \left[\frac{P(\hat{\theta}_1)P(\hat{\theta}_2)}{P(\theta_1)P(\theta_2)(2\beta - 1)} \right]^2 \frac{4}{(2\sqrt{\pi})^p}$$

and hence the proof of the theorem.

Substituting the results of Theorem 3 in Equation (18), the gain of the learning system associated with classifying a pattern $\underline{x}$ from category θ_1 becomes

$$g_s(\underline{x}|\theta_1; n_1, n_2) \geq [1 - \frac{C_1 \beta}{\sqrt{n_1} f_{X|\theta_1}(\underline{x}|\theta_1)}] \\ \times [1 - \frac{C_2(1 - \beta)}{\sqrt{n_2} f_{X|\theta_2}(\underline{x}|\theta_2)}]$$

A similar expression can be derived for the gain associated with classifying a sample $\underline{x}$ from category θ_2 . The gain of the teacher for classifying $\underline{x}$ from category θ_1 is

$$g_t(\underline{x}|\theta_1) = \beta$$

By setting

$$[1 - \frac{C_1 \beta}{\sqrt{n_1} f_{X|\theta_1}(\underline{x}|\theta_1)}][1 - \frac{C_2(1 - \beta)}{\sqrt{n_2} f_{X|\theta_1}(\underline{x}|\theta_1)}] > \beta,$$

one can solve for n_1 and n_2 , the sample size required by the learning scheme to better the performance of the teacher. Hence the justification for the claim that, in the case of non-overlapping densities, the learning scheme performs better than the teacher on the average after looking at a finite but large number of sample patterns.

The sample size required by the learning scheme to better the performance of the teacher is given below in Table I. The densities used in these sample calculations are assumed to be uniformly distributed over non-overlapping intervals of unit length, with $P(\theta_1) = P(\theta_2) = 1/2$.

TABLE I

SAMPLE SIZE REQUIRED BY THE LEARNING SCHEME TO PERFORM BETTER THAN THE TEACHER

β	0.60	0.70	0.80	0.90	0.95
Approximate Sample Size $n_1 + n_2$	5000	1800	500	300	1600

A rather surprising inference that can be derived from this example is that the learning scheme requires less samples to better the performance of a mediocre teacher than the number of samples it requires to better either a very bad or a very good teacher, i.e. it is easier to better a mediocre teacher.

By differentiating with respect to β it can be shown⁶ that the gain increases as β increases, thus showing that the knowledge acquired at a given stage of learning is greater with a better teacher.

SIMULATIONS

The proposed learning scheme was simulated on the IBM-360 computer for both overlapping and non-overlapping density functions. The various density functions used in the simulations are shown in Figures 1 and 2. The prior probabilities for the categories were set equal to 1/2. For each value of β , the densities were estimated using 75 and 100 samples ($n_1 + n_2 = 75, 100$). The risk for the learning scheme was calculated based on the classification of fifty test samples, the loss function being +1 for incorrect classification and 0 for correct classification. For each value of β , ten runs were made and the average risk for the learning scheme was calculated. The results of the simulations are shown in Figures 3 and 4.

Figure 3 shows the plot of average risk versus β for the learning scheme for non-overlapping densities shown in Figure 1. The Bayes' risk R^0 for non-overlapping densities is zero and the average risk for the imperfect teacher is $(1 - \beta)$. Figure 4 shows the same plot for overlapping densities shown in Figure 2. The Bayes' risk now is 0.125 and the average risk for the

teacher is $(1 - \beta)$

From Figures 3 and 4 the following theoretical results can be verified:

- (1) The average asymptotic risk for the learning scheme converges to the Bayes' risk.
- (2) For non-overlapping densities the learning scheme better than the imperfect teacher, and the Nearest Neighbor Rule after looking at a finite number of sample patterns.
- (3) For overlapping densities, the learning scheme is better than the teacher if $R^* < 1 - \beta$. In Figure 4, this corresponds to $\beta < 0.875$.
- (4) For a given number of training samples, the average risk decreases as β increases.

It must be pointed out here that the plots represent only the "average" performance of the learning system. On any given set of samples the performance of the learning scheme will depend on the number of correctly labeled samples. If a particular sequence of sample patterns had too many incorrect labels, then the performance of the learning scheme will be worse than the "average" performance.

Conclusions

A scheme for learning to recognize patterns with an imperfect teacher has been proposed. The proposed learning scheme makes use of patterns incorrectly labeled by the imperfect teacher. The only knowledge about the teacher that is needed is whether β (β is the probability that the teacher labels a sample correctly) is greater than or less than $1/2$. Using Sprecht's approximation, it is possible to make the learning take place serially. The proposed learning scheme has an average asymptotic risk equal to the Bayes' (minimum) risk. If the density functions involved do not overlap, then the proposed learning scheme performs better than the imperfect teacher and the single nearest neighbor rule using the same sample patterns. With overlapping density functions, if the amount of overlap is less than $(1 - \beta)$, the average asymptotic performance of the proposed learning scheme is still better than that of the teacher and the nearest neighbor rule.

Acknowledgements

The authors wish to acknowledge the financial support provided by the Electronics Command of the Army under contract number DAAB 07-68-C-0083.

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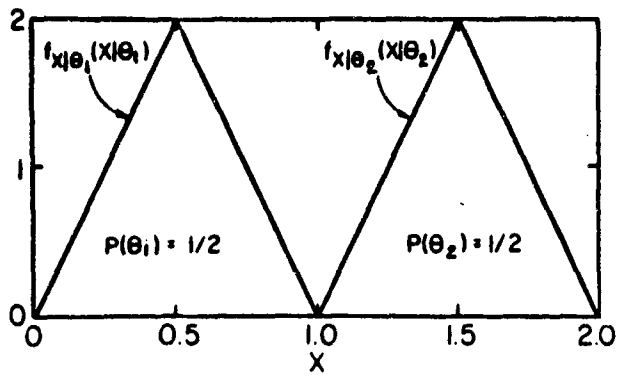


Figure 1. Non-overlapping Densities Used in Simulation

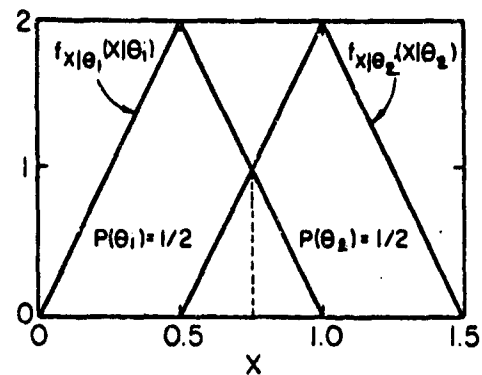


Figure 2. Overlapping Densities Used in Simulations

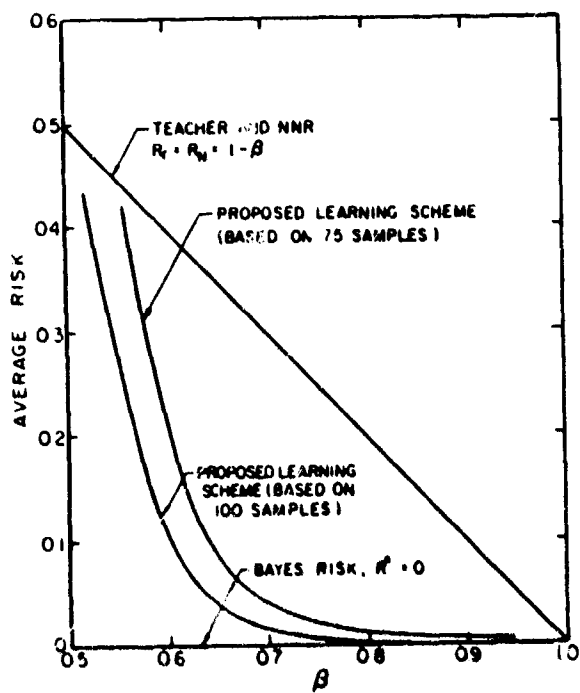


Figure 3. Average Risk vs β for non-overlapping densities.

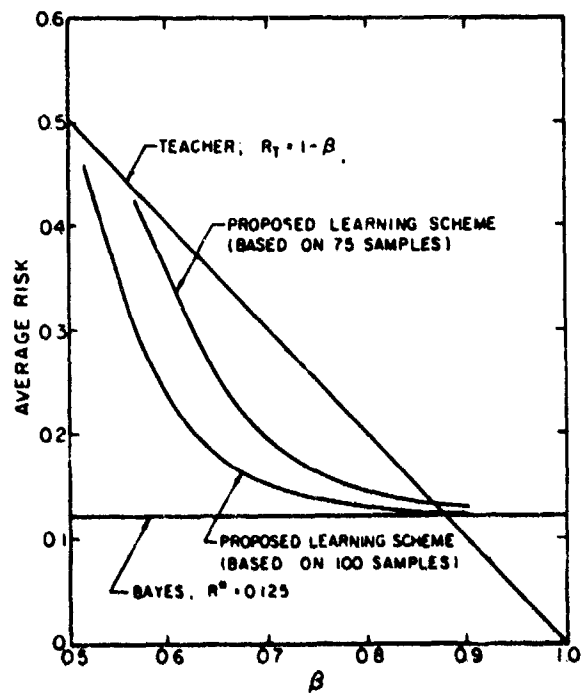


Figure 4. Average Risk vs β for overlapping densities.

AN ERROR CORRECTING PROCEDURE FOR
LEARNING WITH AN IMPERFECT TEACHER

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ABSTRACT

Supervised learning in pattern recognition problems takes place through the use of a set of labeled sample patterns, the labels being provided by a "teacher". In most of the procedures for learning with a teacher, it is commonly assumed that the teacher is perfect, i.e. the labels of the sample patterns are always correct. However, there are many circumstances in which the patterns used for learning are occasionally mislabeled. This paper is concerned with developing a procedure for learning with an imperfect teacher, who occasionally mislabels some of the learning patterns.

The proposed error correction scheme is based on a nonparametric learning scheme. The error correction consists of questioning and correcting the labels provided by the imperfect teacher, using a threshold in the correction scheme. The use of threshold facilitates control over the amount of correction and provides a simple method for combining the knowledge acquired by the learning scheme with that provided by the teacher. Expressions for the threshold are derived and the properties of the proposed error correction scheme are discussed. Through computer simulations, the performance of the proposed error correction scheme is compared with that of an identical learning scheme without error correction.

I. INTRODUCTION

The problem of learning with an imperfect teacher investigated in this paper consists of the following. A set of n measurement pairs $(X_1, \theta^1), \dots, (X_n, \theta^n)$ are given as learning observations. $X_i, (i = 1, \dots, n)$ is a vector measurement drawn from one of the two possible categories θ_1, θ_2 . The label $\theta^i (i = 1, \dots, n)$ takes the form $\hat{\theta}_1$ or $\hat{\theta}_2$ depending whether the teacher identifies X_i as coming from category θ_1 or θ_2 respectively. Based on this set of incorrectly labeled learning observations, we want to learn to classify new observations into θ_1 or θ_2 with minimum probability of misclassification.

The imperfect teacher provides the labels on the sample patterns according to the following probabilities.

$$\begin{aligned} P(\hat{\theta}_1 | \theta_1) &= \beta > 1/2 & i = 1, 2 \\ P(\hat{\theta}_j | \theta_1) &= 1 - \beta & i, j = 1, 2; i \neq j \end{aligned} \quad (1)$$

The patterns are probabilistic in nature with unknown conditional probability density functions $f_{X|\theta_1}$ and $f_{X|\theta_2}$. No particular functional form for these density functions will be assumed. However, it will be assumed that the density functions have disjoint supports. Also it is assumed that

$$f_{X|\theta_i, \hat{\theta}_j} = f_{X|\theta_i} \quad i, j = 1, 2. \quad (2)$$

Many of the procedures for learning with a perfect teacher have been investigated for use with an imperfect teacher [1,2]. R. O. Duda and R. C. Singleton [3] investigated the performance of a threshold logic unit trained with an imperfect teacher. They have shown that for

orthogonal patterns, the average weight vector converges to a solution vector for the correctly labeled pattern set. A. W. Whitney and S. J. Dwyer III [4] analyzed the performance of the k-nearest neighbor rule with an imperfect teacher and obtained error bounds for the performance. The problem of learning without a teacher has been formulated as learning with an imperfect (probabilistic) teacher and a Bayesian reproducing estimation procedure has been developed for this problem by A. K. Agrawala [5].

The authors of this investigation have proposed [6] a nonparametric scheme for learning with an imperfect teacher, which asymptotically performs better than its own imperfect teacher. Since the learning scheme becomes better than the teacher, the authors were motivated towards using the learning scheme's own knowledge to correct the errors in the labels provided by the teacher. The result is an error correcting scheme for learning with an imperfect teacher. The proposed scheme uses a threshold in the correction loop. The use of threshold provides control over the amount of correction and also provides a simple way for combining the learning scheme's knowledge with the knowledge of its teacher. Also the use of threshold facilitates a gradual phasing out of the teacher as the learning scheme acquires more and more knowledge. Expressions for the threshold are derived and the properties of the learning scheme are discussed. Through computer simulations, the performance of the error correcting scheme is compared with the performance of an identical learning scheme using no error correction.

II. LEARNING WITH AN IMPERFECT TEACHER

For nonoverlapping densities $f_{X|\theta_1}$ and $f_{X|\theta_2}$, a discriminant function of the form

$$D_\theta(X) = f_{X|\theta_1} - f_{X|\theta_2} \quad (3)$$

can be used to classify a pattern X into θ_1 or θ_2 with a probability of misclassification equal to zero. The unknown density functions $f_{X|\theta_i}$ can be learned (estimated) from the sample patterns which belong to category θ_i . However, due to the randomness of the labeling of the teacher, the true categories of the sample patterns are not known. The only labeling information available is one of $\hat{\theta}_1$ or $\hat{\theta}_2$. In order to learn to recognize patterns from these incorrectly labeled samples, it is necessary to have a decision rule in terms of $f_{X|\hat{\theta}_1}$ and $f_{X|\hat{\theta}_2}$ rather than in terms of $f_{X|\theta_1}$ and $f_{X|\theta_2}$.

With an imperfect teacher characterized by Equation (1) and with non-overlapping densities, the discriminant function

$$D_{\hat{\theta}}(X) = f_{X|\hat{\theta}_1} - f_{X|\hat{\theta}_2} \quad (4)$$

is equivalent to the discriminant function $D_\theta(X)$ defined in Equation (3). In fact, it can be shown [6] that

$$f_{X|\hat{\theta}_1} = \frac{1}{P(\hat{\theta}_1)} (\beta P(\theta_1) f_{X|\theta_1} + (1-\beta) P(\theta_2) f_{X|\theta_2}) \quad (5)$$

$$f_{X|\hat{\theta}_2} = \frac{1}{P(\hat{\theta}_2)} ((1-\beta) P(\theta_1) f_{X|\theta_1} + \beta P(\theta_2) f_{X|\theta_2}) \quad (6)$$

and hence

$$D_{\hat{\theta}}(X) = \frac{P(\theta_1) P(\theta_2)}{P(\hat{\theta}_1) P(\hat{\theta}_2)} (2\beta - 1) D_{\theta}(X). \quad (7)$$

Since $\beta > 1/2$, Equation (7) implies that

$$D_{\hat{\theta}}(X) \geq 0 \iff D_{\theta}(X) \geq 0$$

and hence the equivalence of the two discriminant functions.

The unknown density functions in the discriminant function $D_{\hat{\theta}}(X)$ are $f_{X|\hat{\theta}_1}$ and $f_{X|\hat{\theta}_2}$ and these can be estimated from the given set of sample patterns carrying labels $\hat{\theta}_1$ and $\hat{\theta}_2$ respectively. Using nonparametric estimators proposed and analyzed by Parzen [7] and Murthy [8], an estimate of $f_{X|\hat{\theta}_1}(x|\hat{\theta}_1)$ based on the sample patterns $X_1, \dots, X_{n_1}$ labeled as $\hat{\theta}_1$ is

$$\hat{f}_{X|\hat{\theta}_1; n_1}(x|\hat{\theta}_1) = \frac{1}{\sqrt{n_1}} \sum_{k=1}^{n_1} \frac{1}{(2\pi)^{\frac{p}{2}}} \exp\left\{-\frac{[x - X_k]^T [x - X_k] (n_1)^{\frac{1}{p}}}{2}\right\} \quad (8)$$

and an estimate of $f_{X|\hat{\theta}_2}(x|\hat{\theta}_2)$ based on the sample patterns $Y_1, \dots, Y_{n_2}$ labeled as $\hat{\theta}_2$ is

$$\hat{f}_{X|\hat{\theta}_2; n_2}(x|\hat{\theta}_2) = \frac{1}{\sqrt{n_2}} \sum_{i=1}^{n_2} \frac{1}{(2\pi)^{\frac{p}{2}}} \exp\left\{-\frac{[x - Y_i]^T [x - Y_i] (n_2)^{\frac{1}{p}}}{2}\right\} \quad (9)$$

In Equations (8) and (9) p is the dimension of the pattern space and T indicates transpose. A multivariate normal density function was chosen as a kernel in the estimators since this would facilitate the use of a polynomial approximation suggested by Sprecht [9]. The polynomial approximation to the estimators is easy to implement on the computer and results in an appreciable reduction in the storage requirements.

Substituting the estimated densities in Equation (4), a procedure for learning to recognize patterns using a set of incorrectly labeled

patterns is:

- (1) From the given set of labeled patterns, estimate $f_{X|\hat{\theta}_1}$ and $f_{X|\hat{\theta}_2}$ according to Equations (8) and (9).
- (2) Using the estimated density functions, compute

$$\hat{D}_{\hat{\theta}}(X) = \hat{f}_{X|\hat{\theta}_1;n_1} - \hat{f}_{X|\hat{\theta}_2;n_2}$$

- (3) Assign X to

$$\theta_1 \text{ if } \hat{D}_{\hat{\theta}}(X) > 0$$

and to

$$\theta_2 \text{ if } \hat{D}_{\hat{\theta}}(X) < 0 \quad (10)$$

Under certain regularity conditions, the estimates given in Equations (8) and (9) have been shown to be consistent and asymptotically normally distributed [7,8]. As a consequence of the consistency properties of the estimators it follows that, with probability one

$$\hat{D}_{\hat{\theta}}(X) = \hat{f}_{X|\hat{\theta}_1;n_1} - \hat{f}_{X|\hat{\theta}_2;n_2} \rightarrow D_{\theta}(X) \text{ as } n_1, n_2 \rightarrow \infty.$$

Hence in the asymptotic case, the proposed learning scheme places a pattern X into the same category as a scheme using a Bayes procedure, with probability one. For a loss function of +1 for misclassification and 0 for correct classification, the average asymptotic risk for the learning scheme is zero. The average risk for the teacher is $1-\beta > 0$. Hence the proposed learning scheme is better than the teacher in the asymptotic case.

Since the learning scheme performs better than its teacher after looking at a large number of samples, the knowledge gained by the learning scheme might be used to verify and perhaps correct the label provided

by the teacher. Such corrections, if done successfully, could result in a lesser number of incorrect labels on the learning observations and hence lead to better performance. The remainder of this paper is devoted to developing such an error correcting procedure.

III. ERROR CORRECTION

Model:

The authors' motivation for considering an error correcting learning procedure comes from an example that is of common occurrence in classrooms. Such an example is the attempt of a student to question and possibly correct errors made by his teacher. In spite of the fact that much of the student's knowledge is derived from his teacher, he is still able to use this knowledge to occasionally correct his teacher and also provide answers to certain questions for which his teacher may not know the correct answer. Hence it seems that such questioning and possibly correcting the labeling information supplied by the teacher in pattern recognition problems is all too relevant especially if the teacher is known to be imperfect.

The model for our error correcting scheme is shown in Figure 1. The block marked student is the learning scheme described in the previous section, capable of learning from a set of labeled sample patterns. The teacher is characterized probabilistically in Equation (1). When a sample observation X is presented, the student provides a label for the observation based on his present knowledge (i.e. based on the latest estimate $\hat{D}_{\hat{\theta}}$ of the discriminant function $D_{\hat{\theta}}$). The label provided by the student is $\hat{\theta}_1$ if $\hat{D}_{\hat{\theta}}(X) \geq 0$ and $\hat{\theta}_2$ if $\hat{D}_{\hat{\theta}}(X) < 0$. The teacher also provides a label for X according to Equation (1). We propose that the error correction scheme compare these two labels and change the label provided by the teacher according to the following algorithm:

(1) Accept the label provided by the teacher if

$$|D_{\hat{\theta}}(X)| = |\hat{f}_{X|\hat{\theta}_1;n_1}(X|\hat{\theta}_1) - \hat{f}_{X|\hat{\theta}_2;n_2}(X|\hat{\theta}_2)| \leq T$$

(2) Change the label provided by the teacher to $\hat{\theta}_1$ if

$$\hat{f}_{X|\hat{\theta}_1;n_1}(X|\hat{\theta}_1) > \hat{f}_{X|\hat{\theta}_2;n_2}(X|\hat{\theta}_2) + T$$

(3) Change the label provided by the teacher to $\hat{\theta}_2$ if

$$\hat{f}_{X|\hat{\theta}_2;n_2}(X|\hat{\theta}_2) > \hat{f}_{X|\hat{\theta}_1;n_1}(X|\hat{\theta}_1) + T. \quad (11)$$

In the above algorithm n_1 and n_2 are the number of sample observations that have been used in the estimators of $f_{X|\hat{\theta}_1}$ and $f_{X|\hat{\theta}_2}$, respectively, and T is a threshold. After the label is decided, X is used to update the estimate of the density function corresponding to that label.

According to the above algorithm, a correction takes place only if the estimators of the density functions differ by more than T . Loosely stated, the label provided by the teacher is questioned and changed only if the student is "certain" that the teacher is wrong. The student accepts whatever the teacher says if he is not sure of himself.

The extent to which the student depends on his teacher during the learning process is determined by T . Two special cases occur when $T = 0$ or $T \rightarrow \infty$. If $T \rightarrow \infty$, then from the first step in algorithm (11) it follows that the label provided by the teacher is always accepted. If $T = 0$, then it can be seen that the student completely ignores his teacher and provides his own label for each sample pattern. By choosing a variable threshold, the dependency of the student on his teacher can be controlled during the learning process.

Selection of Threshold:

Two methods will be presented for selecting a value for the threshold T . These methods are based on the asymptotic normality of the estimators of the density functions. To simplify the following treatment, the sample sizes n_1, n_2 will be assumed equal to a common value n , the value of n being large enough to justify the use of the asymptotic properties of the estimators. From the results of Murthy [8], the estimators given in Equations (8) and (9) have the following asymptotic distributions.

$$\begin{aligned}\hat{f}_{X|\hat{\theta}_1;n}(x|\hat{\theta}_1) &\sim N \left(f_{X|\hat{\theta}_1}(x|\hat{\theta}_1), \frac{f_{X|\hat{\theta}_1}(x|\hat{\theta}_1)}{\sqrt{n} (2\sqrt{\pi})^p} \right) \\ \hat{f}_{X|\hat{\theta}_2;n}(x|\hat{\theta}_2) &\sim N \left(f_{X|\hat{\theta}_2}(x|\hat{\theta}_2), \frac{f_{X|\hat{\theta}_2}(x|\hat{\theta}_2)}{\sqrt{n} (2\sqrt{\pi})^p} \right).\end{aligned}\quad (12)$$

The estimators are independent because of the assumption of independent samples, and hence

$$\begin{aligned}\hat{f}_{X|\hat{\theta}_1;n}(x|\hat{\theta}_1) - \hat{f}_{X|\hat{\theta}_2;n}(x|\hat{\theta}_2) &\sim N \left(f_{X|\hat{\theta}_1}(x|\hat{\theta}_1) - f_{X|\hat{\theta}_2}(x|\hat{\theta}_2), \right. \\ &\quad \left. \frac{f_{X|\hat{\theta}_1}(x|\hat{\theta}_1) + f_{X|\hat{\theta}_2}(x|\hat{\theta}_2)}{\sqrt{n} (2\sqrt{\pi})^p} \right).\end{aligned}\quad (13)$$

If $x \in \theta_1$, then $f_{X|\theta_2}(x|\theta_2) = 0$, and from Equations (5) and (6),

$$f_{X|\hat{\theta}_1}(x|\hat{\theta}_1) = \beta f_{X|\theta_1}(x|\theta_1) \text{ and } f_{X|\hat{\theta}_2}(x|\hat{\theta}_2) = (1-\beta) f_{X|\theta_1}(x|\theta_1).$$

Hence, if $x \in \theta_1$,

$$\hat{f}_{X|\hat{\theta}_1;n}(x|\hat{\theta}_1) - \hat{f}_{X|\hat{\theta}_2;n}(x|\hat{\theta}_2) \sim N \left((2\beta-1) f_{X|\theta_1}(x|\theta_1), \frac{f_{X|\theta_1}(x|\theta_1)}{\sqrt{n} (2\sqrt{\pi})^p} \right).\quad (14)$$

If $x \in \theta_2$, then $f_{X|\theta_1}(x|\theta_1) = 0$, and from Equations (5) and (6),

$$f_{X|\hat{\theta}_1}(x|\hat{\theta}_1) = (1-\beta) f_{X|\theta_2}(x|\theta_2) \text{ and } f_{X|\hat{\theta}_2}(x|\hat{\theta}_2) = \beta f_{X|\theta_2}(x|\theta_2).$$

Hence, if $x \in \theta_2$,

$$\hat{f}_{X|\hat{\theta}_1;n}(x|\hat{\theta}_1) - \hat{f}_{X|\hat{\theta}_2;n}(x|\hat{\theta}_2) \sim N \left(-(2\beta-1) f_{X|\theta_2}(x|\theta_2), \frac{f_{X|\theta_2}(x|\theta_2)}{\sqrt{n} (2\sqrt{\pi})^p} \right). \quad (15)$$

The approximations given in Equations (13), (14) and (15) will be used in deriving expressions for the threshold T . Also the notation P_n (accept the label), P_n (good label) and P_n (bad label) will be used to denote respectively the probabilities that the student accepted the label provided by the teacher, the probability that the student provided a correct label for the sample pattern, and the probability that the student provided an incorrect label for the sample pattern. The subscript n denotes that label provided by the student is based on the estimators of the density functions using sample size n .

The first approach to be discussed for selection of T is based on a minimax principle. In this rather pessimistic approach, T is selected by setting a bound on the maximum probability of a bad label by the student. Hence the quantity of interest is the probability of a bad label by the student. Let us first look at P_n (bad label $|x \in \theta_1$), given by

$$P_n \text{ (bad label } |x \in \theta_1) = P\{\hat{f}_{X|\hat{\theta}_2;n}(x|\hat{\theta}_2) > \hat{f}_{X|\hat{\theta}_1;n}(x|\hat{\theta}_1) + T | x \in \theta_1\}.$$

From Equation (14), the right hand side of the above equation becomes

$$= \int_{-\infty}^{-T} N \left((2\beta-1) f_{X|\theta_1}(x|\theta_1), \frac{f_{X|\theta_1}(x|\theta_1)}{\sqrt{n} (2\sqrt{\pi})^p} \right) d\xi,$$

where the notation $\int_a^b N(\mu, \sigma^2) d\xi$ denotes the integral

$$\int_a^b \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left\{-\frac{1}{2} \frac{(\xi-\mu)^2}{\sigma^2}\right\} d\xi.$$

A change of variable in the above integral gives P_n (bad label $|x\epsilon\theta_1$) =

$$\int_{-\infty}^{\frac{[-T-(2\beta-1)a]c}{\sqrt{a}}} N(0, 1) d\xi = L \quad (16)$$

where

$$c = (2\sqrt{\pi})^{\frac{p}{2}} \frac{1}{n^{\frac{1}{4}}} \text{ and } a = f_{X|\theta_1}(x|\theta_1).$$

It can be shown that L has a maximum at,

$$a = \frac{T}{(2\beta-1)}.$$

This implies P_n (bad label $|x\epsilon\theta_1$) is maximum at

$$a = f_{X|\theta_1}(x|\theta_1) = \frac{T}{(2\beta-1)}.$$

Substituting $a = \frac{T}{(2\beta-1)}$ in Equation (16), the maximum value of P_n (bad label $|x\epsilon\theta_1$) becomes

$$\int_{-\infty}^{\frac{2T}{[T/(2\beta-1)]^{1/2}} c} N(0, 1) d\xi = -2c \sqrt{T(2\beta-1)} \quad (17)$$

Similarly the maximum value of P_n (bad label $|x\epsilon\theta_2$) can also be shown to be equal to the integral in Equation (17). Hence irrespective of whether $x\epsilon\theta_1$ or θ_2 , the maximum probability of a bad label is given by the integral in Equation (17). If α is the desired limit on the maximum

probability of bad label, then a value t_α can be determined such that

$$\alpha = \int_{-\infty}^{-t_\alpha} N(0, 1) d\xi \quad (18)$$

Comparing the upper limits of the integrals in Equations (17) and (18),

$$2T^{1/2}c(2\beta-1)^{1/2} = t_\alpha$$

Solving for T from the above Equation,

$$T = \frac{c_\alpha}{\sqrt{n}(2\beta-1)} \quad (19)$$

where

$$c_\alpha = \frac{t_\alpha^2}{4(2\sqrt{\pi})P}$$

Choosing T according to Equation (19) guarantees that on the average the maximum value of the probability that the student provides a bad label at any given stage of learning is equal to the desired value. For any given pattern x the probability of bad label is less than or equal to α . The choice of α and hence t_α is subjective.

The second method for selecting the threshold T is based on a decision theory approach. In this approach, values are assigned to the possible outcome of error correction and T is chosen such that the "expected value" is maximized. The two main outcomes of the error correction scheme are that the teacher's label is accepted or the student provides a label. There are two outcomes associated with the student providing a label, namely the label provided by the student is correct and label provided by the student is incorrect. Let us assign the values 0, a' and b' respectively to these three outcomes, the teachers label being accepted, the student's label being correct and and the student's label being incorrect.

Let us first look at verifying the label on a sample pattern from θ_1 at the n^{th} stage of learning. The 'expected value' is given by,

$$\begin{aligned} E\{\text{value} | x \in \theta_1\} &= 0 \left\{ P_n (\text{accepting teacher's label} | x \in \theta_1) \right\} \\ &\quad + a' \left\{ P_n (\text{good label} | x \in \theta_1) \right\} \\ &\quad - b' \left\{ P_n (\text{bad label} | x \in \theta_1) \right\} \\ &= a' \int_T^\infty N \left((2\beta-1) f_{X|\theta_1}(x|\theta_1), \frac{f_{X|\theta_1}(x|\theta_1)}{\sqrt{n} (2\sqrt{\pi})^P} \right) d\xi \\ &\quad - b' \int_{-\infty}^{-T} N \left((2\beta-1) f_{X|\theta_1}(x|\theta_1), \frac{f_{X|\theta_1}(x|\theta_1)}{\sqrt{n} (2\sqrt{\pi})^P} \right) d\xi. \end{aligned}$$

Doing the necessary algebra, it can be shown that the value of T that maximizes $E\{\text{value} | x \in \theta_1\}$ is given by

$$\begin{aligned} T &= \frac{\ell_n(\frac{b'}{a'})}{2(2\sqrt{\pi})^P \sqrt{n} (2\beta-1)} \\ &= \frac{c_0}{\sqrt{n} (2\beta-1)}, \end{aligned} \quad (20)$$

where

$$c_0 = \frac{\ell_n(\frac{b'}{a'})}{2(2\sqrt{\pi})^P}.$$

Proceeding along the same lines it can be shown that $E\{\text{value} | x \in \theta_2\}$, is also maximum at T given in Equation (20). This implies that irrespective of whether $x \in \theta_1$ or $x \in \theta_2$, the "average value" of correction is maximum if T is chosen according to Equation (20).

The form of T given in Equation (20) is the same as the one given in Equation (19) for the minimax approach. The only difference is in the constants appearing in the expression. These constants are determined by the choice of the maximum acceptable value of the probability

of bad label in the first approach or the value function in the decision theory approach.

The algorithm for error correction now is:

Accept the label provided by the teacher for x if

$$\left| \hat{f}_{X|\hat{\theta}_1;n}(x|\hat{\theta}_1) - \hat{f}_{X|\hat{\theta}_2;n}(x|\hat{\theta}_2) \right| < T.$$

Correct the label to $\hat{\theta}_1$ if

$$\hat{f}_{X|\hat{\theta}_1;n}(x|\hat{\theta}_1) > \hat{f}_{X|\hat{\theta}_2;n}(x|\hat{\theta}_2) + T$$

and to $\hat{\theta}_2$ if

$$\hat{f}_{X|\hat{\theta}_2;n}(x|\hat{\theta}_2) > \hat{f}_{X|\hat{\theta}_1;n}(x|\hat{\theta}_1) + T \quad (21)$$

where T is the threshold given in Equation (19) for the minimax approach and in Equation (20) for the decision theory approach.

Properties of Thresholded Error Correction:

Besides being an easy algorithm to implement, the proposed error correction scheme has the following-desirable properties:

- 1) The maximum probability of error correction occurs on samples that come from close to the modes of the density functions.
- 2) At any given stage of learning, the probability that the student corrects an error made by the teacher, given that the teacher is in fact in error, increases as β increases, i.e. with a better teacher, there is a better chance that the student corrects an error.
- 3) The teacher is gradually phased out as the knowledge acquired by the student increases.

Let us concern ourselves with correcting a possible error on the label of a sample x that belongs to category θ_1 . The probability of error correction on the label of x is given by

$$\begin{aligned} P_n(\text{error correction} | x \in \theta_1) &= (1-\beta) \{ P(\hat{f}_{X|\hat{\theta}_1;n}(x|\hat{\theta}_1) > \hat{f}_{X|\hat{\theta}_2;n}(x|\hat{\theta}_2) + T | x \in \theta_1) \} \\ &= (1-\beta) \int_T^{\infty} N \left((2\beta-1)f_{X|\theta_1}(x|\theta_1), \frac{f_{X|\theta_1}(x|\theta_1)}{\sqrt{n}(2\sqrt{\pi})^p} \right) d\xi. \end{aligned}$$

From the above, it can be easily verified that if $f_{X|\theta_1}(x_1|\theta_1) > f_{X|\theta_1}(x_2|\theta_1)$, then $P_n(\text{error correction} | x_1 \in \theta_1) > P_n(\text{error correction} | x_2 \in \theta_1)$. Hence, the maximum value of the probability of correcting the label on a sample $x \in \theta_1$ occurs if $f_{X|\theta_1}(x|\theta_1)$ is maximum. Similarly it can be shown that the maximum value of the probability of correcting the label on a sample $x \in \theta_2$ occurs if $f_{X|\theta_2}(x|\theta_2)$ is maximum. These two statements establish the first property listed above. Since samples are more likely to have come from near the modes, it is desirable to have a larger probability of correction here.

The probability that the student corrects a label error on a sample x from category θ_1 , given that the teacher made an error, is

$$P_n(\text{error correction} | x \in \theta_1 \text{ and the teacher made an error}) =$$

$$\begin{aligned} &\int_T^{\infty} N \left((2\beta-1)f_{X|\theta_1}(x|\theta_1), \frac{f_{X|\theta_1}(x|\theta_1)}{\sqrt{n}(2\sqrt{\pi})^p} \right) d\xi \\ &= \int \frac{N(0,1)d\xi}{\frac{[T-(2-\beta)a]c}{\sqrt{a}}} \end{aligned}$$

where

$$a = f_{X|\theta_1}(x|\theta_1) \text{ and } c = (2\sqrt{\pi})^{\frac{p}{2}} \frac{1}{n}.$$

The lower limit of the integral decreases as β increases and hence the probability that the student corrects an error on the label of a sample pattern from category θ_1 , given that the teacher made an error, increases as β increases. A similar argument may be given for x from category θ_2 and hence the property that with a better teacher, there is a better chance that the student corrects an error.

The probability that the student provides his own label for say, a sample pattern x from category θ_1 is

$$\begin{aligned}
 P_n(\text{student provides a label } |x \in \theta_1) &= \\
 1 - P \left(\left| \hat{f}_{x|\hat{\theta}_1;n}(x|\hat{\theta}_1) - \hat{f}_{x|\hat{\theta}_2;n}(x|\hat{\theta}_2) \right| < T | x \in \theta_1 \right) \\
 &= 1 - \int_{\left[\frac{-T - (2\beta - 1)a}{\sqrt{a}} \right]_c}^{\left[\frac{T - (2\beta - 1)a}{\sqrt{a}} \right]_c} N(0,1) d\xi
 \end{aligned}$$

It can be seen that as T increases the value of the above integral increases and hence the probability that the student provides his own label decreases. Conversely as T decreases, the probability that the student provides his own label increases. Since T is a decreasing function of n , T will be large in the initial stage of learning and hence the probability that the student provides his own label is small. This means the student accepts whatever the teacher says when learning begins. As $n \rightarrow \infty$, $T \rightarrow 0$ and the probability that the student provides his own label $\rightarrow 1$, i.e. in the advanced stages of learning, the student provides his own label on each sample and learns independently without the aid

of the teacher. This gradual phasing out of teacher also occurs in most real life learning situations.

The proposed error correcting learning scheme checks the label on one sample at a time serially. Approximate estimators can also be updated serially in a polynomial form as suggested by Sprecht [9]. After updating, only the coefficients of the polynomial are retained and the samples are discarded. A question that is left open here is whether it would be better to store all the samples and verify the labels on all the $(n-1)$ prior samples at the n^{th} stage of learning. The authors feel that the storage requirements and the computation involved for doing this will be formidable when the dimension of the patterns and the sample size are large, both of which are common in pattern recognition problems.

Even though the expressions for threshold given in Equations (19) and (20) display many desirable properties no claim can be made about the "optimality" of these expressions. One of the shortcomings of the analysis presented in this lies in treating β as constant. Due the error correction, the effective value of β , defined as the ratio of the number of sample patterns with correct labels to the total number of sample patterns is changing. A formulation of this change is difficult, if at all possible. The probability statements about the outcomes of error correction involve the unknown density functions. Whereas for the teacher β is independent of x , the sample being labeled, the performance of the student will depend on the value of x and his past performance. If the error correction has been done badly at the initial stages of learning, then error correction on subsequent samples will also be bad. This fundamental difference in labeling procedure presents a very formidable step in the analysis of performance of the error correcting

scheme. The proposed error correction scheme was simulated on the computer and the results of the simulation are presented in the next section.

IV. SIMULATIONS

The performance of the proposed learning scheme was evaluated through simulations on the digital computer. The conditional density functions $f_{X|\theta_1}$ and $f_{X|\theta_2}$ used in the simulations are shown in Figure 2. Samples were drawn randomly from these two categories with $P(\theta_1) = P(\theta_2) = 1/2$ and the labeling was done according to (1). The learning scheme without error correction accepted the label provided by the teacher and the density functions $f_{X|\hat{\theta}_1}$ and $f_{X|\hat{\theta}_2}$ were estimated according to (8) and (9). A total of N_T samples were used for learning. Using the estimates of the density functions based on N_T samples, 40 test samples were classified according to (10).

The error correcting scheme learned from the same set of N_T samples, according to algorithm (11). The value of T corresponded to α , the maximum probability of bad label equal to 0.05 or values of a' and b' such that $a'/b' = e$. Based on the final estimate of the density functions, the same 40 test samples were classified.

For each value of β , ten runs were made. The risk for each run was taken to be the ratio of the number of test samples that were misclassified to the total number of test samples classified. The average risk for the learning scheme was taken to be the average of the risks on ten runs. Figure 3 shows a plot of the average risk versus β for the two learning schemes, for a sample size $N_T = 20$. Figure 4 shows the same plot for a sample size $N_T = 60$.

It appears from Figures 3 and 4 that error correction on the average improves the performance of the learning scheme. A rather interesting aspect of these plots is that error correction does not seem to improve the performance very much for either very high or very low values of β . At lower values of β , i.e. with a very bad teacher, the amount of correction is small because the student does not learn enough to question his teacher very often. At higher values of β , i.e. with a very good teacher, the student acquires his limiting knowledge quickly and error correction does not help here since error correction does not increase the limiting knowledge. Hence it appears that error correction is most effective when the teacher is mediocre.

Simulations were done for the unequal sample size case with $P(\theta_1) = 0.9$ and $P(\theta_2) = 0.1$. The simulation procedure is identical to the one described above except for the error correction algorithm. The algorithm used in this case is given in [10]. Figure 5 shows a plot of average risk versus β for this simulation. Once again it appears that error correction leads to an improvement in the performance of the learning scheme.

V. CONCLUSIONS

In this paper we have proposed a thresholded error correcting scheme for learning with an imperfect teacher. Expressions were derived for the value of the threshold as a function of the reliability of the teacher, the sample size and a subjective constant. The proposed scheme provides a simple means for combining the knowledge acquired by the student and the knowledge of the teacher. It is possible to control the extent to which the student depends on his teacher. Through computer simulations, we have shown that error correction leads to an improvement in the performance of the learning scheme.

We have presented only one of many possible error correcting schemes for learning with an imperfect teacher. Whether the scheme presented in this paper is the "best" is not known. However, the authors feel that this study will aid in an understanding of the problem of error correction in learning with an imperfect teacher and may suggest other optimum schemes of error correction.

More work on this scheme is needed, theoretically to study convergence and experimentally to apply this procedure to more than two categories of patterns.

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CAPTIONS FOR FIGURES

Figure 1. Model for the Error Correcting Procedure

Figure 2. Density Functions used in Simulations

Figure 3. Effect of Error Correction on Performance

Figure 4. "

Figure 5. "

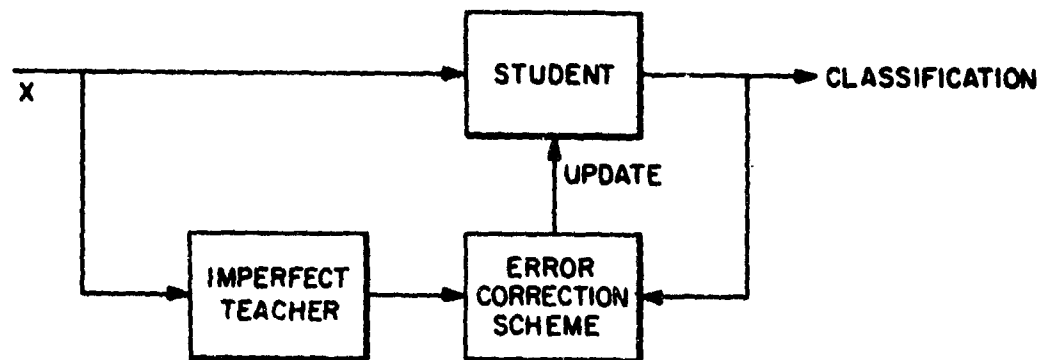


Figure 1. Model for the Error Correcting Procedure

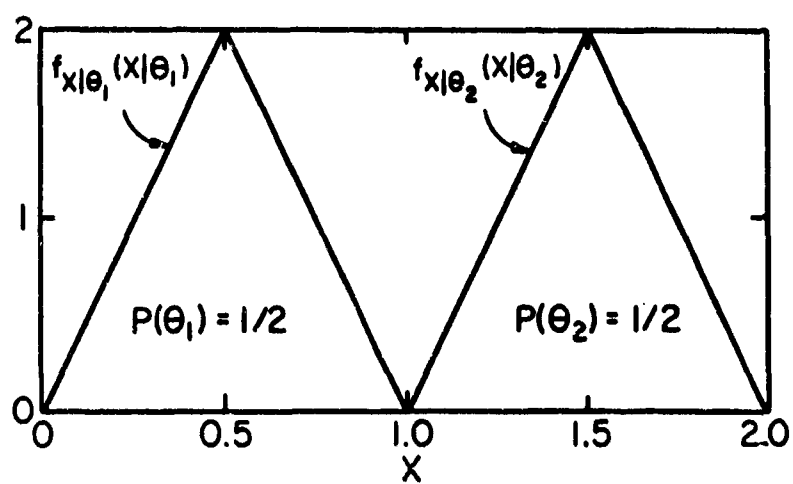


Figure 2. Non-overlapping Densities Used in Simulation

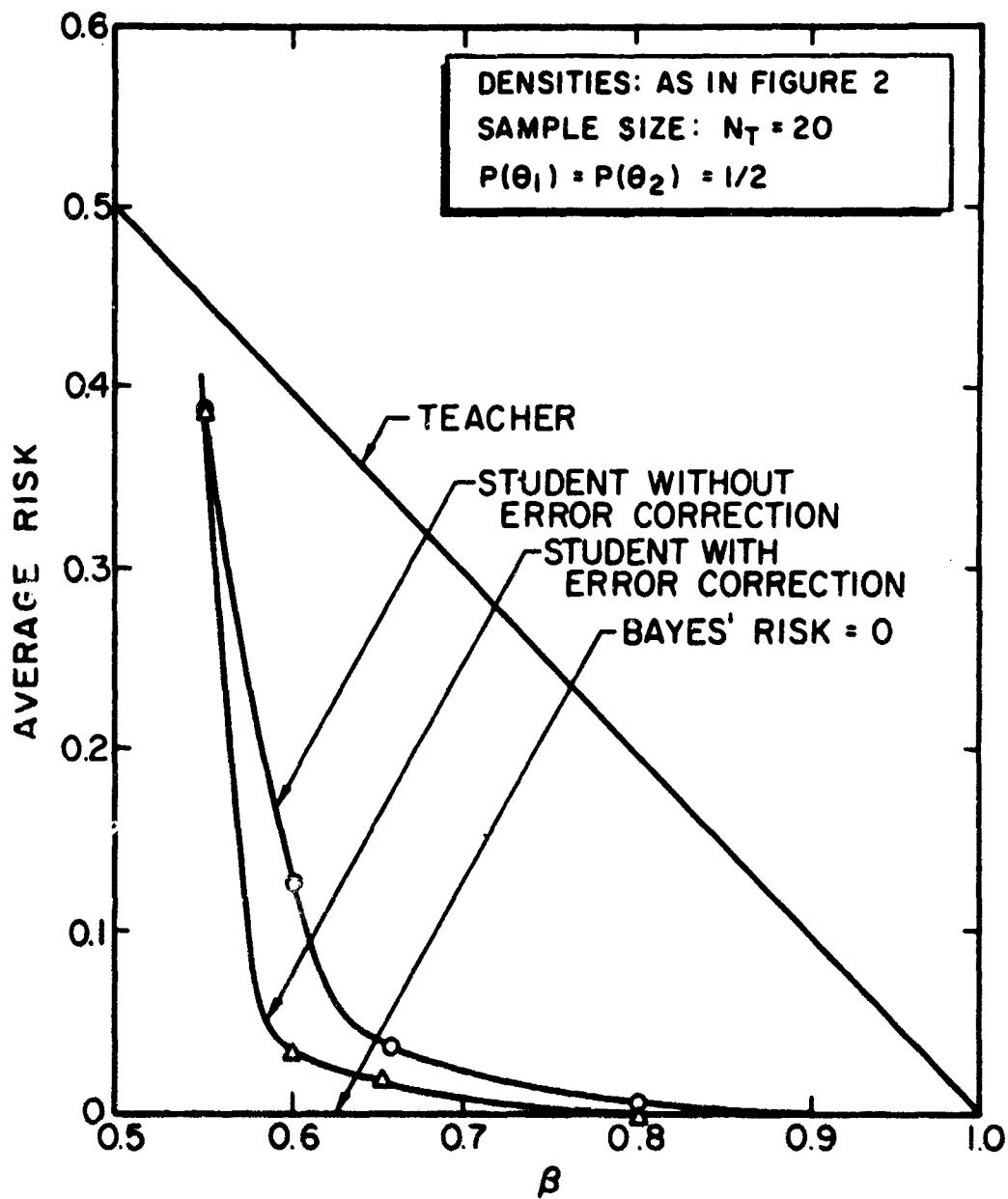


Figure 3. Effect of Error Correction on Performance

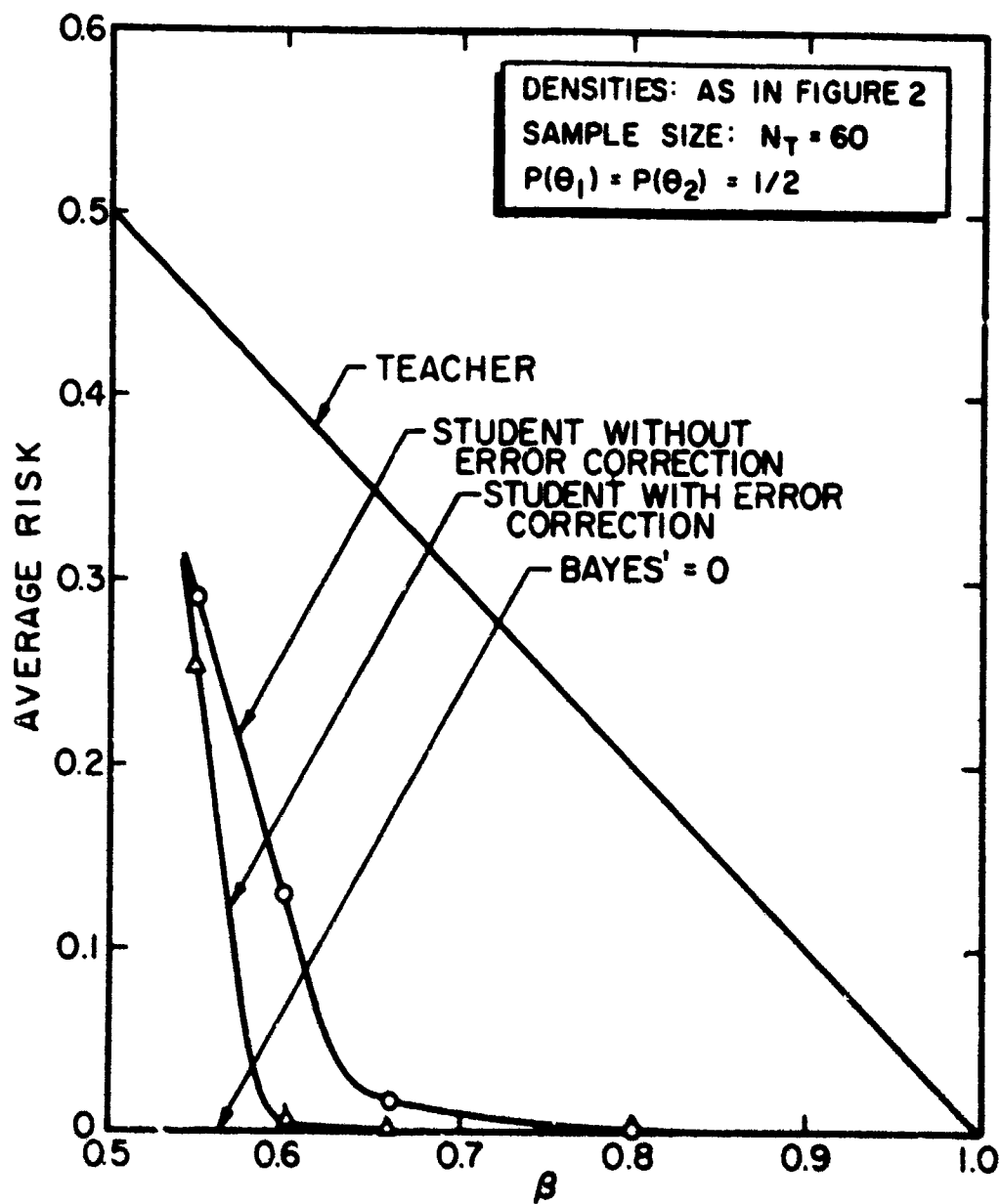


Figure 4. Effect of Error Correction on Performance

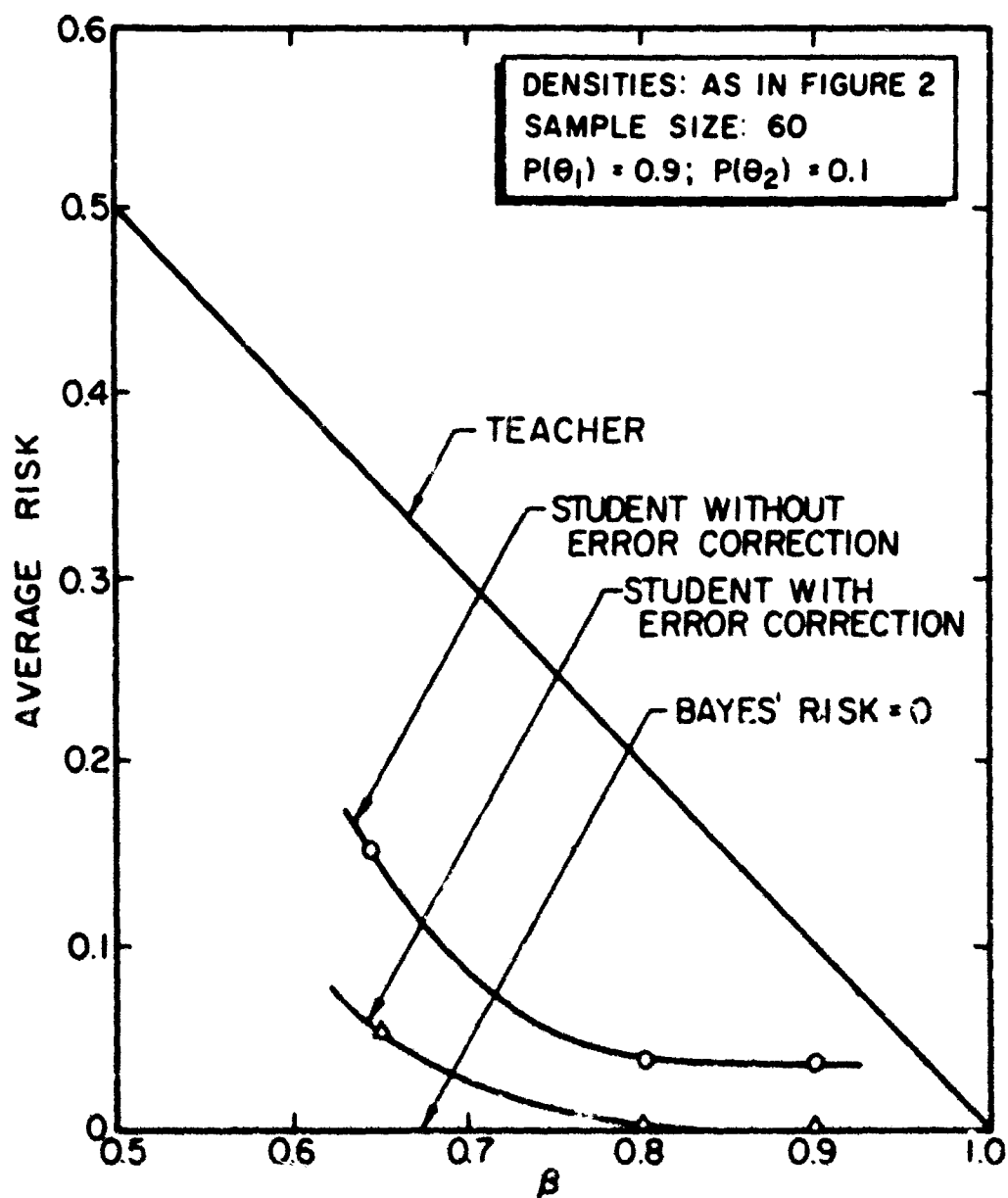


Figure-5. Effect of Error Correction on Performance

APPENDIX B

ASMB,A,B,L,T		
ORG 100B	PROGRAM STARTS AT 100 OCTAL.	
BEGIN NOP		
LDA FL	LOAD TAPE COMMAND WORD. FILE MK.	
OTA 11B		
START NOP		
HLT		
NOP	LOAD SW'S WITH NO. RECORDS.	
LIA 1		
CMA	COMPLEMENT REGISTER A.	
INA	ADD 1 TO A TO GET 2'S COMPL.	
STA REC	STORE 2'S COMPL IN REC.	
ENTER NOP		
HLT		
NOP	PUSH RUN WHEN READY TO START PGM	
LDA REC		
STA CNT	INITIALIZE RECORD COUNT.	
CLC 0	TURN OFF ALL I/O.	
CLB	CLEAR REGISTER B-PARITY ERR CNT.	
CLF 0	TURN INTERRUPT OFF.	
FIRST LDA CNTL1	INITIALIZE DMA1 TO READ ADC.	
OTA 6	CONTROL WORD ONE.	
CLC 2		
LDA ADRI		
OTA 2	CONTROL WORD 2.	
STC 2		
LDA NBUF	NBUF IS "WORDS PER RECORD".	
OTA 2	CONTROL WORD 3.	
STC 14B,C	START ADC.	
STC 6,C	START DMA1.	
LOOP LDA CNTL1	INITIALIZE DMA2 TO READ ADC.	
OTA 7	CW1	
CLC 3		
LDA ADR2		
OTA 3	CW2	
STC 3		
LDA NBUF		
OTA 3	CW3	
SFC 6	SKIP FLAG CLEAR-SKIP DMA1 BUSY.	
HLT 6	ERROR HALT.	
SFS 6	SKIP FLAG SET-SKIP WHEN DMA1 RDY	
JMP *-1	WAIT UNTIL DMA1 IS FINISHED.	
NOP		
STC 14B,C		
STC 7,C	START ADC & START DMA2.	
THIRD LDA CNTL2	INITIALIZE DMA1 TO WRITE TAPE.	
OTA 6		
CLC 2		

Figure B-1. ADC1 Program

	LDA ADR10	
	OTA 2	CW2
	STC 2	
	LDA NBUF	
	OTA 2	CW3
	SFS 11B	SKIP FLAG SET-SKIP WHEN TAPE RDY
	JMP *-1	WAIT UNTIL TAPE IS READY.
	LDA OUT	GET TAPE COMMAND WORD FOR OUTPT
	OTA 11B,C	OUTPUT COMMAND WORD TO TAPE.
	STC 6,C	START DMA1 TO TAPE.
	SFS 6	SKIP FLAG SET-SKIP IF DMA1 FIN.
	JMP *-1	WAIT UNTIL DMA1 IS FINISHED.
	LIA 11B	GET TAPE STATUS WORD.
	AND MASK1	CHECK PARITY STATE.
	SZA	SKIP IF PARITY IS OK.
	JSB ERROR	GO TO ERROR ROUTINE-BAD PARITY.
	ISZ CNT	INCREMENT RECORD COUNT.
	JMP **12	
	LDA JOB1	HALT ON RECORDS COMPLETE WITH
	HLT 6	(A) REGISTER = 70707*****
	JSB ENDFL	PUSH START TO GET EOF MARK*****
	NOP	
	JSB REWND	TAPE REWIND ROUTINE.
	CLC 0	TURN OFF ALL I/O UNITS.
	LDA JOB2	HALT ON NORMAL JOB COMPLETE----
	HLT 6	LOAD A NEW REEL OF TAPE AND PUSH
	NOP	RUN TO REPEAT ENTIRE PROGRAM.
	JMP BEGIN	*****
	NOP	*****
FOUR	LDA CNTL1	INITIALIZE DMA1 TO READ ADC.
	OTA 6	
	CLC 2	
	LDA ADR1	
	OTA 2	CW2
	STC 2	
	LDA NBUF	
	OTA 2	CW3
	SFC 7	SKIP IF DMA2 IS BUSY.
	HLT 7	ERROR HALT.
	SFS 7	SKIP IF BUFFER2 IS FULL.
	JMP *-1	WAIT UNTIL DMA2 FLAG IS SET.
	STC 14B,C	START ADC.
	STC 6,C	START DMA1.
	LDA CNTL2	INITIALIZE DMA2 TO WRITE TAPE.
	OTA 7	CW1
	CLC 3	
	LDA ADR20	
	OTA 3	CW2

Figure B-1. ADC1 Program (continued)

	STC 3	
	LDA NBUF	
	OTA 3	CW3
	SFS 11B	SKIP WHEN TAPE IS READY.
	JMP *-1	WAIT UNTIL TAPE IS READY.
	LDA OUT	GET TAPE COMMAND WORD.
	OTA 11B,C	START TAPE MACHINE.
	STC 7,C	START DMA2 TO TAPE.
	SFS 7	SKIP WHEN DMA2 IS FINISHED.
	JMP *-1	WAIT UNTIL DMA2 IS FINISHED.
	LIA 11B	GET TAPE STATUS WORD.
	AND MASK1	CHECK PARITY STATE.
	SZA	SKIP IF PARITY IS OK.
	JSB ERROR	BAD PARITY.
	ISZ CNT	INCREMENT RECORD COUNT.
	JMP **13	
	LDA JOB1	
	HLT 7	RECORDS COMPLETE. PUSH RUN TO
	NOP	WRITE EOF AND REWIND TAPE.
	JSB ENDFL	GO TO END-OF-FILE ROUTINE.
	JSB REWND	GO TO REWIND ROUTINE.
	NOP	
	CLC 0	TURN OFF ALL I/O UNITS.
	LDA JOB2	
	HLT 7	PUSH REN TO REPEAT ENTIRE PGM.
	NOP	LOAD NEW TAPE*****
	NOP	*****
FIVE	JMP BEGIN	*****
	JMP LOOP	GO READ ANOTHER RECORD.
ERROR	NOP	PARITY ERROR ROUTINE.
	INB	INCREMENT B REGISTER.
	JMP ERROR,I	RETURN TO MAIN PROGRAM.
REWND	NOP	REWIND ROUTINE.
	SFS 11B	SKIP WHEN TAPE IS READY.
	JMP *-1	WAIT UNTIL TAPE IS READY.
	LDA REW	GET REWIND COMMAND WORD.
	OTA 11B,C	REWIND TAPE.
	SFS 11B	SKIP WHEN TAPE IS REWOUND.
	JMP *-1	
	JMP REWND,I	RETURN TO MAIN PROGRAM.
ENDFL	NOP	END-OF-FILE ROUTINE.
	SFS 11B	SKIP WHEN TAPE IS READY.
	JMP *-1	
	LDA FILE	GET TAPE EOF COMMAND WORD.
	OTA 11B,C	WRITE E-O-F.
	SFS 11B	

Figure B-1. ADC1 Program (continued)

	JMP *-1	WAIT UNTIL TAPE IS READY.
	JMP ENDFL,I	RETURN TO MAIN PROGRAM.
FILE	OCT 35	E-O-F COMMAND WORD.
CNTL1	OCT 120014	CONTROL WORD NO. 1 FOR DMA.
NBUF	DEC -2000	NUMBER OF WORDS PER RECORD.
OUT	OCT 31	TAPE WRITE COMMAND WORD.
CNTL2	OCT 160010	CONTROL WORD NO. 2 FOR DMA.
ADR1	OCT 102000	BUFFER1 STARTING ADDRESS. 2000B
ADR2	OCT 106000	BUFFER2 STARTING ADDRESS. 6000B
ADR10	OCT 002000	BUFFER1 STARTING ADDRESS. 2000B
ADR20	OCT 006000	BUFFER2 STARTING ADDRESS. 6000B
MASK1	OCT 2	MASK TO CHECK PARITY ON TAPE.
REW	OCT 201	TAPE REWIND COMMAND WORD.
REC	NOP	ENTER NUMBER OF RECORDS HERE.
CNT	NOP	PUT 2'S COMPLEMENT OF RECORDS H
FL	OCT 35	TAPE E-O-F COMMAND WORD.
JOB1	OCT 77777	
JOB2	OCT 70707	
	END	
	END OF TAPE	
	END OF TAPE	

Figure E-1. ADC1 Program (continued)

```

0001  ASMB,A,B,L,T
0002      ORG 100B
0003  BEGIN NOP
0004      LDA FL
0005      OTA 11B
0006  HLT1  HLT
0007      LIA 1
0008      CPA ZERO
0009      JMP START
0010      CMA
0011      INA
0012      STA CNT
0013  LOOP1 LDA SPC1
0014      OTA 11B
0015      ISZ CNT
0016      JMP LOOP1
0017  START NOP
0018  HALT2 HLT
0019      CLC 0
0020      CLB
0021      CLF 0
0022      LDA CNTL1
0023      OTA 6
0024      CLC 2
0025      LDA ADR1
0026      OTA 2
0027      STC 2
0028      LDA NBUF
0029      OTA 2
0030      STC 14B,C
0031      STC 6,C
0032      SFS 6
0033      JMP *-1
0034      LDA CNTL2
0035      OTA 6
0036      CLC 2
0037      LDA ADR10
0038      OTA 2
0039      STC 2
0040      LDA NBUF
0041      OTA 2
0042      SFS 11B
0043      JMP *-1
0044      LDA OUT
0045      OTA 11B,C
0046      STC 6,C
0047      SFS 6
0048      JMP *-1
0049      LIA 1
0050      AND MASK1

```

Figure B-2. ADC2 Program

```

0051          SZA
0052          JMP ERROR
0053          LDA ZERO
0054          JMP *+1
0055 ERROR LDA ONE
0056 HALT3 HLT
0057          LIA 1
0058          CPA ZERO
0059          JMP START
0060          CPA BACK
0061          JMP BACK1
0062          CPA ENDX
0063          JMP REW
0064 BACK1 LDA SPC2
0065          OTA 11B
0066          SFS 11B
0067          JMP *-1
0068          JMP START
0069 REW    NOP
0070          SFS 11B
0071          JMP *-1
0072          LDA REW1
0073          OTA 11B,C
0074          SFS 11B
0075          JMP *-1
0076          CLC 0
0077          HLT
0078 ZERO   OCT 0
0079 ONE    OCT 1
0080 BACK   OCT 1
0081 ENDX   OCT 2
0082 CNTL1  OCT 120014
0083 ADR1    OCT 102000
0084 NBUF    DEC -2048
0085 CNTL2  OCT 160010
0086 ADR10   OCT 002000
0087 SPC1    OCT 3
0088 OUT     OCT 31
0089 SPC2    OCT 41
0090 FL      OCT 35
0091 MASK1   OCT 2
0092 REW1    OCT 201
0093 CNT     NOP
0094          END
          END OF TAPE

```

Figure B-2 ADC2 Program (continued)

```

0001          ASMB,B,L,A,C,T
0002 00100      ORG 1000      PROGRAM STARTS AT 100 OCTAL.
0003*
0004*****DATACON-CONVT PROGRAM
0005*
0006*      DATA READ FROM A/D CONVERTOR IS PUT ON MAGNETIC TAPE
0007*      IN A FORMAT COMPATABLE TO FORTRAN 360.  USE A SYSTEM
0008*      360 STANDARD LABELED TAPE.
0009*
0010*****
0011*
0012*      FIRST OPERATION IS TO CHECK FOR LEGAL LABELED TAPE.
0013*
0014 00100 060460      LDA HDCON      LOAD FIRST CONTROL WORD.
0015 00101 102606      OTA 6          TYPE OF OPERATION AND UNIT USE
0016 00102 106702      CLC 2          PREPARE FOR SECOND CONTROL WORD
0017 00103 060461      LDA HDAD      SECOND CONTROL WORD.
0018 00104 102602      OTA 2          INPUT ADDRESS IN CORE FOR FIRST
0019 00105 102702      STC 2          PREPARE--
0020 00106 060460      LDA HDLEN      LENGTH OF DATA FIELD TO BE REA
0021 00107 102602      OTA 2
0022 00108 060463      LDA READ      LOAD READ COMMAND FOR MAG. TAP
0023 00109 103611      OTA 118,C     START TAPE DECK.
0024 00110 103706      STC 6,C       START THE DMA CHANNEL # 2.
0025 00111 102311      SFS 118      WAIT FOR TAPE DECK.
0026 00112 024113      JMP *-1
0027 00113 060464      LDA V0        LOAD "V0" FROM 360 HEADER VOL1
0028 00114 020700      XOR 700B     CHECK FIRST DATA WORD.
0029 00115 002002      SZA
0030 00116 024370      JMP DEAD      FIRST WORD DID NOT COMPARE--FOR
0031 00117 060465      LDA L1        LOAD "L1" FROM 360 HEADER RECO
0032 00118 020701      XOR 701B
0033 00119 002002      SZA          CHECK SECOND DATA WORD.
0034 00120 024370      JMP DEAD
0035 00121 014373      JSB FWDSP     SKIP SECOND FILE
0036 00122 014373      JSB FWDSP     SKIP THIRD FILE.
0037 00123 014373      JSB FWDSP     CHECK FOURTH FILE FOR TAPE MARK
0038 00124 034000      ISZ 0
0039 00125 024370      JMP DEAD      TAPE MARK NOT HERE AS SHOULD B
0040*
0041***** OPERATOR      ION--FORWARD SPACE SPECIFIED NUMBER OF RECORDS.
0042*
0043*      SET BIT "15"
0044*****
0045*
0046 00132 102501      LIA 1          LOAD SWITCH REGISTORE
0047 00133 002020      SSA          CHECK SWITCH SETTING
0048 00134 014401      JSB FWDND     JUMP TO SUBROUTINE TO FORWARD SP
0049*
0050*****
0051*
0052 00135 102000      START HLT 0      LOAD SW. REC. WITH NO. RECORDS.
0053 00136 102501      LIA 1
0054 00137 013004      CMA,INA        GENERATE TWO'S COMPLEMENT
0055 00138 070466      STA REC        STORE 2'S COMPL IN REC.
0056 00139 102001      ENTER HLT 1     PUSH RUN TO START PROGRAM
0057 00140 060466      LDA REC

```

Figure B-3. ADC2A Program

0054	00143	070467	STA CNT	INITIALIZE RECORD COUNT.
0059	00144	106700	CLC 0	TURN OFF ALL I/O.
0060	00145	102400	CLA	CLEAR A FOR ERROR COUNT
0061	00146	170455	STA NER	SET ERROR COUNTER
0062	00147	103100	CLF 0	TURN INTERRUPT OFF.
0063	00154	060442	FIRST LDA CNTL1	INITIALIZE DMA1 TO READ ADC.
0064	00151	102606	OTA 6	CONTROL WORD ONE.
0065	00152	106742	CLC 2	
0066	00153	060451	LDA ADDR1	
0067	00154	102602	OTA 2	CONTROL WORD 2.
0068	00155	102702	STC 2	
0069	00156	060443	LDA NBUF	NBUF IS "WORDS PER RECORD".
0070	00157	102602	OTA 2	CONTROL WORD 3.
0071	00160	103714	STC 14H,C	START ADC.
0072	00161	103706	STC 6,C	START DMA1.
0073	00162	060442	LOOP LDA CNTL1	INITIALIZE DMA2 TO READ ADC.
0074	00163	102607	OTA 7	CW1
0075	00164	106703	CLC 3	
0076	00165	060452	LDA ADDR2	
0077	00166	102603	OTA 3	CW2
0078	00167	102703	STC 3	
0079	00170	060443	LDA NBUF	
0080	00171	102603	OTA 3	CW3
0081	00172	102206	SFC 6	SKIP FLAG CLEAR-SKIP DMA1 BUSY.
0082	00173	102006	HLT 6	ERROR HALT.
0083	00174	102306	SFS 6	SKIP FLAG SET-SKIP WHEN DMA1 RDY
0084	00175	024174	JMP *-1	WAIT FOR DMA1.
0085	00176	103714	STC 14H,C	
0086	00177	103707	STC 7,C	START ADC & START DMA2.
0087	00190	060450	THIRD LDA CNTL2	INITIALIZE DMA1 TO WRITE TAPE.
0088	00201	102606	OTA 6	
0089	00202	106702	CLC 2	
0090	00203	060444	LDA ADDR1	
0091	00204	102602	OTA 2	CW2
0092	00205	102702	STC 2	
0093	00206	060446	LDA NBUF	
0094	00207	102602	OTA 2	CW3
0095	00210	060443	LDA NBUF	LOAD COMPLEMENT OF NUMBER OF RECORD
0096	00211	070416	STA COUNT	SAVE COUNTER
0097	00212	060453	LDB ADDR10	STARTING ADDRESS OF A-D BUFFER
0098	00213	074417	STH NUM	
0099	00214	040443	ADB NBUF	BACK UP FOR OUTPUT POINTER
0100	00215	060447	LDA OUT	LOAD MAG TAPE "WRITE" COMMAND
0101	00216	000040	CLE	
0102	00217	102311	SFS 11R	SKIP FLAG SET-SKIP WHEN TAPE RDY
0103	00220	024217	JMP *-1	WAIT UNTIL TAPE IS READY.
0104	00221	103611	OTA 11R,C	OUTPUT COMMAND WORD TO TAPE.
0105	00222	103706	STC 6,C	START DMA1 TO TAPE.
0106	00223	014345	JSR CONV	START CONVERTING NUMBERS
0107	00224	102306	SFS 6	SKIP FLAG SET-SKIP IF DMA1 FIN.
0108	00225	024224	JMP *-1	WAIT UNTIL DMA1 IS FINISHED.
0109	00226	102511	LIA 11R	GET TAPE STATUS WORD.
0110	00227	014456	AND MASK1	CHECK PARITY STATE.
0111	00230	002002	SZA	SKIP IF PARITY IS OK.
0112	00231	014317	JSR ERROR	GO TO ERROR ROUTINE-BAD PARITY.
0113	00232	034467	ISZ CNT	INCREMENT RECORD COUNT.
0114	00233	024244	JMP FOUR	

Figure B-3. ADC2A Program (continued)

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0115	00234	060472	FIVE	LDA JOB1	HALT ON RECORDS COMPLETE WITH
0116	00235	064455		LDB NER	LOAD NUMBER OF ERRORS
0117	00236	106700		CLC 0	TURN OFF ALL I/O DEVICES.
0118	00237	102066		HLT 66B	HLT--END OF RUN.....
0119	00240	014330		JSB ENDFL	PUSH START TO GET EOF MARK*****
0120	00241	014407		JSB VOLEN	SUBROUTINE TO END VOLUME.
0121	00242	014322		JSB REWND	TAPE REWIND ROUTINE.
0122	00243	024371		JMP DEAD+1	
0123	00244	060442	FOUR	LDA CNTL1	INITIALIZE DMA1 TO READ ADC.
0124	00245	102606		OTA 6	
0125	00246	106702		CLC 2	
0126	00247	060451		LDA ADRI	
0127	00250	102602		OTA 2	CW2
0128	00251	102702		STC 2	
0129	00252	060443		LDA NBUF	
0130	00253	102602		OTA 2	CW3
0131	00254	102207		SFC 7	SKIP IF DMA2 IS BUSY.
0132	00255	102007		HLT 7	ERROR HALT.
0133	00256	102307		SFS 7	SKIP IF BUFFER2 IS FULL.
0134	00257	024256		JMP *-1	WAIT UNTIL DMA2 FLAG IS SET.
0135	00260	103714		STC 14B,C	
0136	00261	103706		STC 6,C	START DMA1.
0137	00262	060450		LDA CNTL2	INITIALIZE DMA2 TO WRITE TAPE.
0138	00263	102607		OTA 7	CW1
0139	00264	106703		CLC 3	
0140	00265	060445		LDA RADR2	
0141	00266	102603		OTA 3	CW2
0142	00267	102703		STC 3	
0143	00270	060446		LDA NBUFF	
0144	00271	102603		OTA 3	CW3
0145	00272	060443		LDA NBUF	LOAD COMPLEMENT OF NUMBER OF RECO
0146	00273	070416		STA COUNT	SAVE IN COUNTER
0147	00274	064454		LDB ADDR3	STARTING ADDRESS OF A-D BUFFER
0148	00275	074417		STB NUM	STORE ADDRESS--INPUT POINTER
0149	00276	044443		ADR NBUF	HACK UP THE OUTPUT POINTER
0150	00277	060447		LDA OUT	LOAD MAG TAPE "WRITE" COMMAND
0151	00300	000040		CLE	
0152	00301	102311		SFS 11B	SKIP WHEN TAPE IS READY.
0153	00302	024301		JMP *-1	WAIT UNTIL TAPE IS READY.
0154	00303	103611		OTA 11B,C	START TAPE MACHINE.
0155	00304	103707		STC 7,C	START DMA2 TO TAPE.
0156	00305	014345		JSR CONV	START CONVERTING NUMBERS
0157	00306	102307		SFS 7	SKIP WHEN DMA2 IS FINISHED.
0158	00307	024306		JMP *-1	WAIT UNTIL DMA2 IS FINISHED.
0159	00310	102511		LIA 11B	GET TAPE STATUS WORD.
0160	00311	010456		AND MASK1	CHECK PARITY STATE.
0161	00312	002002		SZA	SKIP IF PARITY IS OK.
0162	00313	014317		JSR ERROR	BAD PARITY.
0163	00314	034467		ISZ CNT	INCREMENT RECORD COUNT.
0164	00315	024162		JMP LOOP	
0165	00316	024234		JMP FIVE	
0166	00317	000000	ERROR	NOP	PARITY ERROR ROUTINE.
0167	00320	034455		ISZ NER	UPDATE THE ERROR COUNT
0168	00321	124317		JMP ERROR,I	RETURN TO MAIN PROGRAM.
0169	00322	000000	REWIND	NOP	REWIND ROUTINE.
0170	00323	102311		SFS 11B	SKIP WHEN TAPE IS READY.
0171	00324	024323		JMP *-1	WAIT UNTIL TAPE IS READY.

Figure B-3. ADC2A Program (continued)

```

0172 00325 061457      LDA REW      GET REWIND COMMAND WORD.
0173 00326 103611      OTA 11B,C    REMIND TAPE.
0174 00327 124322      JMP REWD,I   RETURN TO MAIN PROGRAM.
0175 00330 000000      ENDFL NOP     SUBROUTINE RETURN ADDRESS.
0176*
0177***** TO RETURN TO START--SET BIT "0"
0178*
0179 00331 102501      LIA 1        LOAD SWITCH REGISTER.
0180 00332 000010      SLA          CHECK LEAST SIGNIFICANT BIT
0181 00333 024135      JMP START    JMP TO LOAD DATA
0182*
0183***** SET BIT "15" TO BACKSPACE A SPECIFIED NUMBER OF RECORDS.
0184*
0185 00334 002120      SSA          CHECK BIT "15".
0186 00335 024432      JMP BACK     JUMP TO SUB. TO BACK SPACE RECORD
0187*
0188*****
0189*
0190 00336 102311      SFS 11B      SKIP WHEN TAPE IS READY.
0191 00337 024336      JMP *-1
0192 00340 060420      LDA FILE     GET TAPE EOF COMMAND WORD.
0193 00341 103611      OTA 11B,C    WRITE E-O-F.
0194 00342 102311      SFS 11B
0195 00343 024342      JMP *-1      WAIT UNTIL TAPE IS READY.
0196 00344 124330      JMP ENDFL,I   RETURN TO MAIN PROGRAM.
0197*
0198***** CONVERTING SUBROUTINE *****
0199*
0200*      A/D INPUT NUMBERS ARE CHANGED TO FORTRAN FLOATING WORDS.
0201*
0202 00345 000000      CONV1 NOP      SPACE FOR SUBROUTINE RETURN ADDRESS
0203 00346 160417      STTI LDA NUM,I  LOAD NUMBER TO BE CONVERTED
0204 00347 010470      AND MSKK      DROP LEAST SIGNIFICANT FIGURES(TWO
0205 00350 001623      ELA,RAR       SAVE SIGN IN E REGISTER
0206 00351 002204      CME,INA      CORRECT SIGN-SET EXPONENT SIGN
0207 00352 001325      RAR,ERA      MOVE IN BOTH SIGN BITS
0208 00353 170001      STA 1,I       STORE IN ADDRESS GIVEN IN B REGIS
0209 00354 006004      INB          UPDATE THE OUTPUT ADDRESS
0210 00355 160417      LDA NUM,I     LOAD NUMBER AGAIN
0211 00356 010471      AND MSKL      DROP ALL BUT LEAST TWO SIGNIFICANT
0212 00357 001323      RAR,RAR       ROTATE AROUND TO THE HIGH ORDER E
0213 00360 170001      STA 1,I
0214 00361 006104      CLE,INB      UPDATE THE OUTPUT ADDRESS
0215 00362 034417      ISZ NUM       UPDATE THE INPUT ADDRESS
0216 00363 034416      ISZ COUNT    UPDATE THE COUNTER,SKIP IF END
0217 00364 024346      JMP STTI
0218 00365 102211      SFC 11B      CHECK TO BE SURE TAPE DIDN'T GET
0219 00366 102452      HLT 52B      TAPE DECK AHEAD OF CONVERSION...
0220 00367 124345      JMP CONV1,I   SUBROUTINE RETURN.....
0221*
0222*      DEAD SUBROUTINEHEADER LABEL NOT ACCEPTABLE.
0223*
0224 00370 014322      DEAD JSB REWD    REMIND AN STANDRY.
0225 00371 102025      HLT 25B        STOP FOR OPERATOR ACTION
0226 00372 024100      JMP 100B       RETURN TO START OF PROGRAM
0227*      THE OPERATOR IS EXPECTED TO SUPPLY A NEW REEL OF TAPE--
0228*      A LABELED ONE BEFORE PUSHING "RUN".

```

Figure B-3. ADC2A Program (continued)

```

0229*
0230*****
0231*
0232*      SUBROUTINE TO FORWARD SPACE RECORD ON MAG TAPE UNIT
0233*
0234 00373 000000 FWDSP NOP      RETURN ADDRESS OR SUBROUTINE EXIT
0235 00374 000405 LDA FWD      LOAD FORWARD SPACE RECORD COMMAND
0236 00375 103611 OTA 11B,C    OUTPUT COMMAND
0237 00376 102311 SFS 11B    SKIP WHEN TAPE UNIT COMPLETED.
0238 00377 024376 JMP *-1     WAIT FOR COMPLETION OF OPERATION
0239 00400 102511 LIA 11B    LOAD STATUS WORD
0240 00401 010406 AND CWORD
0241 00402 002002 SZL        CHECK FOR TAPE MARK
0242 00403 003400 CCA        SET "A" TO -1 IF TAPE MARK SENSED
0243 00404 124373 JMP FWDSP,I  RETURN TO MAIN PROGRAM.
0244 00405 000003 FWD OCT 3    TAPE COMMAND--FORWARD SPACE RECOR
0245 00406 000200 CWORD OCT 200 MASK FOR SENSING WHEN TAPE MARK P
0246*
0247*      UPON RETURN-- "A" IS 0 IF NO TPE MARK SENSED.
0248*      "A" IS -1 IS TAPE MARK DETECTED
0249*
0250*
0251*
0252*      SUBROUTINE      ALLOWS OPTION OF ENDING VOLUME OR
0253*
0254*
0255 00407 000000 VOLEN NOP      SAVE RETURN ADDRESS AREA
0256 00410 102070 HLT 70B      HALT FOR OPERATOR RESPONSE
0257 00411 102501 LIA 1      LOAD SWITCH REGISTURE.
0258 00412 002020 SSA        CHECK OPERATORS INSTRUCTION
0259 00413 024135 JMP START   PREPARE TO LOAD DATA SET--MULTIPLE
0260 00414 014330 JSR ENDFL  PLACE SECOND FILE MARK--VOLUME END
0261 00415 124407 JMP VOLEN,I  RETURN TO MAIN PROGRAM.
0262 00416 000000 COUNT OCT 0  COUNTER IN CONVERT ROUTINE
0263 00417 000000 NUM OCT 0    INPUT POINTER IN CONVERT ROUTINE
0264 00420 000035 FILE OCT 35   E-O-F COMMAND WORD.
0265***** FORWARD SPACE A SPECIFIED NUMBER OF RECORDS.
0266*
0267*
0268 00421 000000 FWDNO NOP      SUBROUTINE RETURN ADDRESS.
0269 00422 102414 HLT 14B
0270 00423 102501 LIA 1      LOAD NUMBER OF RECORDS TO FORWARD
0271 00424 003004 CMA,INA    GENERATE TWO'S COMPLEMENT.
0272 00425 070416 STA COUNT   STORE COUNTER.
0273 00426 014373 JSR FWDSP  GO TO SUB TO FORWARD SPACE ONE RE
0274 00427 034416 ISZ COUNT   CHECK COUNTER.
0275 00430 024426 JMP *-2     KEEP IN LOOP UNTIL SATISFIED.
0276 00431 124421 JMP FWDNO,I  SUBROUTINE RETURN
0277*
0278***** BACKSPACE SUB.
0279*
0280 00432 060441 BACK LDA BREC   LOAD COMMAND FOR BACK SPACING REC
0281 00433 071405 STA FWD   LOAD COMMAND IN FWDSP SUBROUTINE.
0282 00434 014421 JSR FWDNO  GO TO SUB. TO GET NO. OF RECORDS
0283 00435 060440 LDA FREC   LOAD FORWARD SPACE COMMAND
0284 00436 071405 STA FWD   RESTORE SUBROUTINE COMMAND WORD.
0285 00437 024135 JMP START   PREPARE TO LOAD DATA.

```

Figure B-3. ADC2A Program (continued)

```

0006 00000 000000 FREQ OCT 3 FORWARD SPACE COMMAND.
0007 00001 000001 BREQ OCT 41 BACK SPACE COMMAND.
0008 00002 000010 GSTLL OCT 100014 CONTROL WORD--NO "CLC" AT END OF
0009 00003 170150 XOFF DEC -1944 BUFFER LENGTH.
0010 00004 000000 XADDR1 OCT 001 TAPE OUTPUT BUFFER #1.
0011 00005 000000 XADDR2 OCT 10000 TAPE OUTPUT BUFFER #2.
0012 00006 170110 XOFF DEC -3892
0013 00007 000001 OFF OCT 31 TAPE WRITE COMMAND WORD.
0014 00008 160010 CNTRL OCT 160010 CONTROL WORD NO. 2 FOR DMA.
0015 00009 104334 ADDR1 OCT 104334
0016 00010 114034 ADDR2 OCT 114034
0017 00011 004334 ADDR3 OCT 4334
0018 00012 004334 ADDR4 OCT 14034
0019 00013 000000 XER OCT 0 STORAGE FOR NUMBER OF PARITY ERROR
0020 00014 000000 MASK1 OCT 0 MASK TO CHECK PARITY ON TAPE.
0021 00015 000000 XER OCT 0 TAPE COMMAND--REWIND AND STAND BY
0022 00016 170650 HLEN OCT -100 HEADER LENGTH
0023 00017 100700 HDAD OCT 100700 LOAD DATA TO CORE 7000 UP.
0024 00018 160010 HDCON OCT 160010 DMA CONTROL--USE UNIT 10
0025 00019 000023 READ OCT 23 MAG TAPE COMMAND TO READ.
0026 00020 160726 VD OCT 160726
0027 00021 151761 LI OCT 151761
0028 00022 000000 REC NOP ENTER NUMBER OF RECORDS HERE.
0029 00023 000000 CNT NOP PUT 2'S COMPLEMENT OF RECORDS H
0030 00024 177774 MSKK OCT 177774 MASK TO DROP LEAST TWO SIGNIFICAN
0031 00025 000000 MSKL OCT 0 MASK TO DROP ALL BUT LEAST TWO SI
0032 00026 177777 J001 OCT 77777 LOADED INTO "A" WHEN RECORDS HAVE
0033*
0034* SET UP INITIAL CONSTANTS FOR FORTRAN TAPE FORMAT
0035 00500 ORG 5000
0036 00501 017150 DEC 7784
0037 00502 000000 OCT 0
0038 00503 017144 DEC 7780
0039 00504 000000 OCT 0
0040*
0041 10200 ORG 10200H START TO SET UP CONSTANTS.
0042 10201 017151 DEC 7784 BYTE LENGTH OF BLOCK
0043 10202 000000 OCT 0 CONTROL WORD
0044 10203 017144 DEC 7780 BYTE LENGTH OF LRECL
0045 10204 000000 OCT 0 CONTROL WORD.
0046*
0047*
0048* THIS IS NECESSARY SINCE FORTRAN WILL NOT ACCEPT
0049* CORE TYPE DUMPS. BLKSIZE AND LRECL MUST BE FURNISHED.
0050*
0051* HALT 6 AND 7 (OCTAL) MEAN USER LOADED INPUT DATA FASTER
0052* THAN TAPE IS LOADING DATA--SLOW INPUT RATE. 13400 WORDS
0053* PER SECOND IS MAXIMUM RATE.
0054*
0055* HALT 6A---DATA LOADED PROPERLY--USER CHECK
0056* "B" REGISTER TO SEE IF ANY TAPE ERRORS
0057* WERE DETECTED DURING LOADING.
0058*
0059* END 778
0060* NO ERRORS*

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Figure B-3. ADC2A Program (continued)

0001		ASMB,A,B,L,T		
0002	16100		ORG 16100B	
0003	16100 000000	TITLE	NOP	A PROGRAM TO READ A TAPE RECORD
0004	16101 000000		NOP	INTO CORE MEMORY.
0005	16102 000000	BEGIN	NOP	
0006	16103 106700		CLC 0	CLEAR ALL CONTROL BITS. I/O OFF.
0007	16104 103100		CLF 0	TURN OFF INTERRUPT SYSTEM.
0008	16105 006400		CLB	CLEAR B REGISTER.
0009	16106 062210		LDA CW1	FORWARD SPACE PAST FILE MARK.
0010	16107 102611		OTA 11B	
0011	16110 062211		LDA CW2	BACKSPACE TO FIRST RECORD.
0012	16111 102611		OTA 11B	
0013	16112 062220		LDA ONE	(A) = 177777 OCTAL.
0014	16113 102006	HALT1	HLT 6	HALT NO. 1
0015	16114 102501		LIA 1	LOAD SWITCHES WITH NUMBER OF
0016	16115 000000		NOP	RECORDS TO BE SKIPPED, OR WITH
0017	16116 000000		NOP	THE REWIND CODE(SW15 UP).
0018	16117 000000		NOP	PUSH "RUN" WHEN READY.
0019	16120 002020		SSA	SKIP IF SW15 IS DOWN.
0020	16121 026174		JMP REWND	GO TO REWIND(SW15 UP).
0021	16122 000000	SPACE	NOP	
0022	16123 003000		CMA	GET 2'S COMPLEMENT OF (A).
0023	16124 002004		INA	
0024	16125 072207		STA COUNT	STORE (A) IN "COUNT".
0025	16126 000000		NOP	
0026	16127 062210		LDA CW1	SPACE FORWARD CONTROL WORD.
0027	16130 102611		OTA 11B	
0028	16131 102311		SFS 11B	
0029	16132 026131		JMP *-1	WAIT UNTIL TAPE IS READY.
0030	16133 036207		ISZ COUNT	INCR COUNT-SKIP IF ZERO.
0031	16134 026130		JMP *-4	GO BACK AND SPACE AGAIN.
0032	16135 062221		LDA TWO	(A) = 000007 OCTAL.
0033	16136 000000	HALT2	NOP	
0034	16137 102006		HLT 6	HALT NO. 2 PUSH "RUN" TO GO.
0035	16140 062212		LDA DMA1	INITIALIZE DMA1 TO READ TAPE.
0036	16141 102606		OTA 6	
0037	16142 106702		CLC 2	
0038	16143 062213		LDA ADDRS	CORE ADDRESS.
0039	16144 102602		OTA 2	
0040	16145 102702		STC 2	
0041	16146 062214		LDA WORDS	WORDS PER RECORD.
0042	16147 102602		OTA 2	
0043	16150 102311		SFS 11B	
0044	16151 026150		JMP *-1	WAIT UNTIL TAPE IS READY.
0045	16152 062215		LDA TAPE	TAPE COMMAND WORD.
0046	16153 103611		OTA 11B,C	READY THE TAPE.
0047	16154 103706		STC 6,C	START DMA1 READING TAPE.
0048	16155 102306		SFS 6	
0049	16156 026155		JMP *-1	WAIT UNTIL DMA1 HAS FINISHED.
0050	16157 000000	CHECK	NOP	ROUTINE TO CHECK PARITY.

Figure B-4. ADC3 Program

0051	16160	102511	LIA 11B	LOAD TAPE STATUS WORD.
0052	16161	012216	AND MASK1	PARITY BIT MASK.
0053	16162	002002	SZA	SKIP IF (A) = 0.(PARITY OK)
0054	16163	026167	JMP ERROR	BAD PARITY.
0055	16164	000000	NOP	PARITY OK. (A)=177777 OCTAL.
0056	16165	006400	CLB	
0057	16166	026112	JMP HALT:-1	
0058	16167	000000	ERROR NOP	PARITY CHECK-COMPUTER WILL
0059	16170	062222	LDA THREE	STOP WITH 070707(OCTAL) IN (A).
0060	16171	006004	INB	INCREMENT THE B REGISTER.
0061	16172	102006	HLT 6	PARITY ERROR HALT.
0062	16173	126167	JMP ERROR,I	CONTINUE.
0063	16174	000000	REWIND NOP	TAPE REWIND ROUTINE.
0064	16175	102311	SFS 11B	
0065	16176	026175	JMP *-1	
0066	16177	062217	LDA REW	
0067	16200	103611	OTA 11B,C	
0068	16201	102311	SFS 11B	
0069	16202	026201	JMP *-1	
0070	16203	106700	CLC 0	
0071	16204	062223	LDA FOUR	(A) = 111111 OCTAL.
0072	16205	102006	LAST HLT 6	
0073	16206	026102	JMP BEGIN	
0074	16207	000000	COUNT NOP	
0075	16210	000003	CW1 OCT 3	
0076	16211	000041	CW2 OCT 41	
0077	16212	120010	DMA1 OCT 120010	READ TAPE CONTROL WORD.
0078	16213	102000	ADDRS OCT 102000	MEMORY INPUT-ADDRESS=2000 OCTAL.
0079	16214	174000	WORDS DEC -2048	NO. WORDS PER RECORD=2048.
0080	16215	000023	TAPE OCT 23	TAPE CONTROL WORD.
0081	16216	000002	MASK1 OCT 2	PARITY BIT MASK WORD.
0082	16217	000201	REW OCT 201	
0083	16220	177777	ONE OCT 177777	
0084	16221	000007	TWO OCT 000007	
0085	16222	070707	THREE OCT 070707	
0086	16223	111111	FOUR OCT 111111	
0087			END	

** NO ERRORS*

Figure B-4. ADC3 Program (continued)

```

0001          ASMB,B,A,L,C
0002 00100      ORG 100B      PROGRAM STARTS AT 100 OCTAL.
0003*          FIRST OPERATION IS TO CHECK FOR LEGAL LABELED TAPE.
0004*
0005 00100 060456      LDA HDCON      LOAD FIRST CONTROL WORD.
0006 00101 102606      OTA 6          TYPE OF OPERATION AND UNIT USE
0007 00102 106702      CLC 2          PREPARE FOR SECOND CONTROL WOR
0008 00103 060455      LDA HDAD      SECOND CONTROL WORD.
0009 00104 102602      OTA 2          INPUT ADDRESS IN CORE FOR FIRS
0010 00105 102702      STC 2          PREPARE--
0011 00106 060454      LDA HDLEN     LENGTH OF DATA FIELD TO BE REA
0012 00107 102602      OTA 2
0013 00110 060457      LDA READ      LOAD READ COMMAND FOR MAG. TAP
0014 00111 103611      OTA 11B,C     START TAPE DECK.
0015 00112 103706      STC 6,C       START THE DMA CHANNEL # 2.
0016 00113 102311      SFS 11B      WAIT FOR TAPE DECK.
0017 00114 024113      JMP *-1
0018 00115 060460      LDA VO          LOAD "VO" FROM 360 HEADER VOLI
0019 00116 020700      XOR 700B      CHECK FIRST DATA WORD.
0020 00117 002002      SZA
0021 00120 024405      JMP DEAD       FIRST WORD DID NOT COMPARE--FOR
0022 00121 060461      LDA L1        LOAD "L1" FROM 360 HEADER RECO
0023 00122 020701      XOR 701B
0024 00123 002002      SZA          CHECK SECOND DATA WORD.
0025 00124 024405      JMP DEAD
0026 00125 014410      JSB FWDSP     SKIP SECOND FILE
0027 00126 014410      JSB FWDSP     SKIP THIRD FILE.
0028 00127 014410      JSB FWDSP     CHECK FOURTH FILE FOR TAPE MAR
0029 00130 034000      ISZ 0
0030 00131 024405      JMP DEAD      TAPE MARK NOT HERE AS SHOULD B
0031*
0032*
0033*
0034*          DATACON-CONVERT PROGRAM
0035*          DATA READ FROM ANALOG TO DIGITAL CONVERTER
0036*          IS OUTPUTTED ON TAPE IN IBM 360/50 FORTRAN
0037*          FLOATING WORD FORMAT. MAGNITUDE OF OUTPUT
0038*          IS LESS THAN ONE.
0039*          MAXIMUM DATA INPUT RATE IS 13 KILOWORDS PER SECOND
0040*
0041*
0042 00132 000000      START NOP
0043 00133 102000      HLT
0044 00134 000000      NOP          LOAD SW'S WITH NO. RECORDS.
0045 00135 102501      LIA 1
0046 00136 003004      CMA,INA        GENERATE TWOS COMPLEMENT
0047 00137 070462      STA REC        STORE 2'S COMPL IN REC.
0048 00140 000000      ENTER NOP
0049 00141 102000      HLT
0050 00142 000000      NOP          PUSH RUN WHEN READY TO START PGM
0051 00143 060462      LDA REC
0052 00144 070463      STA CNT        INI IALIZE RECORD COUNT.
0053 00145 106700      CLC 0          TURN OFF ALL I/O.
0054 00146 002400      CLA          CLEAR A FOR ERROR COUNT
0055 00147 070451      STA NER        SET ERROR COUNTER
0056 00150 103100      CLF 0          TURN INTERRUPT OFF.
0057 00151 060436      FIRST LDA CNTLI INITIALIZE DMA1 TO READ ADC.

```

Figure B-5 ADC4 Program

0058	00152	102606	OTA 6	CONTROL WORD ONE.
0059	00153	106702	CLC 2	
0060	00154	060445	LDA ADR1	
0061	00155	102602	OTA 2	CONTROL WORD 2.
0062	00156	102702	STC 2	
0063	00157	060437	LDA NBUF	NBUF IS "WORDS PER RECORD".
0064	00160	102602	OTA 2	CONTROL WORD 3.
0065	00161	103714	STC 14B,C	START ADC.
0066	00162	103706	STC 6,C	START DMA1.
0067	00163	060436	LOOP LDA CNTRL1	INITIALIZE DMA2 TO READ ADC.
0068	00164	102607	OTA 7	CW1
0069	00165	106733	CLC 3	
0070	00166	060446	LDA ADR2	
0071	00167	102603	OTA 3	CW2
0072	00170	102703	STC 3	
0073	00171	060437	LDA NBUF	
0074	00172	102603	OTA 3	CW3
0075	00173	102206	SFC 6	SKIP FLAG CLEAR-SKIP DMA1 BUSY.
0076	00174	102006	HLT 6	ERROR HALT.
0077	00175	102306	SFS 6	SKIP FLAG SET-SKIP WHEN DMA1 RDY
0078	00176	024175	JMP *-1	WAIT FOR DMA1.
0079	00177	000000	NOP	
0080	00200	103714	STC 14B,C	
0081	00201	103707	STC 7,C	START ADC & START DMA2.
0082	00202	060444	1-1RD LDA CNTRL2	INITIALIZE DMA1 TO WRITE TAPE.
0083	00203	102606	OTA 6	
0084	00204	106702	CLC 2	
0085	00205	060440	LDA RADR1	
0086	00206	102602	OTA 2	CW2
0087	00207	102702	STC 2	
0088	00210	060442	LDA NBUFF	
0089	00211	102602	OTA 2	CW3
0090	00212	060437	LDA NBUF	LOAD COMPLEMENT OF NUMBER OF RECOR
0091	00213	070433	STA COUNT	SAVE COUNTER
0092	00214	064447	LDB ADR10	STARTING ADDRESS OF A-D BUFFER
0093	00215	074434	STB NUM	
0094	00216	044437	ADB NBUF	BACK UP FOR OUTPUT POINTER
0095	00217	060443	LDA OUT	LOAD MAC TAPE "WRITE" COMMAND
0096	00220	000040	CLE	
0097	00221	102311	SFS 11B	SKIP FLAG SET-SKIP WHEN TAPE RDY
0098	00222	024221	JMP *-1	WAIT UNTIL TAPE IS READY.
0099	00223	103611	OTA 11B,C	OUTPUT COMMAND WORD TO TAPE.
0100	00224	103706	STC 6,C	START DMA1 TO TAPE.
0101	00225	014362	JSB CONV1	START CONVERTING NUMBERS
0102	00226	102306	SFS 6	SKIP FLAG SET-SKIP IF DMA1 FIN.
0103	00227	024226	JMP *-1	WAIT UNTIL DMA1 IS FINISHED.
0104	00230	102511	LIA 11B	GET TAPE STATUS WORD.
0105	00231	010452	AND MASK1	CHECK PARITY STATE.
0106	00232	002002	SZA	SKIP IF PARITY IS OK.
0107	00233	014341	JSB ERROR	GO TO ERROR ROUTINE-BAD PARITY.
0108	00234	034463	ISZ CNT	INCREMENT RECORD COUNT.
0109	00235	024251	JMP FOUR	
0110	00236	060467	LDA JOB1	HALT ON RECORDS COMPLETE WITH
0111	00237	064451	LDB NER	LOAD NUMBER OF ERRORS
0112	00240	102006	HLT 6	(A) REGISTER = 70707*****
0113	00241	014352	JSB ENDFL	PUSH START TO GET EOF MARK*****
0114	00242	014424	JSB VOLEN	SUBROUTINE TO END VOLUME.

Figure B-5. ADC4 Program (continued)

0115	00243	014344	JSB REWND	TAPE REWIND ROUTINE.
0116	00244	106700	CLC 0	TURN OFF ALL I/O UNITS.
0117	00245	064451	LDB NER	LOAD ERROR COUNT
0118	00246	060470	LDA JOB2	HALT ON NORMAL JOB COMPLETE----
0119	00247	102006	HLT 6	LOAD A NEW REEL OF TAPE AND PUSH
0120	00250	024405	JMP DEAD	RUN TO REPEAT ENTIRE PROGRAM.
0121	00251	060436	FOUR LDA CNTL1	INITIALIZE DMA1 TO READ ADC.
0122	00252	102606	OTA 6	
0123	00253	106702	CLC 2	
0124	00254	060445	LDA ADR1	
0125	00255	102602	OTA 2	CW2
0126	00256	102702	STC 2	
0127	00257	060437	LDA NBUF	
0128	00260	102602	OTA 2	CW3
0129	00261	102207	SFC 7	SKIP IF DMA2 IS BUSY.
0130	00262	102007	HLT 7	ERROR HALT.
0131	00263	102307	SFS 7	SKIP IF BUFFER2 IS FULL.
0132	00264	024263	JMP *-1	WAIT UNTIL DMA2 FLAG IS SET.
0133	00265	103714	STC 14B,C	START ADC.
0134	00266	103706	STC 6,C	START DMA1.
0135	00267	060444	LDA CNTL2	INITIALIZE DMA2 TO WRITE TAPE.
0136	00270	102607	OTA 7	CW1
0137	00271	10671	CLC 3	
0138	00272	060441	LDA RADR2	
0139	00273	102603	OTA 3	CW2
0140	00274	102703	STC 3	
0141	00275	060442	LDA NBUFF	
0142	00276	102603	OTA 3	CW3
0143	00277	060437	LDA NBUF	LOAD COMPLEMENT OF NUMBER OF RECO
0144	00300	070433	STA COUNT	SAVE IN COUNTER
0145	00301	064450	LDB ADR20	STARTING ADDRESS OF A-D BUFFER
0146	00302	074434	STB NUM	STORE ADDRESS--INPUT POINTER
0147	00303	044437	ADB NBUF	BACK UP THE OUTPUT POINTER
0148	00304	060443	LDA OUT	LOAD MAG TAPE "WRITE" COMMAND
0149	00305	000040	CLE	
0150	00306	102311	SFS 11B	SKIP WHEN TAPE IS READY.
0151	00307	024306	JMP *-1	WAIT UNTIL TAPE IS READY.
0152	00310	103611	OTA 11B,C	START TAPE MACHINE.
0153	00311	103707	STC 7,C	START DMA2 TO TAPE.
0154	00312	014362	JSB CONV	START CONVERTING NUMBERS
0155	00313	102307	SFS 7	SKIP WHEN DMA2 IS FINISHED.
0156	00314	024313	JMP *-1	WAIT UNTIL DMA2 IS FINISHED.
0157	00315	102511	LIA 11B	GET TAPE STATUS WORD.
0158	00316	010452	AND MASK1	CHECK PARITY STATE.
0159	00317	002002	SZA	SKIP IF PARITY IS OK.
0160	00320	014341	JSB ERROR	BAD PARITY.
0161	00321	034463	ISZ CNT	INCREMENT RECORD COUNT.
0162	00322	024163	JMP LOOP	
0163	00323	060467	LDA JOB1	
0164	00324	064451	LDB NER	LOAD NUMBER OF ERRORS
0165	00325	102007	HLT 7	RECORDS COMPLETE. PUSH RUN TO
0166	00326	000000	NOP	WRITE EOF AND REWIND TAPE.
0167	00327	014352	JSB ENDFL	GO TO END-OF-FILE ROUTINE.
0168	00330	014424	JSB VOLEN	END VOLUME OR START MULTIPLE DA
0169	00331	014344	JSB REWND	GO TO REWIND ROUTINE.
0170	00332	000000	NOP	
0171	00333	106700	CLC 0	TURN OFF ALL I/O UNITS.

Figure B-5 ADC4 Program (continued)

0172	00334	060470	LDA JOB2	
0173	00335	064451	LDB NER	LOAD NUMBER OF ERRORS
0174	00336	102007	HLT 7	PUSH REN TO REPEAT ENTIRE PGM.
0175	00337	024405	FIVE JMP DEAD	
0176	00340	024163	JMP LOOP	GO READ ANOTHER RECORD.
0177	00341	000000	ERROR NOP	PARITY ERROR ROUTINE.
0178	00342	034451	ISZ NER	UPDATE THE ERROR COUNT
0179	00343	124341	JMP ERROR,I	RETURN TO MAIN PROGRAM.
0180	00344	000000	REWND NOP	REWIND ROUTINE.
0181	00345	102311	SFS 11B	SKIP WHEN TAPE IS READY.
0182	00346	024345	JMP *-1	WAIT UNTIL TAPE IS READY.
0183	00347	060453	LDA REW	GET REWIND COMMAND WORD.
0184	00350	103611	OTA 11B,C	REWIND TAPE.
0185	00351	124344	JMP REWND,I	RETURN TO MAIN PROGRAM.
0186	00352	000000	ENDFL NOP	END-OF-FILE ROUTINE.
0187	00353	102311	SFS 11B	SKIP WHEN TAPE IS READY.
0188	00354	024353	JMP *-1	
0189	00355	060435	LDA FILE	GET TAPE EOF COMMAND WORD.
0190	00356	103611	OTA 11B,C	WRITE E-O-F.
0191	00357	102311	SFS 11B	
0192	00360	024357	JMP *-1	WAIT UNTIL TAPE IS READY.
0193	00361	124352	JMP ENDFL,I	RETURN TO MAIN PROGRAM.
0194	00362	000000	CONVT NOP	SPACE FOR SUBROUTINE RETURN ADDRE
0195	00363	160434	STTT LDA NUM,I	LOAD NUMBER TO BE CONVERTED
0196	00364	010465	AND MSKK	DROP LEAST SIGNIFICANT FIGURES(TWO
0197	00365	001623	ELR,RAR	SAVE SIGN IN E REGISTURE
0198	00366	002204	CME,INA	CORRECT SIGN-SET EXPONENT SIGN
0199	00367	001325	RAR,ERA	MOVE IN BOTH SIGN BITS
0200	00370	170001	STA 1,I	STORE IN ADDRESS GIVEN IN B REGIS
0201	00371	006004	INB	UPDATE THE OUTPUT ADDRESS
0202	00372	160434	LDA NUM,I	LOAD NUMBER AGAIN
0203	00373	010466	AND MSKL	DROP ALL BUT LEAST TWO SIGNIFICANT
0204	00374	001323	RAR,RAR	ROTATE AROUND TO THE HIGH ORDER E
0205	00375	170001	STA 1,I	
0206	00376	006104	CLE,INB	UPDATE THE OUTPUT ADDRESS
0207	00377	034434	ISZ NUM	UPDATE THE INPUT ADDRESS
0208	00400	034433	ISZ COUNT	UPDATE THE COUNTER,SKIP IF END
0209	00401	024363	JMP STTT	
0210	00402	102211	SFC 11B	CHECK TO BE SURE TAPE DIDN'T GET
0211	00403	102066	HLT 66B	
0212	00404	124362	JMP CONVT,I	BRANCH BACK TO MAIN PROGRAM.
0213*				
0214*	DEAD SUBROUTINE--HEADER LABEL NOT ACCEPTABLE.			
0215*	TAPE IS REWOUND AND MAG TAPE UNIT RETURNED TO LOCAL.			
0216*				
0217	00405	014344	DEAD JSB REWND	REWIND AN STANDBY.
0218	00406	102025	HLT 25B	STOP FOR OPERATOR ACTION
0219	00407	024100	JMP 100B	RETURN TO START OF PROGRAM
0220*	THE OPERATOR IS EXPECTED TO SUPPLY A NEW REEL OF TAPE--			
0221*	A LABELED ONE BEFORE PUSHING "RUN".			
0222*				
0223*	*****			
0224*				
0225*	SUBROUTINE TO FORWARD SPACE RECORD ON MAG TAPE UNIT			
0226*				
0227	00410	000000	FWDSP NOP	RETURN ADDRESS OR SUBROUTINE EXIT
0228	00411	060422	LDA FWD	LOAD FORWARD SPACE RECORD COMMAND

Figure B-5. ADC4 Program (continued)

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0229 00412 103611      OTA 11B,C      OUTPUT COMMAND
0230 00413 102311      SFS          11B      SKIP WHEN TAPE UNIT COMPLETED
0231 00414 024413      JMP *-1      WAIT FOR COMPLETION OF OPERATION
0232 00415 102511      LIA 11B      LOAD STATUS WORD
0233 00416 010423      AND CWORD
0234 00417 002002      SZA          CHECK FOR TAPE MARK
0235 00420 003400      CCA          SET "A" TO -1 IF TAPE MARK SENSED
0236 00421 124410      JMP FWDSP,1  RETURN TO MAIN PROGRAM.
0237 00422 000003      FWD      OCT 3      TAPE COMMAND--FORWARD SPACE RECOR
0238 00423 000200      CWORD      OCT 200    MASK FOR SENSING WHEN TAPE MARK P
0239*
0240*      UPON RETURN--  "A" IS 0 IF NO TPE MARK SENSED.
0241*      "A" IS -1 IS TAPE MARK DETECTED
0242*
0243*
0244*
0245*      SUBROUTINE      ALLOWS OPTION OF ENDING VOLUME OR
0246*                      CONTINUE LOADING DATA UNDER MULTIPLE
0247*                      DATA SET IBM 360 OPTION.
0248*
0249*
0250 00424 000000      VOLEN NOP      SAVE RETURN ADDRESS AREA
0251 00425 102070      HLT 70B      HALT FOR OPERATOR RESPONSE
0252 00426 102501      LIA 1      LOAD SWITCH REGISTURE.
0253 00427 002020      SSA          CHECK OPERATORS INSTRUCTION
0254 00430 0241      JMP START      PREPARE TO LOAD DATA SET--MULTIPLE
0255 00431 014352      JSB ENDFL    PLACE SECOND FILE MARK--VOLUME END
0256 00432 124424      JMP VOLEN,1  RETURN TO MAIN PROGRAM.
0257 00433 000000      COUNT OCT 0    COUNTER IN CONVERT ROUTINE
0258 00434 000000      NUM      OCT 0    INPUT POINTER IN CONVERT ROUTINE
0259 00435 000035      FILE      OCT 35   E-O-F COMMAND WORD.
0260 00436 100014      CNTL1      OCT 100014 CONTROL WORD--NO "CLC" AT END OF
0261 00437 174150      NBUF      DEC -1944 BUFFER LENGTH.
0262 00440 000500      RADR1      OCT 500    TAPE OUTPUT BUFFER #1.
0263 00441 010200      RADR2      OCT 10200   TAPE OUTPUT BUFFER #2.
0264 00442 170314      NBUFF      DEC -3892
0265 00443 000031      OUT      OCT 31      TAPE WRITE COMMAND WORD.
0266 00444 160010      CNTL2      OCT 160010 CONTROL WORD NO. 2 FOR DMA.
0267 00445 104334      ADR1      OCT 104334
0268 00446 114034      ADR2      OCT 114034
0269 00447 004334      ADR10      OCT 4334
0270 00450 014934      ADR20      OCT 14034
0271 00451 000000      NFR      OCT 0      STORAGE FOR NUMBER OF PARITY ERRO
0272 00452 000002      MARK1      OCT 2      MASK TO CHECK PARITY ON TAPE.
0273 00453 000101      REW      OCT 101    TAPE COMMAND--REWIND AND STAND BY
0274 00454 177660      MULEN      OCT -120   HEADER LENGTH
0275 00455 100700      HDAD      OCT 100700 LOAD DATA TO CORE 7000 UP.
0276 00456 160010      HDCON      OCT 160010 DMA CONTROL--USE INIT 10
0277 00457 000023      READ      OCT 23     MAG TAPE COMMAND TO READ.
0278 00460 162726      VO      OCT 162726
0279 00461 151761      LI      OCT 151761
0280 00462 000000      REC      NOP
0281 00463 000000      CNT      NOP      ENTER NUMBER OF RECORDS HERE.
0282 00464 000035      FL      OCT 35      PUT 2'S COMPLEMENT OF RECORDS M
0283 00465 177774      MSKK      OCT 177774 TAPE E-O-F COMMAND WORD.
0284 00466 000003      MSKL      OCT 3      MASK TO DROP LEAST TWO SIGNIFICAN
0285 00467 077777      JOB1      OCT 77777   MASK TO DROP ALL BUT LEAST TWO SI
                                         LOADED INTO "A" WHEN RECORDS HAVE

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Figure B-5 ADC4 Program (continued)

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0286 00470 070707 JOB2 OCT 70707 LOADED INTO "A" --END OF JOB
0287*
0288* SET UP INITIAL CONSTANTS FOR FORTRAN TAPE FORMAT
0289 00500 ORG 500B
0290 00500 017150 DEC 7784
0291 00501 000000 OCT 0
0292 00502 017144 DEC 7760
0293 00503 000000 OCT 0
0294*
0295 10200 ORG 10200B START TO SET UP CONSTANTS.
0296 10200 017150 DEC 7784 BYTE LENGTH OF BLOCK
0297 10201 000000 OCT 0 CONTROL WORD
0298 10202 017144 DEC 7780 BYTE LENGTH OF LRECL
0299 10203 000000 OCT 0 CONTROL WORD.
0300*
0301*
0302* THIS IS NECESSARY SINCE FORTRAN WILL NOT ACCEPT
0303* CORE TYPE DUMPS. ALL RECORDS MUST BE HEADED
0304* WITH RECORD LENGTH AND BLOCK LENGTHS WHERE APPLICABLE
0305*
0306* HALT 66(OCTAL) MEANS TAPE DRIVE LOADED NUMBERS FASTER THAN
0307* THE CONVERT PROGRAM WAS ABLE TO CONVERT THE OUTPUT
0308* DATA--THIS SHOULD NEVER HAPPEN
0309*
0310* HALT 6 AND 7 ARE ERROR HALTS UNLESS "A" REGISTURE IS LOADED
0311* WITH JOB1 OR JOB2 -- OPERATOR CORRECTION IS TO SLOW
0312* DOWN THE INPUT RATE OF DATA--MAXIMUM RATE IS
0313* APPROXIMATELY 13.000 WORDS PER SECOND.
0314 END 77B
** NO ERRORS*

```

Figure B-5 ADC4 Program (continued)

```

0001          ASMB,B,L,A,C,T
0002 00100          ORG 100B          PROGRAM STARTS AT 100 OCTAL.
0003*
0004*
0005*
0006*      DATACON-CONVERT PROGRAM
0007*      DATA READ FROM ANALOG TO DIGITAL CONVERTER
0008*      IS OUTPUTTED ON TAPE IN IBM 360/50 FORTRAN
0009*      FLOATING WORD FORMAT.  MAGNITUDE OF OUTPUT
0010*      IS LESS THAN ONE.
0011*      MAXIMUM DATA INPUT RATE IS 13 KILOWORDS PER SECOND
0012*
0013*
0014 00100 000000 BEGIN NOP
0015 00101 060402      LDA FILE          LOAD COMMAND WORD FOR FILE MARK.
0016 00102 102611      OTA 11B
0017 00103 000000 START NOP
0018 00104 102600      HLT
0019 00105 000000      NOP          LOAD SW'S WITH NO. RECORDS.
0020 00106 102501      LIA 1
0021 00107 003004      CMA, INA          GENERATE TWO'S COMPLEMENT
0022 00110 070421      STA REC          STORE 2'S COMPL IN REC.
0023 00111 102001 ENTER HLT 1          PUSH RUN TO START LOADING DATA.
0024 00112 000000      NOP          PUSH RUN WHEN READY TO START PGM
0025 00113 060421      LDA REC
0026 00114 070422      STA CNT          INITIALIZE RECORD COUNT.
0027 00115 106700      CLC 0          TURN OFF ALL I/O.
0028 00116 002400      CLA          CLEAR A FOR ERROR COUNT
0029 00117 070416      STA NER          SET ERROR COUNTER
0030 00120 103100      CLF 0          TURN INTERRUPT OFF.
0031 00121 060403 FIRST LDA CNTL1      INITIALIZE DMA1 TO READ ADC
0032 00122 102606      OTA 6          CONTROL WORD ONE.
0033 00123 106702      CLC 2
0034 00124 060412      LDA ADR1
0035 00125 102602      OTA 2          CONTROL WORD 2.
0036 00126 102702      STC 2
0037 00127 060404      LDA NBUF          NBUF IS "WORDS PER RECORD".
0038 00130 102602      OTA 2          CONTROL WORD 3.
0039 00131 103714      STC 14B,C      START ADC.
0040 00132 103706      STC 6,C      START DMA1.
0041 00133 060403 LOOP LDA CNTL1      INITIALIZE DMA2 TO READ ADC.
0042 00134 102607      OTA 7          CW1
0043 00135 106703      CLC 3
0044 00136 060413      LDA ADR2
0045 00137 102603      OTA 3          CW2
0046 00140 102703      STC 3
0047 00141 060404      LDA NBUF
0048 00142 102603      OTA 3          CW3
0049 00143 102206      SFC 6          SKIP FLAG CLEAR-SKIP DMA1 BUSY.
0050 00144 102006      HLT 6          ERROR HALT.
0051 00145 102306      SFS 6          SKIP FLAG SET-SKIP WHEN DMA1 RDY
0052 00146 024145      JMP *-1        WAIT UNTIL DMA1 IS FINISHED.
0053 00147 000000      NOP
0054 00150 103714      STC 14B,C
0055 00151 103707      STC 7,C      START ADC & START DMA2.
0056 00152 061411 THIRD LDA CNTL2      INITIALIZE DMA1 TO WRITE TAPE.
0057 00153 102606      OTA 6

```

Figure B-6. ADC5 Program

00158	00154	106702	CLC 2	
00159	00155	060405	LDA RADRI	
00160	00156	102602	OTA 2	CW2
00161	00157	102702	STC 2	
00162	00160	060407	LDA NBUFF	
00163	00161	102602	OTA 2	CW3
00164	00162	060404	LDA NBUF	LOAD COMPLEMENT OF NUMBER OF RECOR
00165	00163	070400	STA COUNT	SAVE COUNTER
00166	00164	064414	LDR ADRI	STARTING ADDRESS OF A-D BUFFER
00167	00165	074411	STB NUM	
00168	00166	044434	ADR NBUF	BACK UP FOR OUTPUT POINTER
00169	00167	060410	LDA OUT	LOAD MAG TAPE "WRITE" COMMAND
00170	00170	000040	CLE	
00171	00171	102311	SFS 119	SKIP FLAG SET-SKIP WHEN TAPE RDY
00172	00172	024171	JMP *-1	WAIT UNTIL TAPE IS READY.
00173	00173	103611	OTA 119,C	OUTPUT COMMAND WORD TO TAPE.
00174	00174	103706	STC 6,C	START DMA1 TO TAPE.
00175	00175	014346	JSR CONV	START CONVERTING NUMBERS
00176	00176	102306	SFS 6	SKIP FLAG SET-SKIP IF DMA1 FIN.
00177	00177	024176	JMP *-1	WAIT UNTIL DMA1 IS FINISHED.
00178	00200	102511	LIA 119	GET TAPE STATUS WORD.
00179	00201	010417	AND MASK1	CHECK PARITY STATE.
00180	00202	002002	SZA	SKIP IF PARITY IS OK.
00181	00203	014303	JSR ERROR	GO TO ERROR ROUTINE-BAD PARITY.
00182	00204	034422	ISZ CNT	INCREMENT RECORD COUNT.
00183	00205	004426	JMP FOUR	
00184	00206	060405	LDA JOB1	HALT ON RECORDS COMPLETE WITH
00185	00207	064416	LDB NER	LOAD NUMBER OF ERRORS
00186	00210	102306	SFS 6	WAIT FOR TAPE DECK TO FINISH.
00187	00211	024210	JMP *-1	
00188	00212	106700	CLC 0	CLEAR ALL I/O
00189	00213	102366	HLT 668	HALT FOR OPERATOR ACTION.
00190	00214	014336	JSR ENDF	PUSH START TO GET EOF MARK*****
00191	00215	014371	JSR VOLEN	SUBROUTINE TO END VOLUME.
00192	00216	014326	JSR REMND	TAPE REWIND ROUTINE.
00193	00217	106700	CLC 0	TURN OFF ALL I/O UNITS.
00194	00224	064416	LDR NER	LOAD ERROR COUNT
00195	00221	064426	LDA JOB2	HALT ON NORMAL JOB COMPLETE----
00196	00222	102704	HLT 6	LOAD A NEW REEL OF TAPE AND PUSH
00197	00223	000000	NOP	RUN TO REPEAT ENTIRE PROGRAM.
00198	00224	024100	JMP BEGIN	*****
00199	00225	000000	NOP	*****
0100	00226	060403	FOUR LDA CNTL1	INITIALIZE DMA1 TO READ ADC.
0101	00227	102606	OTA 6	
0102	00230	106702	CLC 2	
0103	00231	060412	LDA ADRI	
0104	00232	102602	OTA 2	CW2
0105	00233	102702	STC 2	
0106	00234	060404	LDA NBUF	
0107	00235	102602	OTA 2	CW3
0108	00236	102207	SFC 7	SKIP IF DMA2 IS BUSY.
0109	00237	102007	HLT 7	ERROR HALT.
0110	00240	102307	SFS 7	SKIP IF BUFFER2 IS FULL.
0111	00241	024243	JMP *-1	WAIT UNTIL DMA2 FLAG IS SET.
0112	00242	103714	STC 14B,C	START ADC.
0113	00243	103706	STC 6,C	START DMA1.
0114	00244	061411	LDA CNTL2	INITIALIZE DMA2 TO WRITE TAPE.

Figure B-6. ADC5 Program (continued)

Best Available Copy

0115	00245	102607	OTA 7	CW1
0116	00246	106703	CLC 3	
0117	00247	060406	LDA RADR2	
0118	00250	102603	OTA 3	CW2
0119	00251	102703	STC 3	
0120	00252	060407	LDA NBUFF	
0121	00253	102603	OTA 3	CW3
0122	00254	060404	LDA NBUF	LOAD COMPLEMENT OF NUMBER OF RECO
0123	00255	070400	STA COUNT	SAVE IN COUNTER
0124	00256	064415	LDB ADDR20	STARTING ADDRESS OF A-D BUFFER
0125	00257	074401	STB NUM	STORE ADDRESS--INPUT POINTER
0126	00260	044404	ADR NBUF	BACK UP THE OUTPUT POINTER
0127	00261	060410	LDA OUT	LOAD MAG TAPE "WRITE" COMMAND
0128	00262	000040	CLE	
0129	00263	102311	SFS 11B	SKIP WHEN TAPE IS READY.
0130	00264	024263	JMP *-1	WAIT UNTIL TAPE IS READY.
0131	00265	103611	OTA 11B,C	START TAPE MACHINE.
0132	00266	103707	STC 7,C	START DMA2 TO TAPE.
0133	00267	014346	JSB CONVT	START CONVERTING NUMBERS
0134	00270	102307	SFS 7	SKIP WHEN DMA2 IS FINISHED.
0135	00271	024270	JMP *-1	WAIT UNTIL DMA2 IS FINISHED.
0136	00272	102511	LIA 11B	GET TAPE STATUS WORD.
0137	00273	014417	AND MASK1	CHECK PARITY STATE.
0138	00274	000002	S7A	SKIP IF PARITY IS OK.
0139	00275	014323	JSB ERROR	BAD PARITY.
0140	00276	034422	ISZ CNT	INCREMENT RECORD COUNT.
0141	00277	024133	JMP LOOP	
0142	00300	060425	LDA JOB1	LOAD NUMBER OF ERRORS
0143	00301	064416	LDB NER	WAIT FOR TAPE DECK TO FINISH.
0144	00302	102307	SFS 7	
0145	00303	024302	JMP *-1	
0146	00304	106700	CLC 0	CLEAR ALL I/O DEVICES.
0147	00305	102077	HLT 77H	RECORDS COMPLETE. PUSH REN TO
0148	00306	000000	NOP	WRITE EOF AND REWIND TAPE.
0149	00307	014336	JSB ENDFL	GO TO END-OF-FILE ROUTINE.
0150	00310	014371	JSB VOLEN	END VOLUME OR START MULTIPLE DA
0151	00311	014326	JSB REWND	GO TO REWIND ROUTINE.
0152	00312	000000	NOP	
0153	00313	106700	CLC 0	TURN OFF ALL I/O UNITS.
0154	00314	060426	LDA JOB2	
0155	00315	014416	LDB NER	LOAD NUMBER OF ERRORS
0156	00316	112007	HLT 7	PUSH REN TO REPEAT ENTIRE PGM.
0157	00317	000000	NOP	LOAD NEW TAPE*****
0158	00320	000000	NOP	*****
0159	00321	024100	FIVE JMP BEGIN	*****
0160	00322	024133	JMP LOOP	GO READ ANOTHER RECORD.
0161	00323	000000	ERROR NOP	PARITY ERROR ROUTINE.
0162	00324	034416	ISZ NER	UPDATE THE ERROR COUNT
0163	00325	124323	JMP ERROR,I	RETURN TO MAIN PROGRAM.
0164	00326	000000	REWND NOP	REWIND ROUTINE.
0165	00327	102311	SFS 11B	SKIP WHEN TAPE IS READY.
0166	00330	024327	JMP *-1	WAIT UNTIL TAPE IS READY.
0167	00331	060420	LDA REW	GET REWIND COMMAND WORD.
0168	00332	103611	OTA 11B,C	REWIND TAPE.
0169	00333	102311	SFS 11B	SKIP WHEN TAPE IS REWOUND.
0170	00334	024333	JMP *-1	
0171	00335	124326	JMP REWND,I	RETURN TO MAIN PROGRAM.

Figure B-6. ADC5 Program (continued)

0172	00336	000000	ENDFL	NOP	END-OF-FILE ROUTINE.
0173	00337	102311		SFS 11B	SKIP WHEN TAPE IS READY.
0174	00340	024337		JMP *-1	
0175	00341	060402		LDA FILE	GET TAPE EOF COMMAND WORD.
0176	00342	103611		OTA 11B,C	WRITE E-O-F.
0177	00343	102311		SFS 11B	
0178	00344	024343		JMP *-1	WAIT UNTIL TAPE IS READY.
0179	00345	124336		JMP ENDFL,I	RETURN TO MAIN PROGRAM.
0180	00346	000000	CONVT	NOP	SPACE FOR SUBROUTINE RETURN ADDRE
0181	00347	164401	STTT	LDA NUM,I	LOAD NUMBER TO BE CONVERTED
0182	00350	010423		AND MSKK	DROP LEAST SIGNIFICANT FIGURES(TWO
0183	00351	001623		ELA,RAR	SAVE SIGN IN E REGISTURE
0184	00352	002204		CME,INA	CORRECT SIGN-SET EXPONENT SIGN
0185	00353	001325		RAR,ERA	MOVE IN BOTH SIGN BITS
0186	00354	170001		STA 1,I	STORE IN ADDRESS GIVEN IN H REGIS
0187	00355	006004		INH	UPDATE THE OUTPUT ADDRESS
0188	00356	160401		LDA NUM,I	LOAD NUMBER AGAIN
0189	00357	010424		AND MSKL	DROP ALL BUT LEAST TWO SIGNIFICANT
0190	00360	001323		RAR,RAR	ROTATE AROUND TO THE HIGH ORDER E
0191	00361	170001		STA 1,I	
0192	00362	006104		CLE,INH	UPDATE THE OUTPUT ADDRESS
0193	00363	034401		ISZ NUM	UPDATE THE INPUT ADDRESS
0194	00364	034400		ISZ COUNT	UPDATE THE COUNTER,SKIP IF END
0195	00365	024347		JMP STTT	
0196	00366	102211		SFC 11B	CHECK TO BE SURE TAPE DIDN'T GET
0197	00367	102052		HLT 52H	ERROR HALT--SERIOUS---
0198	00370	124346		JMP CONVT,I	BRANCH BACK TO MAIN PROGRAM.
0199*					
0200*					
0201*	SUBROUTINE			ALLOWS OPTION OF ENDING VOLUME OR	
0202*				CONTINUE LOADING DATA UNDER MULTIPLE	
0203*				DATA SET IBM 360 OPTION.	
0204*					
0205*					
0206	00371	000000	VOLEN	NOP	SAVE RETURN ADDRESS AREA
0207	00372	102070		HLT 70B	HALT FOR OPERATOR RESPONSE
0208	00373	060001		LDA 1	LOAD SWITCH REGISTURE
0209	00374	002020		SSA	CHECK OPERATORS INSTRUCTION
0210	00375	024103		JMP START	PREPARE TO LOAD DATA SET--MULTIPLE
0211	00376	014336		JSR ENDFL	PLACE SECOND FILE MARK--VOLUME END
0212	00377	124371		JMP VOLEN,I	RETURN TO MAIN PROGRAM.
0213	00400	000000	COUNT	OCT 3	COUNTER IN CONVERT ROUTINE
0214	00401	000000	NUM	OCT 0	INPUT POINTER IN CONVERT ROUTINE
0215	00402	000035	FILE	OCT 35	E-O-F COMMAND WORD.
0216	00403	120014	CNTL1	OCT 120014	CONTROL WORD NO. 1 FOR DMA.
0217	00404	174142	NBUF	DEC -1953	SHORT BUFFER LENGTH
0218	00405	000503	RADR1	OCT 500	TAPE OUTPUT BUFFER #1.
0219	00406	010200	RADR2	OCT 10200	TAPE OUTPUT BUFFER #2.
0220	00407	170300	NBUFF	DEC -3904	LENGTH OF TAPE BUFFER.
0221	00410	000031	OUT	OCT 31	TAPE WRITE COMMAND WORD.
0222	00411	160010	CNTL2	OCT 160010	CONTROL WORD NO. 2 FOR DMA.
0223	00412	104342	ADP1	OCT 104342	A-D INPUT BUFFER #1.
0224	00413	114342	ADP2	OCT 114342	A-D INPUT BUFFER #2.
0225	00414	004342	ADP1	OCT 004342	SHORT BUFFER #1.
0226	00415	014342	ADP2	OCT 014342	SHORT BUFFER #2.
0227	00416	001000	NER	OCT 0	STORAGE FOR NUMBER OF PARITY ERRO
0228	00417	000002	MASK1	OCT 2	MASK TO CHECK PARITY ON TAPE.

Figure B-6. ADC5 Program (continued)

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0229 00420 000201 REW OCT 201 TAPE REWIND COMMAND WORD.
0230 00421 000000 REC NOP ENTER NUMBER OF RECORDS HERE.
0231 00422 000000 CNT NOP PUT 2'S COMPLEMENT OF RECORDS H
0232 00423 177774 MSKK OCT 177774 MASK TO DROP LEAST TWO SIGNIFICAN
0233 00424 000003 MSKL OCT 3 MASK TO DROP ALL BUT LEAST TWO SI
0234 00425 077777 JOB1 OCT 77777 LOADED INTO "A" WHEN RECORDS HAVE
0235 00426 070707 JOB2 OCT 70707 LOADED INTO "A" --END OF JOB
0236*
0237* SET UP INITIAL CONSTANTS FOR FORTRAN TAPE FORMAT
0238 00500 ORG 500B
0239 00501 017200 DEC 7808
0240 00501 000000 OCT 0
0241 00502 017174 DEC 7804
0242 00503 000000 OCT 0
0243*
0244 10200 ORG 10200B START TO SET UP CONSTANTS.
0245 10200 017200 DEC 7808 BLKSIZE ENTRY.
0246 10201 000000 OCT 0 CONTROL WORD
0247 10202 017174 DEC 7804 LRECL SIZE.
0248 10203 000000 OCT 0 CONTROL WORD.
0249*
0250*
0251* THIS IS NECESSARY SINCE FORTRAN WILL NOT ACCEPT
0252* CORE TYPE DUMPS. ALL RECORDS MUST BE HEADED
0253* WITH RECORD LENGTH AND BLOCK LENGTHS WHERE APPLICABLE
0254*
0255* HALT 66(OCTAL) MEANS TAPE DRIVE LOADED NUMBERS FASTER THAN
0256* THE CONVERT PROGRAM WAS ABLE TO CONVERT THE OUTPUT
0257* DATA--THIS SHOULD NEVER HAPPEN
0258*
0259* HALT 6 AND 7 ARE ERROR HALTS UNLESS "A" REGISTURE IS LOADED
0260* WITH JOB1 OR JOB2 -- OPERATOR CORRECTION IS TO SLOW
0261* DOWN THE INPUT RATE OF DATA--MAXIMUM RATE IS
0262* APPROXIMATELY 13,000 WORDS PER SECOND.
0263 END 77B
** NO ERRORS*

```

Figure B-6 ADC5 Program (continued)

```

0001
0002 07000 ASMB,B,L,T,A,C
0003 07000 102077 ORG 7000B
0004 07001 103714 START HLT 77B STOP FOR CONVENIENCE
0005 07002 102314 STC 14B,C START THE A-D CONVERTOR
0006 07003 027002 SFS 14B SKIP IF DATA READY
0007 07004 106514 JMP *-1 WAIT FOR NEXT DATA WORD
0008 07005 102501 LIB 14B LOAD THE DATA WORD
0009 07006 002020 LIA 1 PICK UP OPERATOR DATA WORD
0010 07007 027000 SSA IF 15 BIT IS UP -- STOP
0011 07010 027002 JMP START GO BACK AND STOP
0012 JMP START+2 GO BACK AND WAIT FOR NEXT DATA WOR
END
** NO ERRORS*

```

Figure B-7. DIAG1 Program

```

0001          ASMB,B,L,A,T,C
0002 00100      ORG 1008
0003 00100 102007 HLT 7      STOP FOR RECORD LENGTH
0004 00101 102501 LIA 1      LOAD RECORD LENGTH
0005 00102 003004 CMA,INA    GENERATE THE TWOS COMPLEMENT
0006 00103 070147 STA CW3    SAVE THE RECORD LENGTH
0007 00104 002400 CLA        CLEAR FOR RECORD COUNTER
0008 00105 070155 STA SAVE   SAVE THE COUNTER
0009 00106 060155 START LDA SAVE LOAD THE RECORD COUNTER
0010 00107 064155 LDB SAVE
0011 00110 102076 HLT 76B
0012 00111 002004 INA        UPDATE THE COUNTER
0013 00112 070155 STA SAVE   SAVE THE UPDATED COUNTER
0014*
0015* INITIALIZE DATA STORAGE AREA
0016*
0017 00113 060153 LDA BEGN    LOAD STARTING ADDRESS
0018 00114 064150 LDB COUNT  LOAD COUNTER
0019 00115 074151 STB TEMP    STORE COUNTER
0020 00116 064152 LDB FILL    LOAD CLEARING WORD
0021 00117 174000 STB 0,I     STORE CLEARING WORD IN ADDRESS IN
0022 00120 002004 INA        GENERATE NEXT ADDRESS
0023 00121 034151 ISZ TEMP    CHECK COUNTER
0024 00122 024117 JMP *-3     KEEP GOING
0025 00123 000000 NOP
0026 00124 060145 LDA CW1     LOAD FIRST CONTROL WORD
0027 00125 102606 OTA 6
0028 00126 106702 CLC 2      PREPARE FOR SECOND CONTROL WORD
0029 00127 060146 LDA CW2    LOAD SECOND CONTROL WORD
0030 00130 102602 OTA 2
0031 00131 102702 STC 2      PREPARE FOR THIRD CONTROL WORD
0032 00132 060147 LDA CW3    LOAD THIRD CONTROL WORD
0033 00133 102602 OTA 2
0034 00134 060154 LDA READ    TELL MAG TAPE UNIT TO READ CHARAC
0035 00135 103611 OTA 110,C   START MAG TAPE UNIT
0036 00136 103705 STC 6,C    START DMA CHANNEL 1
0037 00137 102501 STAY LIA 1   LOAD ADDRESS
0038 00140 002020 SSA        CHECK FOR RETURN
0039 00141 024106 JMP START
0040 00142 040153 ADD BEGN
0041 00143 164000 LDB 0,I
0042 00144 024137 JMP STAY   KEEP IN LOOP
0043 00145 160010 CW1 OCT 160010 CONTROL WORD #1
0044* SET CONTROL BIT ON I/O CHANNEL
0045* USE BYTE MODE OF UNPACKING DATA
0046* CLEAR CONTROL BIT IN I/O CHANNEL AT END DATA TRANSFER
0047 00146 104000 CW2 OCT 104000 CONTROL WORD #2
0048* INPUT DATA INTO LOCATION 4000 OCTAL
0049 00147 170400 CW3 OCT -7400 EACH RECORD IS 7400 OCTAL IN LENG
0050 00150 170300 COUNT OCT -7500 as large as 12700
0051 00151 003000 TEMP OCT 0
0052 00152 102077 FILL OCT 102077
0053 00153 004000 BEGN OCT 4000
0054 00154 000023 READ OCT 23 MAGNETIC TAPE COMMAND TO READ CHA
0055 00155 000000 SAVE OCT 0
0056 00200 000000 ORG 2000 START AT NEW ORIGIN
0057 00200 064115 LDA FWD    LOAD COMMAND TO FORWARD SPACE
0058 00201 103611 OTA 110,C   OUTPUT COMMAND

```

Figure B-8. DIAG2 Program

```

0059 00202 102311      SFS 11B      WAIT FOR MAG TAPE OPERATION
0060 00203 024202      JMP *-1
0061*      CHECK TO SEE IF END OF FILE
0062 00204 102511      LIA 11B
0063 00205 010216      AND MSK
0064 00206 002002      SZA
0065 00207 024212      JMP AA
0066 00210 002400      CLA          CLEAR A FOR INDICATOR
0067 00211 024213      JMP **2
0068 00212 003400      AA          SET A FOR EOF MARK
0069 00213 102000      HLT
0070 00214 024200      JMP 200B
0071 00215 000003      FWD      OCT 3      FORWARD SPACE RECORD COMMAND
0072 00216 000200      MSK      OCT 200    BIT "7" IS SET FOR EOF MARK
0073      END
** NO ERRORS*

```

Figure B-8. DIAG2 Program (continued)

```

0001          ASMB,B,L,A,C
0002*
0003***** SUM NUMBERS FROM CHANNEL 14--USE TO SET OFFSET VOLTAGE.
0004*
0005 07000          ORG 7000B
0006 07000 102077    HLT 77B
0007 07001 102314    G02  SFS 14B          WAIT FOR FLAG FROM A/D.
0008 07002 027001    JMP *-1
0009 07003 107514    LIB 14B,C
0010 07004 000040    CLE
0011 07005 005623    ELB,RBR
0012 07006 002041    SEZ,RSS
0013 07007 007004    CMB,INB
0014 07010 040001    ADA 1
0015 07011 106501    LIB 1
0016 07012 006020    SSB
0017 07013 002400    CLA
0018 07014 027001    JMP G02
0019*
0020***** SAVE LARGEST VALUE FOR PEAK DETERMINATION.
0021*
0022 07100          ORG 7100B
0023 07100 102055    HLT 55B
0024 07101 102314    G01  SFS 14B
0025 07102 027101    JMP *-1
0026 07103 107514    LIB 14B,C
0027 07104 000040    CLE
0028 07105 005623    ELB,RBR
0029 07106 077125    STB HOLD
0030 07107 007004    CMB,INB
0031 07110 047126    ADB LARGE
0032 07111 006021    SSB,RSS
0033 07112 027116    JMP G03
0034 07113 067125    LDB HOLD
0035 07114 077126    STB LARGE
0036 07115 374000    STB 0
0037 07116 106501    G03  LIB 1
0038 07117 006021    SSB,RSS
0039 07120 027101    JMP G01
0040 07121 106400    CLB
0041 07122 077126    STB LARGE
0042 07123 074000    STB 0
0043 07124 027101    JMP G01
0044 07125 000000    HOLD OCT 0
0045 07126 000000    LARGE OCT 0
0046          END
** NO ERRORS*

```

Figure B-9. DIAG3 Program

* Security Classification		
DOCUMENT CONTROL DATA - R & D		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1. ORIGINATING ACTIVITY (Corporate author) Oklahoma State University of Agriculture And Applied Science, Stillwater, Okla.		2a. REPORT SECURITY CLASSIFICATION
		2b. GROUP
3. REPORT TITLE A Center for the Description of Environmental Conditions - Weather Phenomena.		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Third Annual Report for 1 October 1969 to 1 October 1970		
5. AUTHOR(S) (First name, middle initial, last name) William L. Hughes K. Shanmugam Paul A. McCollum Emmett J. Pybus		
6. REPORT DATE December, 1970	7a. TOTAL NO. OF PAGES 158	7b. NO. OF REFS 0
8a. CONTRACT OR GRANT NO. DAAB07-68-C-0083	8b. ORIGINATOR'S REPORT NUMBER(S) WP70-I-12	
9. PROJECT NO. ITO.61102.B81A.00.00	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) TR ECOM-0083- ~~8~~ 12	
10. DISTRIBUTION STATEMENT Distribution of this document is unlimited.		
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY U. S. Army Electronics Command Fort Monmouth, New Jersey
13. ABSTRACT The Oklahoma State University Themis Weather Phenomena Project sampled severe storm sferics in the vicinity of central Oklahoma, at Black Hills, South Dakota; Greeley, Colorado and Las Cruces - White Sands, New Mexico The doctoral dissertations have been written using Themis sferic data. The first paper derived a theory of computer learning in which the teacher is considered to be both perfect and another, more general case, where the teacher is imperfect. The second paper derived a theoretical computer model for describing various lightning strokes. The third paper describes the spectral power density content of the sampled sferics. Sferic stroke rate is shown to strongly correlate with the rate of growth of a convective cell.		

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Security Classification

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14.	KEY WORDS	LINK A		LINK B		LINK C
		ROLE	WT	ROLE	WT	ROLE
	Meteorology Instrumentation Pattern Recognition Electromagnetic Radiation Sferics Severe Weather Airborne Data Gathering					

Security Classification