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PROGRESS REPORT

UNITED STATES ATOMIC ENERGY COMMISSION
CONTRACT AT(11-1)-1332

VERTEBRATE BEHAVIOR AND ECOLOGY

JULY 1974

Reporting Period
July 1, 1973-June 30, 1974

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Project Titles:

Overall Project Title:

VERTEBRATE BEHAVIOR AND ECOLOGY

Subproject Titles:

- (1) Engineering Design and Development
- (2) Statistical Procedures and Quantitative Methods For
Analysis of Ecological and Behavioral Data
- (3) Coexistence and Population Dynamics of Selected
Vertebrates

Contract Number:

AT (11-1)-1332

Period Covered in PROGRESS REPORT:

July 1973 through June 1974

TECHNICAL PROGRESS REPORT: JULY 1973 - JUNE 1974Project Summary

Progress is reported under three subprojects, (1) Engineering Design and Development, (2) Statistical Procedures and Quantitative Methods for Analysis of Ecological and Behavioral Data, and (3) Coexistence and Population Dynamics of Selected Vertebrates.

A system has been designed to use a small computer to record and partially process telemetry and environmental data at Cedar Creek Laboratory and bids are currently being evaluated for the system hardware. Ten new portable tracking receivers using a frequency synthesizer as the tuning oscillator were built and are currently being tested and used in the field. Preliminary designs for heart rate transmitters were field tested and some improvements were made in the design of conventional transmitters. Lithium batteries have been functioning in 30 transmitters for nine months in the field in a pilot study to test this power source.

A cooperative study with the University of Minnesota Hybrid Computer Laboratory solved the problem of how to analyze the radio signal coming from the tracking antennas to make it possible to record data directly onto magnetic tape. Efforts continued in our investigations on habitat selection and vegetation analysis and a computer program was developed to visually display the vegetation pattern on a cathode ray scope to allow an operator to verify or correct line segments.

Gray (Sciurus carolinensis), fox (S. niger) and red squirrels (Tamiasciurus hudsonicus) are being studied in three oak stands at Cedar Creek. Radios were placed on 48 squirrels and 146 additional squirrels have been ear-tagged. Observations to detect effects of the radio collar on behavior are being made at an artificial feeding station and on squirrels held in a large outdoor pen. Analysis of data collected on gray squirrels last year indicated home ranges varied from 9.7 to 69.0 acres. Overlap of home ranges suggests that this species may not be territorial. Circadian activity patterns revealed a very consistent relationship between time of activity and sunrise and sunset. Analysis of data is continuing for all three species and we plan to evaluate interspecific relations during the coming year.

SUBPROJECT ONE

ENGINEERING DESIGN AND DEVELOPMENT

A. Automatic Radio Tracking System

The present Cedar Creek telemetry system provides bearing and activity information on up to 52 animals every 45 seconds. These data are recorded on 16 mm microfilm via electro-optical readouts for later "reading" and decoding. Tabulated information is then punched, verified and put on magnetic tape for data processing. This has resulted in considerable time delay and expenditure of manpower. We plan to replace the film recording system and subsequent reading, punching and verifying by adapting a small, general purpose computer for this purpose.

As explained in last year's Renewal Proposal, consideration was given to contracting development and implementation of the entire processing system to an outside agency; however, because of the uniqueness of the problem and the costs involved, it was felt that the best results would be obtained by in-house development. We have proceeded along these lines with consulting and programming help from the Hybrid Computer Laboratory at the University of Minnesota.

Various analysis methods, algorithms and sampling rates were tested by recording data on magnetic tape, digitizing it and then analyzing with a computer. In summary, it was found that using an algorithm to determine the centroid of the antenna pattern with a sample every degree would provide accuracy equal to or better than the present system. Subproject Two provides a complete description of this analysis.

Bids have been received and are currently being evaluated for the system hardware. Funds have been made available by the University's Field Biology Program.

B. Receiver Design

To meet the increased demands of reliability and ease of operation a new field receiver was developed. It uses a frequency synthesizer approach where all channels are phase-locked to a single crystal. Field-effect transistors are utilized for low noise and minimum cross modulation. Mechanical filters in the intermediate frequency amplifiers provide narrow bandwidth and frequency stability without adjustment. Ten receivers have been built and are currently undergoing field testing.

Receiver characteristics are:

Frequency	Any 1 MHz range
Number of channels	1000
Channel Spacing	1KHz
Frequency Stability	$\pm 0.025\%$
Noise Figure	4 db max depending on frequency

IF Bandwidth	1.2 or 1.9 KHz depending on filter
Sensitivity	-145 dbm minimum
Power required	12 vdc, 60 ma.

C. Heart Rate Transmitter

We have designed and tested several heart rate transmitters and have also investigated a number of transmitters designed by others. Most of these transmitters can be classified as either frequency modulated (FM) or those which provide a pulse output synchronized to the heart beat. Present FM designs are adequate for most short distance telemetering needs. We have concentrated on developing a long distance telemeter that sends a pulse for each QRS complex. A circuit diagram of our most recent transmitter is shown in Figure 1-1.

The field-effect transistor provides high input impedance and some gain. The operational amplifier provides the major part of the gain and frequency bandpass shaping. Bandpass to 3 db points is from 10 Hz to 120 Hz using the components in the diagram. Transistor T_2 acts as an amplifier as long as the rate of change remains below approximately 0.2 volts/second. If it exceeds that level a pulse is sent to D. Stage D determines the pulse width and the minimum and maximum rates are set by capacitor C, providing a pulse out at a base rate even though there is no trigger pulse. The base rate is set lower than the expected lowest heart rate. Several of these transmitters have been implanted in white-tailed deer (*Odocoileus virginianus*). The range we have obtained is acceptable; however, we have experienced susceptibility to external noise and difficulty in setting the trigger at the correct level.

D. Transmitter Design

Electronic Design - Time limitations have not allowed us to do as extensive design work as we had hoped. Some tests have been done on an antenna test range to determine measurement accuracy and reliability. Our experiments to date indicate that accuracies and consistency will be well within our requirements.

Power tests were run in the lab on mockups of transmitters. The results of these tests indicate that the power into the last stage for conventional class-C operation is insufficient to properly bias the transistor we are using. This problem has been partially alleviated using a diode in the biasing network of the class-C stage. However, even with the diode the gain of the second stage is much less than required for good design. The problem could be eliminated if the power source voltage was higher; unfortunately, that would mean greater weight and volume, an unsatisfactory solution.

Power Sources - Lithium cells have been used in 30 transmitters to evaluate their performance under field conditions. The cells have not been in the field long enough (nine months or less) to make a determination of their acceptability; however, there are no complications at this time.

HEART RATE TRANSMITTER

Fig. 1-1

SUBPROJECT TWO

STATISTICAL PROCEDURES AND QUANTITATIVE METHODS FOR
ANALYSIS OF ECOLOGICAL AND BEHAVIORAL DATA

During the past year complications arose in connection with the methods of analysis which would be used to record directly the bearing and activity information at the Cedar Creek telemetry system. The statistical procedures required to interpret the signal as it comes from the receiving tower presented us with a problem which needed solving before we could proceed with the computer purchase and installation. This work was carried out during the past year in cooperation with staff of the University of Minnesota Hybrid Computer Laboratory and a solution to the problem was found as reported below. Because of the time required to complete with work, we were not able to carry out some of the projects outlined in the Renewal Proposal for 1973. As indicated in the attached Renewal Proposal, these projects will continue during the next year.

In spite of the time required to solve the above problem, we did proceed with aspects of habitat selection and vegetation analysis. We believe that the home range polygon provides a boundary which can be used to indicate the habitat available to an individual animal. Programs have been prepared which allow us to superimpose the home range polygon on a vegetation matrix obtained with the aid of a digitizer. The digitizer defines all vegetation polygons and stores this information on magnetic tape. The problem which was encountered in the merging of the various programs for this set of analyses was that as the boundaries are defined on the digitizer, some overlap occurs in adjacent vegetation polygons. Thus, an additional program was required to visually display the vegetation pattern on a cathode ray scope and allow the operator to correct various line segments. This program was prepared during the past year and we are currently in the process of testing it and incorporating it into our software system.

A. Conversion of Cedar Creek Antenna Pattern Information Into Position and Activity Data

Abstract - On September 28, 1973, a preliminary proposal was submitted by the Hybrid Computer Laboratory (HCL) for the development of a computerized data acquisition and storage system at the Cedar Creek Biological Research Station of the University of Minnesota. Excluding preliminary conversations, principal work on this project was initiated about November 1, 1973, and has continued to the present. The results and recommendations arising from this research and development effort are given herein and provide a basis for the next stage of decision making as well as bring to conclusion the preliminary analysis of this project.

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I. Introduction

The preliminary proposal prepared by the Hybrid Computer Laboratory (HCL) included recommendations regarding the basic hardware needed by the computer system desired at the Cedar Creek Biological Research Station. Much of the past three month's work has been directed toward determining in greater detail the hardware needs and specifications of the proposed system illustrated in Figure I.1 on page 2. Such a determination necessitates simultaneous consideration of the performance desired from the system, software and programming restrictions as well as hardware costs.

Given the range of suitable hardware components in the \$25,000 to \$30,000 cost category and their operating potential, considerable time has been spent in establishing the nature of the telemetry input to this computer system as well as in developing a computationally fast and reliable procedure for performing the following activities in a real time computer setting.

1. Determine the suitability of a signal for analysis.
2. Estimate the bearing of the signal when suitable for such analysis.
3. Provide quantitative measures of animal activity.
4. Suitably format and retain the information from 2 and 3 by using digital magnetic tape storage.

As part of this research, an in depth system analysis was conducted at the Cedar Creek Natural History Area. Tape recordings of the signal produced by the present receivers have been made on different animals as well as on the reference signal. These tapes have proved invaluable in substantiating many of the conclusions and recommendations of this report. Of particular importance in this regard is the conditioning of the signal prior to sampling for

FIG. I.1

PRELIMINARY PROPOSAL SKETCH OF SYSTEM

SEPTEMBER 28, 1973

computer analysis. These tape recordings strongly indicate the need for some form of automatic frequency and gain control at the receivers. Without this control, it is doubtful that any computerized system could produce reliable information except under ideal signal transmission conditions.

The computational algorithms presented in this report have been tested on carefully taped signals obtained from the Cedar Creek receivers with frequent manual gain and frequency adjustments. On such data, these algorithms perform at least as well as a human reader. Using the computational time requirements of these algorithms, various projections can be made regarding the final software-organization of the computer system. All these issues are considered in more detail later.

II. Frequency and Gain Control

The dynamic range of radio signal strengths at the Cedar Creek station is large enough so that small shifts in animal location and orientation can result in quite different signal strengths from minute to minute when all other physical parameters including range remain the same. This fact was recognized when a tape recording was made of an owl at dusk during November 1973. After tuning the owl-in at the start of the observational period and adjusting the gain to produce an acceptable signal for taping, movement and flight by the owl produced results which could not be analyzed numerically. During flight the signal was very strong and the characteristic three lobed antenna pattern was severely clipped. At other times, the signal strength dropped so low that only noise was recorded. Whether such signal strength variation would hinder a human reader

who looks for the signal nulls is open to question. However, in the digital domain no algorithm was found that could reliably detect signal nulls under reasonably general conditions. The tape of the owl indicated other experiments which should be performed.

The dynamic range of the standard whip transmitter was measured on November 14, 1973 and the results are presented in Table II.1 on page 5. At each range and polarization, the signal was tuned in and its strength assessed against the gain adjustment found suitable at the closest experimental range of 100 yards. The relative signal strength variation observed is indicative of what would be observed if a flying bird landed on the ground. It is clear that fixed frequency and gain settings are inadequate in the face of such variation and that some compensation in this area is required.

With this in mind and in an effort to obtain a tape recording of an active animal for analysis, experiments were conducted on December 13, 1973 and December 28, 1973. A loop transmitter was placed on an English Setter and the resultant signal was taped at locations .15 mile and 1.0 mile from the 100 foot tower. About 20 minutes of data were collected at each site on both occasions. The dog was free to move as it would, but it was kept in a confined region by verbal commands. On December 13, 1973, the receiver was tuned and the gain adjusted once at the start of each taping session per site. On December 28, 1973, the receiver was retuned and the gain set every couple of minutes. This change represents the only difference in experimental procedure between the two dates. The latter tape was much easier to study and was numerically analyzed. Visual comparison of strip chart recordings of the two tapes leads one to the conclusion that frequency and gain control are necessary if signals are to be analyzed by a computer. Since such control or

	Approximate line-of-sight Distance from Transmitter to 100' Antenna	Relative Signal Vertical Ant. Polarization	Strength at Recvr. Horizontal Ant. Polarization
	(Miles)		
1	.057 (100 yards)	10.0	5.0
2	.2	4.0	2.0
3	.45	3.6	2.2
4	.6	2.0	1.0
5	.95	1.5	.75
6	1.2	1.75	1.0
7	1.5	.5	No Copy

Comments: No reliably readable signals received for transmitter distances exceeding 1.5 miles. All measurements done with whip transmitter held at approximately 4 feet above the ground, along County Roads 24 and 12.

Table II.1 - Dynamic Range of Signal From Whip Transmitter

signal conditioning was not covered in the preliminary HCL proposal, it is felt that a decision needs to be made regarding who will study this problem further. This problem is solvable and would involve building or purchasing additional hardware.

III. Signal Sampling

While the proposed computer system would have to sample the voltage variation on 100 different channels, it is sufficient for the purposes of exposition to restrict attention to a single channel.

Assuming a signal of adequate strength with a properly tuned receiver, the digitally sampled voltage variation obtained by the computer should look like Figure III.1 on page 7 in the case of the reference signal. Figure III.1 represents a digitally sampled signal from one antenna revolution where the true bearing is centrally located in the cycle. The other extreme is illustrated by Figure III.2 on page 8. These two figures demonstrate that the starting point for sampling needs to be about 180° in advance of the true bearing. To accomplish this on a sustained basis, the preceding estimated bearing will have to be used to set the starting point for sampling the next signal.

Independently of whether 180 or 360 points are taken per 360° , it is recommended that the sampling be triggered by the photocell and light source at each tower. Such synchronization will prevent any rotation rate variations from influencing the shape of the signal pattern and hence the bearing estimate.

IV. Bearing Estimation

For a digitized signal pattern similar to Figure III.1 on page 7, the estimation problem is relatively simple. However, not all procedures which can be devised for the reference signal will

FIG. III. 1

FIG. III. 2

work for active patterns. The procedure given below was developed to yield robust estimates on very distorted signal patterns. It represents the result of much experimentation.

If the digitized pattern in Figure III.1 is viewed as a discrete mass distribution over a set of bearings, then the greatest mass is located about the true but unknown bearing. This intuitive observation provides a justification for the bearing estimation algorithm of this section. Let $X_1, \dots, X_{360}$ be the values obtained from sampling every degree for one revolution. Note that X_i does not necessarily correspond to the bearing i but rather to say b_i . Define a_i , ($i=46, \dots, 315$) as

$$a_i = \frac{1}{91} \sum_{k=-45}^{45} X_{i+k} \quad (\text{IV.1})$$

The set $A=(a_{46}, \dots, a_{315})$ represents the successive average mass values for each set of 91 adjacent sampled values,

$X_{i-45}, \dots, X_i, \dots, X_{i+45}$. If the maximum value of A is a_m , then b_m can be taken as an estimate of the true rounded bearing.

Mathematically this corresponds to seeking the maximum of a moving average of length 91, and using the mid-point of the set of 91 values which yields the maximum average as an estimate. Such a procedure is fast since

$$a_{i+1} = a_i + (X_{i+46} - X_{i-45})/91 \quad (\text{IV.2})$$

Figures IV.1 and IV.2 on pages 10 and 11 show typical results obtained on reference signals. The middle line of the three vertical lines is the location of the estimate. The two outside vertical lines mark the boundary of the associated 91 interval. Note that the scale of the figures is 395 points per 360° . Occasionally, a fourth vertical line appears marking the signal maximum.

FIG. IV.1

FIG. IV. 2

Unfortunately, the present procedure does not detect situations such as in Figure III.2 on page 8 and it only yields whole degree estimates. One might expect that some type of interpolative modification of this routine would yield more precise estimates. Expression (IV.3) below does this:

$$b = \frac{\sum_{k=-15}^{15} (a_{m+k}) (b_{m+k})}{\sum_{k=-15}^{15} a_{m+k}}$$

The value b can be calculated provided the maximum of the set A , a_m is such that $61 \leq m \leq 300$. Should $m < 61$ or $m > 300$, then the signal is as in Figure III.2. When this is true, the sample must be rejected and the starting point for the next sample placed at the bearing b_{180} . Then the next sample should be centered as in Figure III.1. This adaptive procedure should work well except in the unusual case of a fast moving animal within a couple hundred yards of a tower.

Some additional information about signal quality (an additional legacy) is available for this procedure. If the maximum and minimum of the set $A = (a_{46}, \dots, a_{315})$ are too close together, the 360 sampled points $x_1, \dots, x_{360}$ can be rejected as not having a recognizable signal. This can be very useful in periods of high noise relative to the signal level.

The properties of this estimator were investigated using a digitized tape recording of the reference signal. Table IV.1 on page 14 presents a standard deviation estimate and confidence interval reflecting the observed precision of the procedure on the taped signal.

In the case of active signals, the same procedure is functional

however, its performance is less precise. The results of a computational experiment using active signals taped on a dog on December 28, 1973 are presented in Table IV.1 on page 14. Both the results for the reference signal and the active signal are conservative. Appendix II on page 55 discusses the analysis of these data and the reason for the conservative nature of the standard deviation estimates. The basic problem seems to stem from analyzing a long sequence of taped images when there can be variations in taping speed and tape recorders. The end effect of such extraneous variation introduced by the experimental measurement system is an inflated variance estimate.

The results in Table IV.1 page 14 for the active signal are conditional on signal shape. For reasons yet to be explained, only signals with all three main lobes present or with only the middle lobe missing were used in calculating the values presented in this table. Figures IV.3 to IV.17 on pages 15 to 29 are representative examples of the signals studied.

V. Measures of Activity

As mentioned earlier, the bearing estimation algorithm was evaluated on a tape prepared December 28, 1973. During the analysis of this tape, it was noted that the estimation routine worked best on two types of signal shapes. These types are those with three recognizable main lobes and those with two well defined side lobes -- the middle lobe suppressed by animal movement. Other types of signal shape can introduce a significant bias (as large as 30° to 40°). Figures V.1 to V.4 on pages 30 to 33 illustrate four cases when such a bias was observed. Only by analyzing the tape as a whole was it possible to determine where the true bearing was located in each case and so establish the extent of the error. A human observer

	Standard Deviation Estimate	95% Confidence Interval	95% Confidence Interval for Unknown Bearing
Reference Signals	Λ $\sigma = .31$	$0 \leq \sigma \leq .49$	$\pm .64$
Active Signals	Λ $\sigma = 1.28$	$0 \leq \sigma \leq 1.75$	± 2.65

Table IV.1 Standard Deviation Estimates and Confidence Intervals

All stated values have units of degrees.

FIG. IV.3

Fig. IV. 6

FIG. IV.7

FIG. IV. 8

FIG. IV. 9

25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400

FIG. IV .10

FIG. IV. 11

FIG. IV. 12

FIG. IV. 13

25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400

FIG. IV. 14

FIG. IV. 15

FIG. IV. 16

FIG. V.1

FIG. V. 2

FIG. V. 3

FIG. V. 4

can study the time sequence of positions and determine if a significant bias has occurred on the indicated occasions.

A classification procedure was devised and tested on the reference signal tape and on the December 28, 1973 active signal tape. This procedure is discussed in more detail in Appendix III on page 61. Table V.1 gives the results of this procedure on these two tapes.

TABLE V.1

RESULTS OF SIGNAL SHAPE
CLASSIFICATION PROCEDURE

Tape	Total number signal pattern	Bias prone classification		# of Classif- ication errors
		yes	no	
reference	38	0	38	0
active	58	9	49	1

The only classification error involved a boundary line case classified as bias prone when the estimated bearing was in fact reasonable. Table V.1 gives an indication that bias prone signals occur only as active signals and then 13.8% of the time. A 95% confidence interval for this percentage is $6.5\% \leq p \times 100\% \leq 28\%$.

Classifying signals by shape provides one measure of activity, presumably that type which causes large shifts in the antenna polarization. A second measure of activity to be used in conjunction with the preceding is given below and is based on a classification of signal breaks. Signal breaks are what give active signals their jagged appearance and they seem to be present in all active signals as well as in some reference signals. The major difference between

active signal breaks and the reference signal breaks is one of magnitude.

Once an estimate is obtained as described in Section IV, an interval of 91 has been selected and presumably this interval contains one or more of the main signal lobes. It is a simple matter to count the breaks in this interval and classify each by its magnitude relative to the maximum signal height within the interval. Figure V.5 on page 36, illustrates how breaks are defined, counted and classified by the computer. A break is associated with a "corner" and in Figure V.5 there are "corners" at points 158, 163, 170, 172, 175, 181, 198, 214, 223, 232, 234, 238, 243, 247 and consequently 13 breaks. Each break is classified by the vertical distance between its defining "corners". The "breaks" of Figure V.1 are such that 2 are $\leq 5\%$ of the maximum signal height, 6 are $>5\%$ but $\leq 40\%$ of the maximum height and $13-6-2=5$ are $>40\%$ of the maximum height.

It is felt that this classification in conjunction with the general signal shape classification provides sufficient information for biological interpretations... Table V.2 on page 37 gives these classifications for all the preceding signal examples.

Thus, the computational procedures presented so far calculate the signal to noise level, provide a bearing estimate if possible, indicate the possibility of bias if necessary and measure animal activity. An abbreviated flow chart of the present operating program is given in Appendix I on page 54.

There is one important point which must be mentioned and that is one of validation. All these procedures if programmed in the mini-computer should be checked out on a fresh set of data when the system is operational. Such an action can provide refined variance estimates as well as point out possible improvements.

However, it is felt that present results provide a sound basis for decision making.

TABLE V.2 - Signal Classifications

Signals	Bias Prone Classifications		Classification of Breaks		
	Yes	No	<5%	>5% but <40%	>40%
Figure IV.1		x	2	0	5
Figure IV.2		x	0	0	5
Active Signals					
Figure IV.3		x	13	19	3
Figure IV.4		x	27	6	2
Figure IV.5		x	30	7	8
Figure IV.6		x	10	11	6
Figure IV.7		x	5	15	9
Figure IV.8		x	18	12	3
Figure IV.9		x	3	14	32
Figure IV.10		x	13	12	5
Figure IV.11		x	5	3	5
Figure IV.12		x	11	2	8
Figure IV.13		x	12	16	3
Figure IV.14		x	7	34	7
Figure IV.15		x	7	22	6
Figure IV.16		x	15	15	5
Figure IV.17		x	6	22	5
Figure V.1	x		33	10	3
Figure V.2	x		26	3	2
Figure V.3	x		22	10	3
Figure V.4	x		27	10	2
Figure V.5		x	2	6	5

VI. Hardware Compatibility and Design

The Need for Signal Conditioning

It has already been pointed out that the computerized data acquisition routines are rather sensitive to the signal quality. The following requirements should be met in order to process data by means of the special purpose mini-computer.

1. The peak values of filtered analog signals which represent the maximum strength portions of received radio signals, should lie in the range of 1.0 to 9.5 volts. This requirement can be achieved by the automatically controlled gain of the receivers.

2. Of the greatest importance for the quality of signals is the proper frequency tracking and adjustment for each of the pairs transmitter-receiver. The automatic frequency tracking on the side of the receiver seems to be necessary. An illustration in Figure VI.1 on page 39 shows how severe attenuation of the signal can appear within several minutes due to the shift of the carrier frequency. Both signals were taken under identical environmental conditions and the transmitter was immobile at the distance of one mile. Before the upper signal was received, the receiver's 80 KHz local oscillator had been adjusted. Gradually, the frequency adjustment became increasingly improper and resulted in the second signal with the poor signal-to-noise ratio. Obviously, the first signal could be analyzed successfully while the second signal would be rejected due to the low signal-to-noise ratio.

3. The second requirement above takes care of the low strength signals and the signal-to-noise ratio. On the other hand, very strong signals tend to be clipped off by the present hardware configuration. Clearly, any distortion of the signals would lead

FIG. VI-1

- a) RECEIVER ADJUSTED TO THE TRANSMITTER FREQUENCY
- b) TRANSMITTER FREQUENCY SHIFTED

FIG. VI-2
CLIPPED SIGNAL

to inaccurate results for measurement of the animal's bearing and activity. Figure VI.2 on page 40 shows an example of the clipped signal which is clearly unsuitable for processing. The automatic gain control required in (1) above will also solve this signal conditioning problem.

A brief discussion of possible ways to build the control circuitry for signal conditioning is presented in the following sections.

Signal Conditioning-Gain Control

There are two general ways of providing feedback for gain control. The classical proportional-integral control is the basis for both of them.

1. An integration of the output filtered signal over a long period of time can provide the control variable which would change the operating point of the tubes in the last stage of a receiver. A low pass filter with the transfer function

$$T_1 = \frac{K}{1+sT}$$

(where K is dc gain and the time constant in seconds is $50 \leq T \leq 100$) can be used as a circuit in the control feedback shown in Figure VI.3 on page 42. Here, each receiver would be equipped with such a control, accomplishing the control for any time interval whether or not the sampled data is analyzed by the computer. This type is relatively inexpensive with an estimated price per control unit in the range of \$10.00.

2. A similar structure for the controller can be obtained by using the digital computer as the feedback element (Figure VI.4 on page 43.) The control function of the computer is based on the calculation of the minimum noise level as well as average level of the signal con-

FIG. VI-3
CONTINUOUS GAIN CONTROL

FIG. VI-4
COMPUTER BASED GAIN CONTROL

tained in the three main lobes. The difference of the two gives information about the necessary changes in the receiver gain. This information would be transformed from digital to analog form and as an analog voltage applied to the last stage of a receiver to change the gain. This approach would allow gain control only for receivers which are being currently processed. The other receivers would be uncontrolled at this time, allowing possible distortion of their signals. Thus, due to this period of unattendance, it is conceivable that the gain and frequency settings for a group of channels would be inappropriate at the time of sampling. This could result in the sequential rejection of all sampled information from each group of channels. This can be avoided only with continual gain and frequency control at all channels.

Price estimation for this type of controller is based on digital-to-analog converters and hold circuits needed in the implementation. Approximately the price for 20 channels (10 animals) would be between \$1000 and \$1500. It is recommended that the control discussed in (1) above be used since it is cheaper and more continual in nature and thus better.

Signal Conditioning-Frequency Control

The computer cannot be used by any means to control the local oscillator of a receiver. Instead, the control circuitry should be built to perform this very important task. The goal is to have each receiver adjusted to the frequency of corresponding transmitters. The received radio signals are being converted through several stages in order to transform the 50MHz signal into the 80KHz output signal. 1. The experiments have shown that the band widths of all the stages of conversion are wide enough except for the last one. It

DISCRIMINATOR CHARACTERISTIC

FIG. VI-5,6
FREQUENCY CONTROLLER

means that the goal of frequency control is narrowed to that of controlling the last stage local oscillator. Any change of the output frequency of 80 KHz shows the presence of a small transmitter frequency shift. This shift tends to decrease the level of the output which influences the quality of the signal pattern. The proposed structure of the controller (Figure VI.5 on page 45) employs the reference oscillator of 80 KHz and the discriminator circuit for comparing output frequency with the reference signal. The discriminator produces dc voltage as the function of this difference which is used as the control signal for the control oscillator. (Figure VI.6 on page 45.)

The characteristics of the discriminator depend on the construction of the local oscillator and so are yet to be determined.

Interface between Receivers and the Computer

The output signals of 80 KHz are modulated by a 1 KHz sine wave which should be extracted in the first step of demodulation. The final signal pattern is obtained by the filtering of the 1 KHz signal.

The low pass filter (Figure VI.7 on page 47) is constructed in such a way as to preserve information about the activity of an animal and to provide the computer with an undistorted signal. The sampling rate determines the break frequency of the filter. It is assumed that the sampling points will correspond to each degree of the antenna rotation.

$$T_{\text{sample}} = T_{\text{rotation}} / 360$$

For the present rotational speed of 40 seconds per revolution, the sampling interval is .11 sec. The maximum speed is estimated to be 20 seconds per revolution which gives $T_{\text{sample}} = .055$ seconds.

$$T = \frac{K}{1 + \tau s} = \frac{-\frac{a}{b}}{1 + \frac{1}{b} s}$$

FIG. VI-7

FIG. VI-8

INTERFACE CIRCUIT, $\log|T| = \xi(f)$

The break frequency was chosen to be:

$$f_{\text{break}} \leq f_{\text{sample}}/2$$

$$f_{\text{break}} \leq 1/2T_{\text{sample}} = 9\text{Hz}$$

Figure VI.8 on page shows the frequency characteristic of the active filter used in experiments and proposed as the interface in the final implementation. The activity information is well defined for the frequency spectrum shown. The circuit should be build for each channel providing the computer with the acceptable signal for further processing.

VII. Computer and Peripheral Equipment

Memory Requirements

As the result of many experiments with the recorded signals on tape, not only the estimation procedure was defined but also how many memory locations are needed for storing the program and data arrays. It is estimated that the complete program requires about 4K memory. In addition, the most optimal procedure with regard to the memory requirements is based on the 200 memory locations per channel. If a minimum 8K memory is to be used, this fixes the number of channels at 20 per group. In other words, with an 8K memory and the present analysis routine, only 10 animals can be studied simultaneously.

Computer Hardware Requirements

The minimum computer configuration should consist of the digital processor with 8K memory, teletypewriter, 100 input analog to digital converter, multiplexer and magnetic tape unit. It is recommended that a 16 K memory be obtained so that a maximum of 20 animals could be studied per group and so that memory is available

for additional software yet to be developed.

The digital processor can be any general purpose mini-processor with built in hardware for multiplication and division. This hardware is very important because of the nature of the estimation algorithm which requires a certain number of divisions. It is necessary to perform these calculations with the maximum possible speed, which is about $10\mu s$ with hardware and $1ms$ with software arithmetic. The analog to digital converter should have buffer registers built in the central processor which would allow performing other calculations during the analog to digital conversion which takes about $35\mu s$ per channel. The other rather standard capabilities of the digital processor are assumed (priority interrupts, direct memory access channel, various protection capabilities, etc.).

The computational time available between two samples allows the digital processor to perform about 8000 basic instructions (load, add, subtract, multiply transfer, etc.) with rather conservative assumptions that the average time for an instruction is $7\mu s$. It means that there are 400 available instructions per channel. On the other hand, preliminary considerations show that 200-250 instructions per channel will be well enough to process data in the sampling interval in the real time case.

Organization of the Real Time Processing

This discussion is based on the assumption that the system is completely used, that is, all channels are employed in tracking the animals. It has already been concluded that it is possible to process 20 channels at the same time (10 animals). Therefore,

channels are divided into five groups with animals arbitrarily assigned to the particular group. Denote these groups as A, B, C,

D, and F. The fundamental question is that of the frequency of switching from one group to another. This is again arbitrary and depends on the user, but assuming that all animals are of equal interest to the user, we can establish the maximum frequency for processing a particular group. Figure VII.1 on page 51 shows the distribution for this case. If T = the processing time per group, then $5T$ = the waiting time between successive processings of the same group. The basic sampling time or unit per group is two antenna revolutions. (Two revolutions of an antenna are necessary per group so that all possible spatial arrangements of a group of animals can be properly sampled.) Let this sampling unit be $2T_{rot}$, where T_{rot} = the period of one antenna rotation. If $T_{rot} = 20$ seconds, then $5T = 5(2T_{rot}) = 3.33$ minutes is the time lapse for a single group of animals.

We now turn to the analysis of the real time procedure for one particular group keeping in mind that the same applies for the following groups. The basic flowchart (Appendix I) shows the structure of the algorithm. Figure VII.1 on page 51 shows how the total time is divided into basic modules within which certain calculations are made. The interval α is used for analog to digital conversion, which takes $35\mu s$ per channel. If the computer is equipped with the parallel loading of registers it is also the time of conversion for all channels. Otherwise, this process takes $700\mu s$. During the interval β , the computer performs the necessary computations on the signal which was loaded during the α interval. There are about 200 instructions per channel performed within β which gives $\beta = 20 \times 200 \times 3 \mu s = 1.2$ ms. This value is obtained for the worst case in computing. The time interval δ is used for the

FIG. VII-1
SCHEMATIC OF REAL TIME PROCESSING

activity and signal quality computation for the previously obtained maximum average window. There are about 500 instructions of this type per channel which gives a value $\Delta\delta = 500.0 \times 7\mu s = 3.5 \text{ ms}$. It is denoted here $\Delta\delta$ because these calculations can be distributed over the great number of sampling intervals due to their non real-time nature. For 20 channels, these instructions need 70 ms which can be concentrated in the last 50 samples thus allowing other user programs to be executed whenever it is possible. It is clear now that about 40% of the time is available for the user applications. In such a case, a larger memory would be necessary for storing other programs (up to 16K).

The transfer of the results to the magnetic tape is placed in the last 1 sec. of the processing interval (Figure VII.1 on page 51). The magnetic tape should contain the following information:

1. Date, placed once on the beginning of the day.
2. Weather information, placed every hour or as desired.
3. The following data should be recorded after the basic processing interval of 40 sec is finished:
 - a. Time: hour, minute, second
 - b. Group number, channel number
 - c. Bearing
 - d. Activity code, signal pattern code
 - e. Reliability code, signal to noise ratio code

VIII. Conclusions and Recommendations

The results of the foregoing feasibility study are summarized in the following list of conclusions and recommendations.

1. It is possible to build a computerized data acquisition system at Cedar Creek using a modified version of the existing signal tracking

and reception components. The principal modifications are:

- a. The implementation of automatic frequency and gain control in the receivers.
- b. The construction of a suitable analog data interface for the computerized system to ensure that all analog signal components are between 0.0 and 10.0 volts.

2. Using the signal estimation algorithm developed and discussed in the report, animal tracking reliability will be at least as good and in most cases better than that obtained using present data analysis and reduction techniques.

3. The computer and associated system hardware should be specified and ordered as soon as possible. The Hybrid Computer Laboratory (HCL) will be prepared to make specific recommendations in this area following a careful review of the contents of this report.

Moreover, HCL recommends that the project move rapidly into Phase II of the software development phase to preserve the program continuity and ensure that an operable system is "on-the-air" by the end of the year.

Appendix I - Abbreviated Flowchart

Appendix II - Analysis of Taped Signals

A tape recording of the signal at the receiver presents a repetitive sequence of signal images. Ideally, all the patterns are equidistant from each other. Thus, the bearing estimate for the n^{th} signal pattern in the sequence can be written as

$$y_n = f(n) + e_n$$

where $f(n)$ = true but unknown bearing for the n^{th} pattern and e_n is the estimation error. Ideally, $f(n) = a + bn$ implying a shift of b units from each bearing to its successor. Consequently, $y_{n+1} - y_n = b + e_{n+1} - e_n$ and the successive differences should show an oscillation about a constant. Graphs AI.1, AI.2 and AI.3 present plots of these differences. Graph AI.1 is a plot derived from the reference signal tape which shows a decided trend. Graphs AI.2 and AI.3 show less of a clear trend, however, the jagged appearance of these latter graphs testifies to the importance of discriminating between bias prone and not bias prone patterns. Bias prone signals occurred at locations 3, 6, 10, 12, 13, 14, 28, 44, 48, 51, 52, 55, and 59. Some of these signals had low signal to noise ratios.

The presence of this curvature might be explained as systematic variation introduced in the process of taping the signal and then digitizing the tape. The trend is not a result of the particular estimator used. This was determined by locating the nulls of each signal visually and observing a similar trend with time. To obtain a valid variance estimate, it becomes necessary to statistically eliminate the curvature. A standard statistical tool for eliminating trends in time series data is that of calculating successive differences of adjacent terms in the series. Using this technique, the estimate given in Table IV.1 on page 14 was

Graph AI.1 - PLOT OF DIFFERENCE OF ESTIMATES ($y_{n+1} - y_n$)
AGAINST LOCATION (n) FOR
REFERENCE TAPE

($y_{n+1} - y_n$)
Difference of
Bearing
Estimates

Graph AI.2 - PLOT OF DIFFERENCE OF ESTIMATES ($y_{n+1} - y_n$)
 AGAINST LOCATION (n) FOR
 DEC. 28, 1973 ACTIVE TAPE (.15 MILE RANGE)

($y_{n+1} - y_n$)
 Difference
 of Bearing
 Estimates

Graph AI.3 - PLOT OF DIFFERENCE OF ESTIMATES $(y_{n+1} - y_n)$
 AGAINST LOCATION (n) FOR
 DEC. 28, 1973 ACTIVE TAPE (1.0 MILE RANGE)

$(y_{n+1} - y_n)$
 Difference
 of Bearing
 Estimates

calculated. Such a calculation does not eliminate all the extraneous variation in this case and so the variance estimate must be considered inflated or conservative. A much more refined estimate could be computed after the system is operational.

The analysis of the active data presents different difficulties due to the spatial movement of the dog during the experiment. Ignoring those points calculated on bias prone signals and computing the times series $y_n - 400n = f(n) - 400n + e_n$ on the remaining points gives a time series of adjusted locations. Eliminating the trends present by differencing and treating the .15 mile and 1.0 mile ranges separately, one obtains variance estimates of 2.9 for the 1.0 mile range and 2.1 for the .15 mile range on the December 28, 1973 tape. Both of these calculations must be considered as a sum of two components - one due to the estimator and one due to the animal. For the ranges involved and size of region explored by the dog at each range, it is possible by geometric considerations to eliminate the component of variability due to animal movement. Mathematically, it is true that:

$$\frac{\Delta x}{y} = \tan \Delta\theta \approx \Delta\theta$$

for small $\Delta\theta$. Statistically, this means

$$\frac{\epsilon(\Delta x)^2}{y^2} \approx \epsilon(\Delta\theta)^2$$

At .15 miles, the standard deviation of the side to side translations of the dog was at least 5 yards and at 1.0 miles it was at least 15 yards. This allows the preceding variances to be adjusted.

$$\text{Range} = .15 \text{ mile} \quad 2.1 - 1.2 = .9$$

$$\text{Range} = 1.0 \text{ mile} \quad 2.9 - .25 = 2.65$$

These estimates assume small contributions by the animal and so are conservative estimates of the estimator's variance on active signals.

Pooling the estimates using the degrees of freedom gives a conservative estimate of 1.64 or a conservative standard deviation estimate of 1.28° , which was presented in Table IV.1. This experiment should be conducted a second time to obtain a refined variance estimate from the computerized system.

Appendix III - Signal Shape Determination

As explained earlier, it is necessary to classify a signal pattern as being prone to bias or not prone. This reduces to determining the signal's shape. A fast way of doing this is to take the 91 points which have the maximum moving average for the signal and study them. The specific procedure for this investigation involves two steps. The first step is to divide the 91 points into six regions of 15 points each -- discarding the middle point. The second step is to find the maximum signal value in each region and code it as 0, 1 or 2 dependent on its height relative to the maximum of the signal over all six regions. Specifically, if x_i is the maximum value in region i , and x is the overall maximum of $x_1, x_2, \dots, x_6$ put

$$F(x_i) = \begin{cases} 0 & \text{if } x_i \leq .25x \\ 1 & \text{if } .25x < x_i \leq .75x \\ 2 & \text{otherwise} \end{cases}$$

This yields a six digit code for each signal. Figure AIII.1 on page 62 shows how the six regions are defined and gives their corresponding values of x_i as well as x . The code for this digitized signal would be 212221. The code for a perfect reference signal is 222222. Bias prone signals generate codes which have two or more adjacent zeros that are immediately preceded or followed by a 2 cyclically. Examples are: 200100, 002111, 001112, 211100, etc. Signals lacking this characteristic pattern are not bias prone.

FIG. A III. 1

(This report was prepared by R. Sanford, Department of Ecology and Behavioral Biology and M. Buric and R. Houska, Hybrid Computer Laboratory).

SUBPROJECT THREE

COEXISTENCE AND POPULATION DYNAMICS OF SELECTED VERTEBRATES

The rationale for proposing a study of interspecific relations among tree squirrels on the Cedar Creek Natural History Area was based on the existence of the automatic radio tracking system, the specialized computer software system, and on the significant amount of baseline information from our previous studies on the gray squirrel.

For example, during the period of July 1971 to September 1972, seasonal activity patterns of 15 radio-marked gray squirrels were recorded. Data from 31 two-week periods during this time are currently being evaluated to assess effects of environmental conditions of each season on the home ranges and movements of the squirrels.

In addition, a more intensive investigation of habitat use, activity patterns, and home ranges of gray squirrels was initiated and completed in spring 1973 to determine the feasibility of capturing and monitoring many squirrels in an area and to acquire more detailed knowledge of breeding behavior.

A woodlot located in the high radio accuracy area was chosen as the study site. Vegetative cover was predominantly mixed oaks (Quercus spp.) on the upland and white birch (Betula papyrifera), yellow birch (Bilutea), trembling aspen (Populus tremuloides), and ash (Fraxinus spp.) on the lowlands. The site was somewhat isolated from other oak upland habitat by being surrounded by open fields, swamp, or the buildings and grounds of the laboratory.

Within the study area all old and new leaf nests, as well as possible and actual den trees, were located; tree and shrub species composition and density were determined; and photo points were established for recording phenology. Thirty-six live traps were used in a grid pattern to capture animals for marking and for mapping home ranges. Variations in activity patterns and trapping success as influenced by such environmental parameters as precipitation, snow cover, barometric pressure, air temperature, wind velocity, and wind direction are being determined.

Trapping periods began in the last week of each of the four months and were suspended after three or four days when all marked squirrels had been captured. This point was determined when only ear-tagged, toe-clipped squirrels were recaptured, and no unmarked animals were caught. Not all squirrels were radio-tagged. A total of 27 gray squirrels were fitted with radio transmitters. Trapping operations were undertaken every month as the battery life of the radio was only 40 days, and an accurate description of the physical attributes of all subjects was necessary. Reproductive conditions, body weights, pelage conditions, and body measurements were obtained each month. All animals were refitted with a new battery and released within a few hours after capture.

Nests and movements of all pregnant females were located and monitored closely. A closed-circuit television camera was positioned on two den trees to monitor litter movements. Whenever a litter movement occurred, the new nesting site was located. Destruction of litters was detected immediately with the telemetry system by monitoring the activity and location of the female. Such females showed significant increases in activity and began to use many different nest sites. Recapture and examination of abdominal hair growth on these females verified the findings. All young of the females on the study area were also captured and ear-tagged, but they were not radio-marked.

Mortality was closely monitored, and during the four month duration of the investigation, only three squirrels were preyed upon; two by owls and one by a hawk. No other mortality occurred.

Computer analyses of the data from ten squirrels have been completed and have yielded very interesting results. For example, home ranges were substantially larger than expected (Table 3-1). Moreover, ranges have been found to overlap suggesting that this species may not be territorial.

Table 3-1. Home range in acres of male and female gray squirrels during the months of March through June 1973. All females were lactating and were determined to have young.

Squirrel No.	Sex	Home Range Size (acres)	
		March-April	May-June
1461	Male	31.3	63.3
1466	Male	17.5	17.1
1458	Male	58.1	69.0
1476	Male	20.7	23.9
1455	Female	10.9	28.4
1452	Female	9.7	16.2
1468	Female	13.5	29.5

Circadian activity has also been analyzed and representative examples of daily activity patterns and cumulative percent of activity by two-month periods are presented in Figures 3-1 and 3-2. These figures point out quite clearly the unique circadian activity records which the automatic radio tracking system provides. Onset, duration, and cessation of activity are quite discernible, especially in relation to sunrise and sunset. Such output will enable us to make comparisons of circadian activity patterns of several species within the same area.

Figure 3-1. Daily activity plot of a male gray squirrel during March through June 1973 as a function of time of day. Solid lines indicate that animal is active; broken represent resting; blank indicates unknown. Solid vertical lines denote sunrise and sunset.

Figure 3-2. Cumulative percent of activity of a male gray squirrel as a function of time. Top curve represents March-April; the bottom curve represents May-June.

With this extensive field and lab experience and baseline information on the gray squirrel as a foundation, three investigations were initiated in March 1974 to study coexistence and population dynamics of three species of tree squirrels. A primary study site and two secondary ones were chosen in the high radio accuracy area. All three areas were approximately equal in size and included 10-15 acres of optimal mixed oak (Quercus spp.) habitat.

Twenty-seven gray and eight fox squirrels were captured and marked with radio collars and ear-tags in the primary study area. The animals were monitored for a period of 70 days (battery life of the transmitter) at which time they were recaptured and the transmitter removed. In addition, all nest and den sites, litter movements, and physical characteristics of the squirrels were recorded. The methodology described above in the summary of the spring 1973 investigation was closely duplicated in these studies.

Two problems should be elucidated at this point. We were unsuccessful in capturing red squirrels in those areas which had high populations in 1973. In all, only seven were captured in four months of trapping the three areas. At present we do not know why these populations are low.

Secondly, a relatively high transmitter failure drastically reduced the number of individuals for which we acquired continuous data for the two months. The problem has been partially solved and is being investigated for future studies. Essentially, in order to acquire longer transmission periods, a slightly larger and thus heavier battery was utilized in the radio collars. Therefore, to reduce the total package weight to an optimal weight of 18.0 - 21.0 grs., a different encapsulating procedure was employed. It was discovered, however, that the animals in some instances were able to scratch through the encapsulating material and damage the electronic components.

A significant objective of this first phase of the field experiments was to provide an adequate test situation for the new receiver described in Subproject One. The receivers were utilized throughout the investigation, and, thus, a realistic evaluation of performance was possible. Not only were new design changes subjected to severe field conditions before final adoption, but several minor improvements also resulted from the field tests.

One of the secondary sites was trapped intensively during the spring and early summer 1974 to acquire population estimates of the three species, data on age and sex composition, and on immigration and emigration. To date, a total of 89 gray squirrels and seven red squirrels have been examined and ear-tagged. In addition, five adult lactating females and eight juveniles have been instrumented with radios to obtain data on litter movement and on dispersal of the young.

The third study area is being examined only by means of ear-tagging; no radios have been fitted. At present, a total of six fox and 44 gray squirrels have been ear-tagged and examined. Not only has this woodlot provided information concerning species composition, immigration, and emigration, but more important, it has supplied additional information on

weights, pelage conditions, and general health of non-instrumented squirrels during the time period when squirrels in other areas were carrying radios.

The fourth and final phase of field investigation in Subproject Three has sought to detect and quantify any effects on general behavior which might be attributed to the radio transmitters. An artificial feeding station 1.5 miles from the study areas was established and monitored by direct observation and time lapse photography. Twenty-one gray and four fox squirrels were fitted with radio collars. Observations and retrapping have not presented any evidence that jumping, running, climbing or feeding behaviors were different than those of animals marked only with ear-tags. Animals were not observed spending an inordinate amount of time manipulating the collar. Instrumented females with young at the feeder did not differ from the controls in feeding relations with the young. No differentiation in aggressive or threat postures was observed between instrumented and control squirrels.

The second approach to this problem required observation and measurement of juvenile gray squirrels held captive in a large outdoor pen. This procedure has been quite important for two reasons. Initially we believed this to be an excellent way to measure neck size increases to determine the time to change radio collars on the free-ranging juveniles. More recently, however, we have utilized the pen to test the longevity of the small loop transmitters. We have experienced some difficulty achieving the expected 30-day transmission life when these small units were placed on juvenile grays and adult red squirrels even though lab and field tests of the transmitters alone yielded acceptable results. The pen study with radio-marked juveniles was initiated to assess what was occurring in the natural state on a free-ranging squirrel. No conclusive results have been reached to date.

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PAPERS PRESENTED DURING REPORT PERIOD

- September 1973. XI International Congress of Game Biologists, Stockholm, Sweden. J. R. Tester and D. B. Siniff. "Relevance of home range concepts to game biology".
- March 1974. Minnesota Chapter American Fisheries Society, Minneapolis, Minnesota. J. D. Winter. "An aquatic radio tracking system and the movement and behavior of largemouth bass and rainbow trout".
- April 1974. North American Hawk Migration Conference, Syracuse, New York. P. Redig, M. Fuller, and D. Evans. "Techniques for determining some biomedical parameters of migrating raptors".
- May 1974. Minnesota Academy of Science 42nd Annual Meeting, St. Paul, Minnesota. J. D. Winter. "Development of an aquatic radio tracking system and some movement patterns of largemouth bass and rainbow trout".
- June 1974. American Society of Mammalogists, Binghamton, New York. S. C. Pierson and J. R. Tester. "Significance of the olfactory bulbs on temporal and spatial behavior of gray squirrels (Sciurus carolinensis)".

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EFFORT REPORT

Percent Effort
Devoted to Project

Dr. J. R. Tester, Principal Investigator	
October 15, 1973 through July 15, 1974	25%
July 16, 1974 through October 14, 1974	25%
Dr. D. B. Siniff, Principal Investigator	
October 15, 1973 through July 15, 1974	20%
July 16, 1974 through October 14, 1974	20%
Dr. D. F. McKinney	
October 15, 1973 through July 15, 1974	0%
July 16, 1974 through October 14, 1974	20%
Mr. V. B. Kuechle	
October 15, 1973 through July 15, 1974	17%
July 16, 1974 through October 14, 1974	17%
Dr. S. C. Pierson	
March 15, 1974 through July 15, 1974	100%
July 16, 1974 through October 14, 1974	100%