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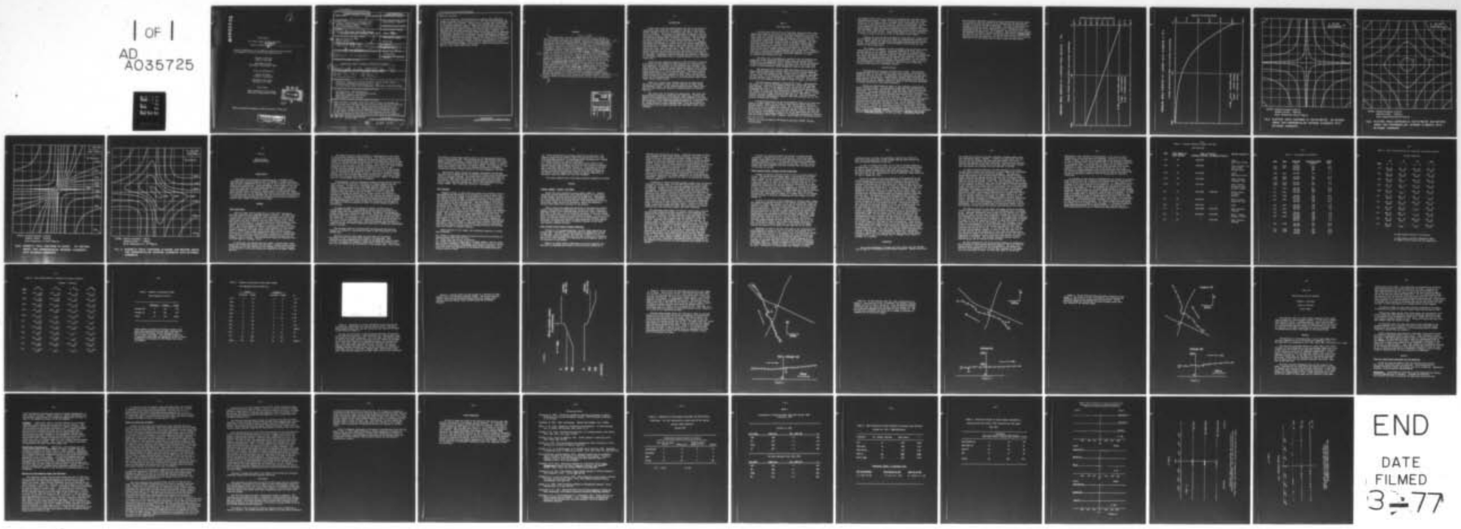

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A Radar Investigation of the Effects of Extremely Low Frequency Electromagnetic Fields on Free Flying Migrant Birds

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High resolution, low power radars were used to detect the movement of migrant birds over the Wisconsin Test Facility during the fall of 1974 and 1975 and the spring of 1975. These observations indicated that the extremely low frequency (ELF) emissions of the Wisconsin Test Facility in its present configuration with MSK modulation is unlikely to have a major impact on the orientation of birds migrating over the site. Preliminary analysis of data indicates that some birds may be sensitive

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to the ELF emissions. Data obtained with a search radar indicated a change in average flight direction of 5° to 25° when the North-South leg of the antenna is activated. Studies with a tracking radar revealed that an increased tendency of birds to depart from straight and level flight was associated with ELF exposure. Both the tracking radar and the Ornithar indicate that change in migratory direction due to activation of the Wisconsin Test Facility antenna is likely to be small. However, the demonstration of any effect of ELF on free flying migrant birds represents a significant addition to our knowledge of the orientational systems used by birds for guiding their migrations. Present data indicate no effect of distance within the operational range of the radars (1 km in the present experiment). Duration of exposure to ELF was not included as a variable in the experimental design. Without further information on at least duration and distance effects, we believe it unwise to extrapolate present data to a full scale antenna grid system.

ABSTRACT

High resolution, low power radars (detected) were used to detect the movements of migrant birds over the Wisconsin Test Facility (WTF) during the fall of 1974 and 1975 and ~~the~~ spring ~~of~~ 1975. ~~These~~ observations indicated that ~~the extremely low frequency (ELF)~~ emissions of the ~~Wisconsin Test~~ F ~~Facility~~ in its present configuration with MSK modulation is unlikely to have ~~a~~ major impact on the orientation of birds migrating over the site. Preliminary analysis ~~of data~~ indicates, however, that some birds may be sensitive to ~~the~~ ELF emissions. ~~Data obtained with a~~ search radar data indicated a change in average flight direction of 5° to 25° deg when the ~~North-South~~ N-S leg of the antenna is activated. ~~Studies with a~~ tracking radar studies revealed that an increased tendency of birds to depart from straight and level flight was associated with ELF exposure. While ~~B~~oth ~~the~~ tracking radar and ~~the~~ Ornithar indicate that change in migratory direction due to activation of the ~~Wisconsin Test Facility~~ antenna is likely to be small, ~~However, the~~ demonstration of any effect of ELF on free flying migrant birds represents a significant addition to ~~our~~ knowledge of the orientation~~al~~ systems used by birds ~~for~~ to guid~~ing their~~ migrations. Present data indicate no effect of distance within the operational range of the radars (1 km in the present experiment). Duration of exposure to ELF was not included as a variable in the experimental design. Without further information on at least duration and distance effects, ~~we be-~~ the writers believe it unwise to extrapolate present data to a full scale antenna grid system.

INTRODUCTION

Recent work involving homing pigeons and wild birds tested in orientation cages indicates that magnetic cues may be utilized by several species of birds for orientation (see Keeton, 1974; Emlen, 1975 for reviews). The history of experiments in magnetic cues for orientation is one of repeated negative results followed by significant positive findings under the proper conditions. The phenomenon is still poorly understood and the sensory mechanism unknown. Of particular relevance to our studies is that the effect of changing the magnetic environment is evident under only certain experimental conditions and, for homing pigeons, only under certain conditions at the release site. However, when the proper conditions are found, the results are clear (see reviews above). Thus, for a preliminary set of observations such as those which we have undertaken for the past 24 months, negative results should probably not be given much weight in the analysis. Significant positive findings may indicate a phenomenon of considerable importance which is normally masked by other orientational cues.

During the fall migration seasons of 1974 and 1975 we operated a low power but high resolution radar designed for observation of bird migration, the Ornithar, at the Wisconsin Test Facility, Clam Lake, Wisconsin. During the spring migration season of 1975 we were joined by Dr. Ronald Larkin and Ms. Pamela Sutherland of the Rockefeller University, N.Y., with a tracking radar. The radars radiate comparatively little power, operate at short range, and provide detailed information on the movements of birds at very low altitudes (100 m for the tracking radar and 10 m for the Ornithar) which larger radars cannot usually detect.

There is at present much evidence that at the power levels emitted by these radars, birds are not sensitive to radar energy (see Eastwood, 1967). In our opinion these low power radars represent the least disruptive method of observing birds in nocturnal migration.

This report will be divided into three parts: The first part gives general information concerning the study site, electric and magnetic fields generated by the antenna, and a summary of the bird species most probably migrating during the period of our observations. The second part covers the investigations made by Dr. Larkin and Ms. Sutherland with a small tracking radar. Part three covers our observations with the mobile Ornithar and "Starlight" night vision telescope.

Part I

The Study Site

The Wisconsin Test Facility at Clam Lake, Wisconsin where these studies were made is located in north central Wisconsin in an area of small lakes and coniferous forest. The land is flat and except for the lakes there are no major topographical features of the terrain that would appear significant for orientation of avian migrants. The area contains no cities large enough to cause a sky glow visible near the Wisconsin Test Facility. Recent studies by Griffin (1974) suggest that sound might be an important cue in orientation. We know of no major sources of such sounds other than the shore of Lake Superior 50 km to the north. Sound recordings made by R. Larkin and P. Sutherland with a calibrated microphone located approximately 75 m southwest of the antenna intersection showed no detectable difference in sound as antennas were turned on or off.

The study area is situated in a region of iron ore deposits and especially to the north east of Clam Lake, there are several major anomalies in the geomagnetic field. Suthern (1973) reports the presence of some anomalies within 30 miles of the study area, but we have been unable to locate detailed, recent geomagnetic maps of the study area.

The Wisconsin Test Facility (WTF) ELF Communications System has been previously described in detail (Naval Electronic Systems Command, 1972). The system consists of two crossed antenna segments, each about 14 miles long. The north/south leg is oriented approximately 20°-200° and the east/west leg is oriented approximately 300°-120°. The relative location of the antennas and the radar is shown in Figure 3 of Part II.

The WTF antennas transmit a modulated ELF signal. The modulated ELF signal is a form of FM (frequency modulation) called MSK (minimum shift keying). This type of modulation will be used by the Navy's ELF Communications Project. The signal utilized shifts between frequencies of 72-80Hz, the space and mark frequencies, respectively. When energized, the current in an antenna could be varied from 75 to 300 amperes. A load resistor was used to shunt an antenna when shut off. The two antennas could be operated independently; however, when both antennas were on, the antenna currents were in phase.

A detailed description of the electromagnetic fiels in the earth produced by an ELF antenna can be found in other sources (Naval Electronic Systems Command, 1972; Valentino, 1971). The electromagnetic fields produced in the air are somewhat more difficult to calculate and measure. For locations near the antenna (i.e., less than 1000 m), however, the magnitude of the electric and magnetic fields in air may be approximated by calculating the fields at the earth's surface at an equivalent perpendicular distance from the antenna (Sunde 1968). Figures 1 and 2* show the calculated electric

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*Figures 1-6 were provided by IIT Research Institute (IITRI), Chicago, Illinois 60616 and magnetic field levels as a function of perpendicular distance from a single antenna element. These calculated values do not take into account deviations of the antenna from a straight line or perturbations in the fields due to the ends of the antenna or antenna intersections. The calculated magnetic flux densities at distances of 30 m and 300 m from a single antenna element carrying 300 amperes of current would be .02 gauss and .002 gauss, respectively; the corresponding electric field intensities would be .14 V/m and .07 V/m. These values should be reliable estimates to within at least a factor of 10 (A. R. Valentino, pers. comm.).

Figures 3-6 show electric and magnetic field contours, respectively, for horizontal planes 30 m and 300 m above two perpendicular antenna elements. These results are theoretical and assume in-phase antenna currents, as well as neglecting straight line deviations of the antenna and the effects of the antenna ends.

The examples in Figures 1-6 were calculated using an effective earth conductivity of 5×10^{-4} mho/m, an antenna frequency of 76 Hz, and an antenna current of 300 amperes. These were the typical operating values for the WTF during the observation period. However, some of the observations were made with antenna currents of 150 amperes and, therefore, the field levels for this operating mode should also be determined. As the electric and magnetic field levels are directly proportional to current, the field levels in Figures 1-6 may be divided by a factor of two to yield the correct field levels of a 150-ampere antenna.

Species Counts

Identification of migrants is difficult on radar. The principal parameters used are the airspeed and radar cross section of the bird (see Eastwood, 1967) of the echo. To supplement this information we made daily counts of all birds seen on a predetermined transect which included the major habitats of the region. Other sources of information were counts of birds made at several wildlife refuges by staff of the Wisconsin Department of Natural Resources at Park Falls, Wisconsin.

During our observations we appear to have sampled a broad distribution of avian species. Airspeeds and average echo size detected by the radars indicated a full range of both large and small targets and slow and fast birds. Our ground observations, along with those from the various wildlife refuges in the northern Michigan and Wisconsin area, indicate that we observed both passerine birds and waterfowl. In the fall of 1974, migration was about two weeks early, and thus during our observation period, 13-26 October, we were seeing only the end of the Canada goose migration. Passerines had already gone through the area. In the spring of 1975, migration was delayed about two weeks by late winter conditions and heavy rains in April. During our observation period, 21 April-3 May, passerines had started to migrate, and of 20 migrant species seen on the ground, movements of Flickers (Colaptes auratus), Woodpeckers, Swallows (fam. Hirundinidae) Robins (Turdus migratorius), Red-winged Blackbirds (Agelainus phoeniceus), Grackles (Quiscalus quiscula), and Sparrows (fam. Fringillidae) were the most prominent. Waterfowl movements during this period were very light. In the fall of 1975, the period of our observations (29 September-17 October) coincided with heavy migrations. The peak of goose migration through the area was around 10-15 October, with smaller movements occurring during all of our observation period. Passerines were also migrating during the period. Of 23 migrant species seen on the ground, the movements of Robins, Thrushes, Warblers, Pine Siskins (*Spinus pinus*), and Sparrows were most evident. The ground observations of heavy bird migration during this period in the fall of 1975 correlate well with the high density of bird echoes seen on radar during the same period.

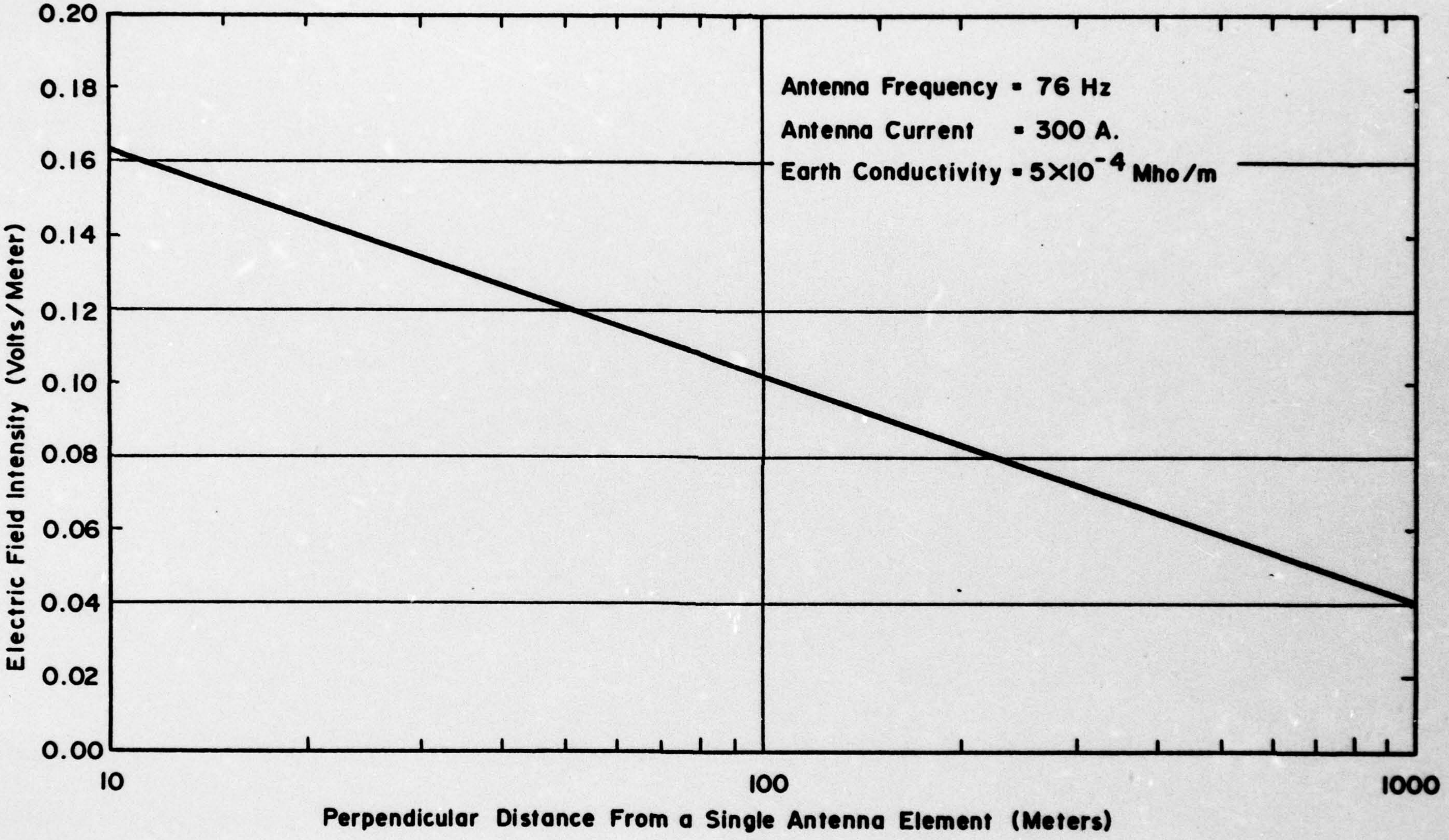


Fig. 1 ELECTRIC FIELD INTENSITY VS. DISTANCE FROM ANTENNA

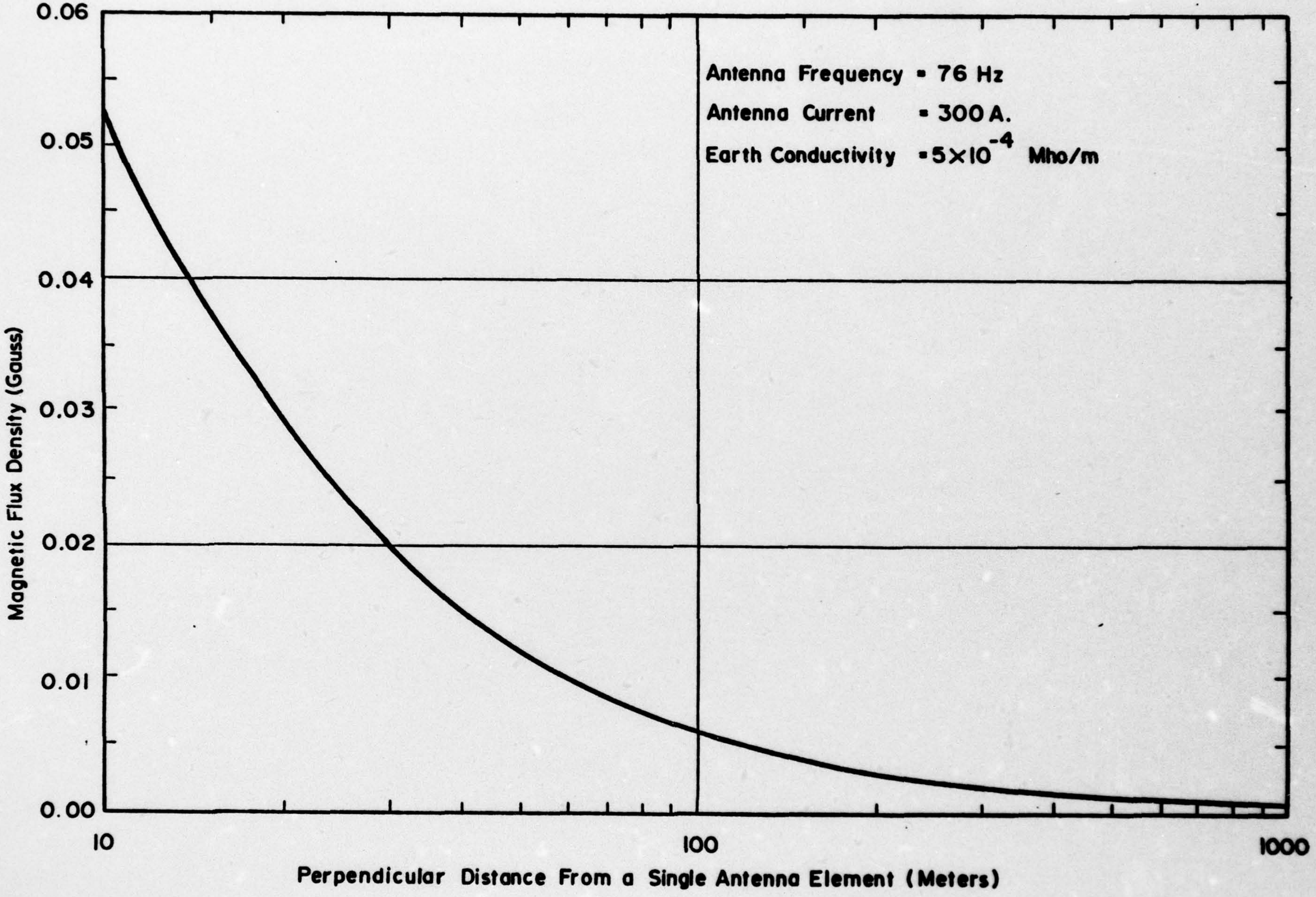
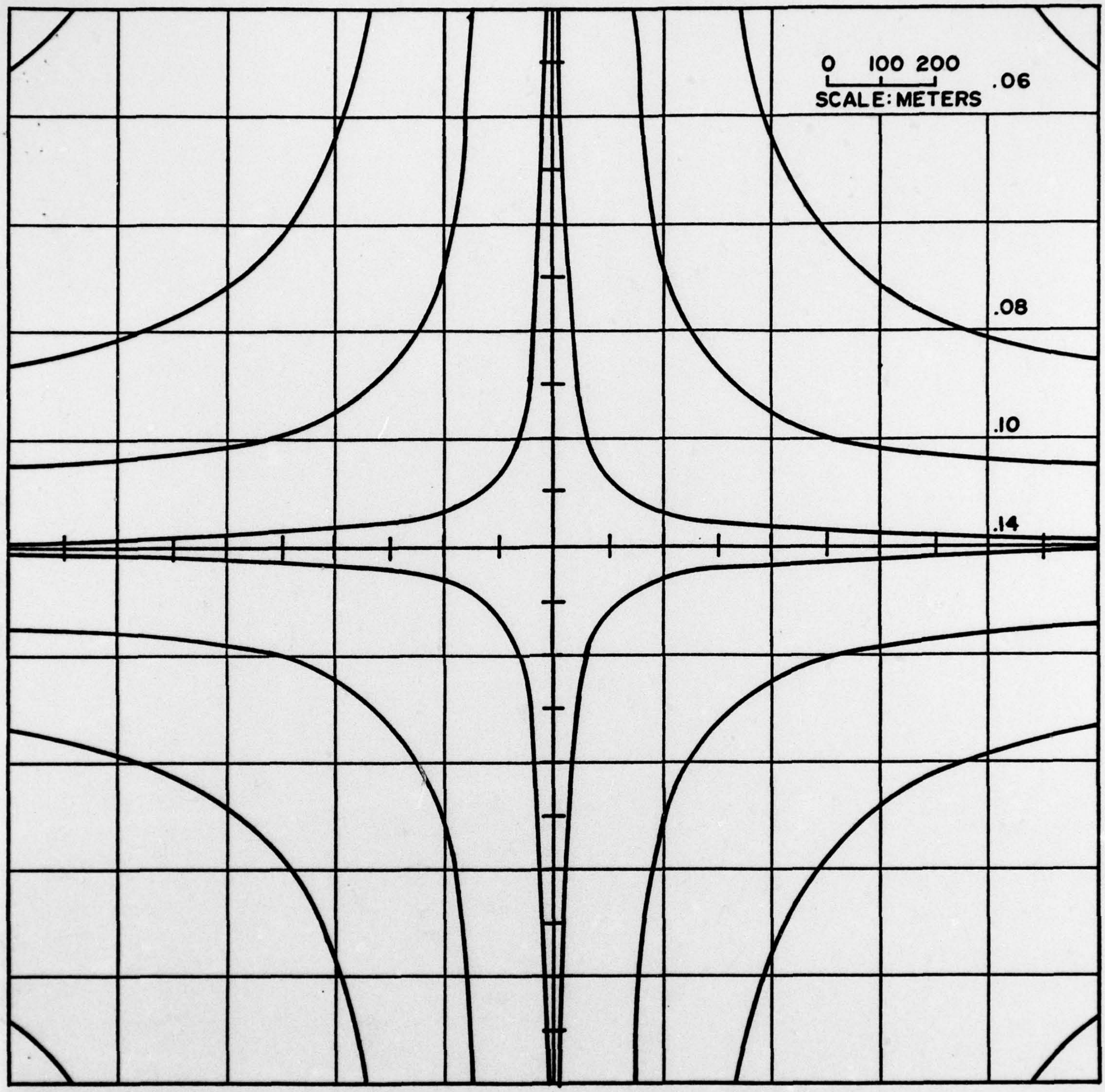
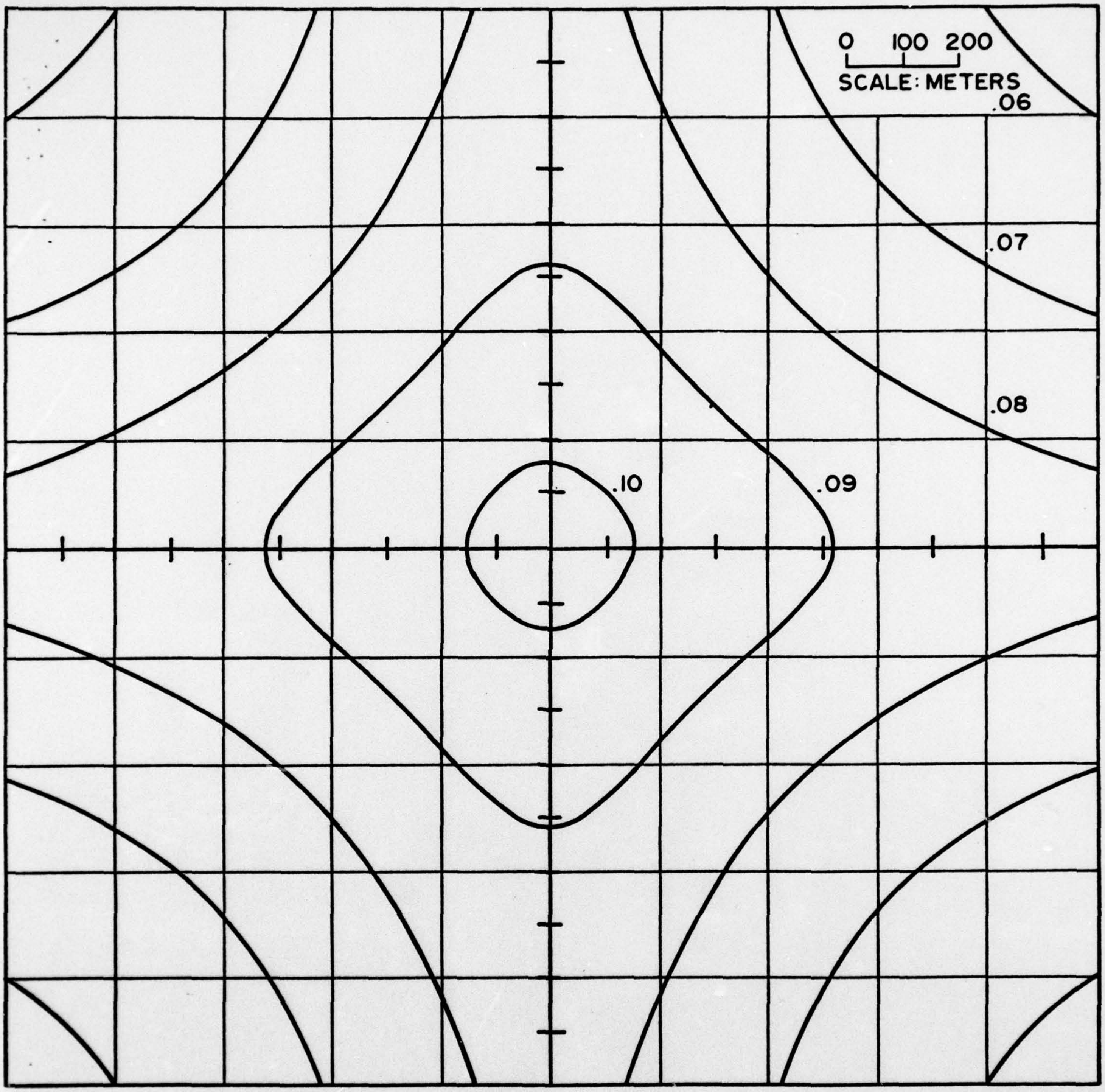


Fig. 2 MAGNETIC FLUX DENSITY VS. DISTANCE FROM ANTENNA



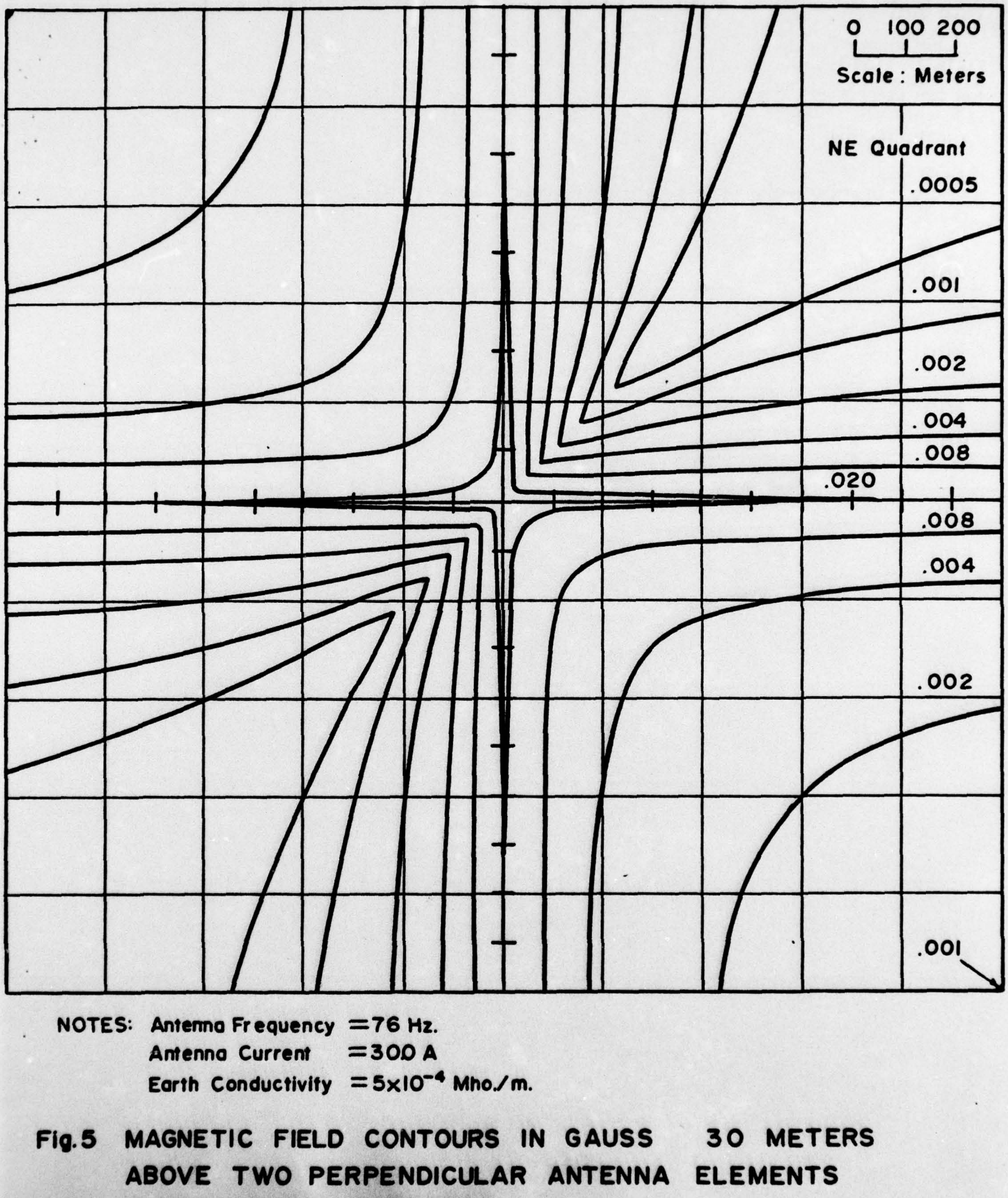
NOTES: Antenna Frequency = 76 Hz.
Antenna Current = 300 A.
Earth Conductivity = 5×10^{-4} Mho/m.

Fig. 3 ELECTRIC FIELD CONTOURS IN VOLTS/METER 30 METERS ABOVE TWO PERPENDICULAR ANTENNA ELEMENTS WITH IN-PHASE CURRENTS



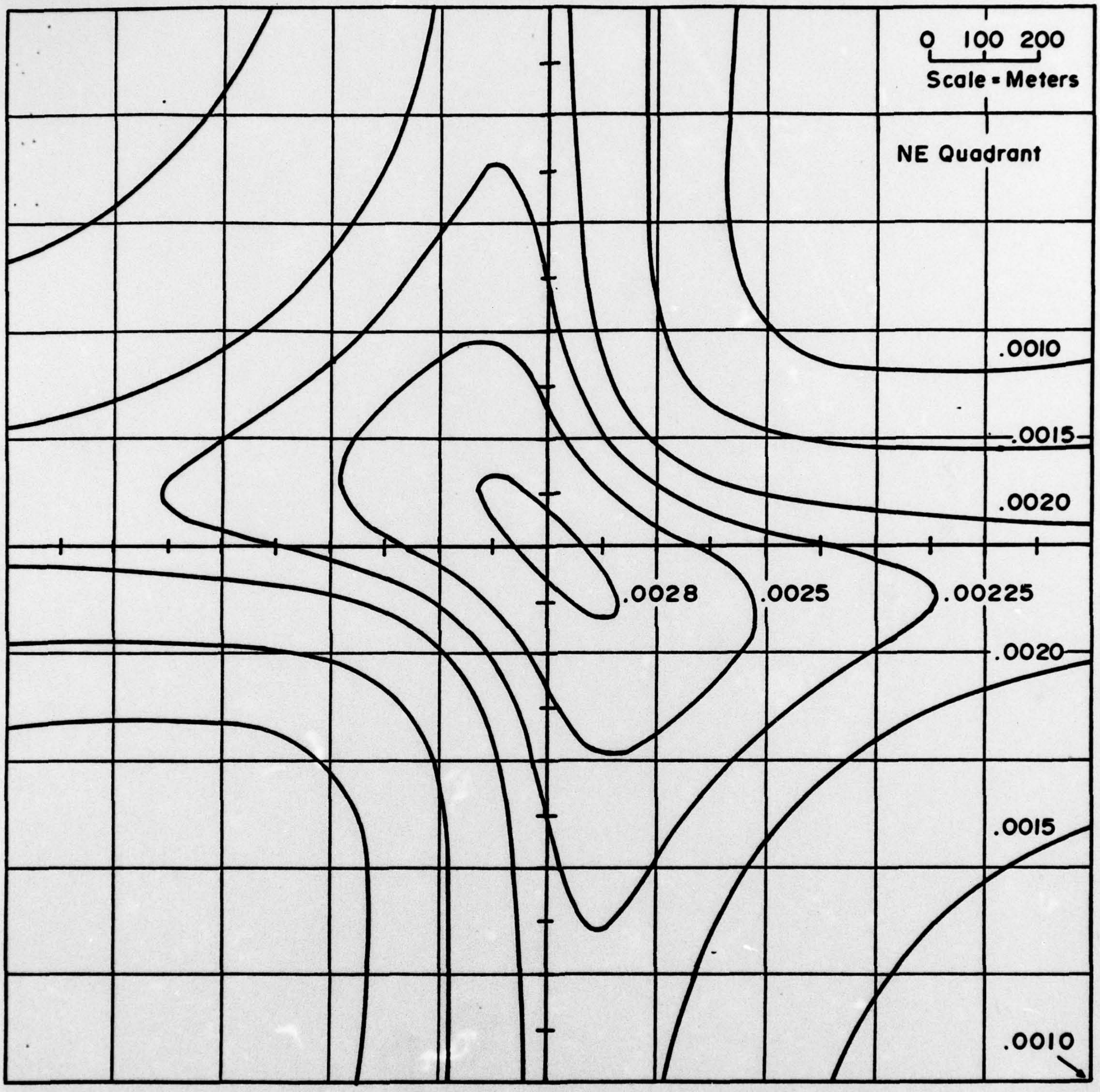
NOTES: Antenna Frequency = 76 Hz.
Antenna Current = 300 A.
Earth Conductivity = 5×10^{-4} Mho./m.

Fig. 4 ELECTRIC FIELD CONTOURS IN VOLTS/METER 300 METERS ABOVE TWO PERPENDICULAR ANTENNA ELEMENTS WITH IN-PHASE CURRENTS



NOTES: Antenna Frequency =76 Hz.
Antenna Current =300 A
Earth Conductivity $=5\times10^{-4}$ Mho./m.

Fig. 5 MAGNETIC FIELD CONTOURS IN GAUSS 30 METERS ABOVE TWO PERPENDICULAR ANTENNA ELEMENTS WITH IN-PHASE CURRENTS



NOTES Antenna Frequency = 76 Hz
Antenna Current = 300 A.
Earth Conductivity = 5 10^{-4} Mho/m

Fig. 6 MAGNETIC FIELD CONTOURS IN GAUSS 300 METERS ABOVE TWO PERPENDICULAR ANTENNA ELEMENTS WITH IN-PHASE CURRENTS

Part II

Ronald Larkin
Pamela Sutherland

INTRODUCTION

Preliminary data collected by Williams et al. in November 1974 indicated that nocturnal migrants flew in different compass directions when different combinations of the two legs of the Wisconsin Test Facility antenna were transmitting. These preliminary results suggested that the birds were affected by the ELF signal emitted by the antenna. In order to better understand this possible effect, it was decided to employ a small tracking radar, as well as a search radar, in observations during April and May, 1975 at the Sanguine Test Facility near Clam Lake, Wisconsin. The tracking radar has the advantage that the altitude and true position of a single bird being tracked can be recorded with an accuracy sufficient to observe small changes in flight path or speed.

METHODS

Data Acquisition

Data were taken from 21 April 1975 to 10 May 1975, starting at dusk and continuing until 0200-0300 whenever possible. The radar used to track birds is a Type AN-MPQ-29 X band, nutating scan, pencil beam tracker with a nominal beamwidth of 3°, a peak power of 40 kw, and a pulse repetition rate of 3800 Hz (Griffin, 1973; Larkin et al., 1975). The radar is interfaced to an on-line minicomputer which provides a CRT display of XY and altitude, updated at 1-1.5 sec. intervals (Larkin, 1974). The on-line display of tracks is sufficiently accurate to allow the operator to see almost any turn or other maneuver by a bird which causes a deviation of at least 10-20 m and lasts at least 3-5 sec. (Fig. 1). Tracks which showed nonlinearities that were not immediately attributable to artifacts (see below) were transferred to punched paper tape; the tapes were later used to produce complete printouts and incremental plotter records. (No punched paper tapes were available from the first night of tracking, 4/21.)

At least once, and usually twice per night, a balloon-borne radar target was launched and tracked with the radar. Balloon tracks provided information on the wind velocity at all altitudes of interest starting at the altitude at which the balloon was acquired by the radar, usually 100-150 m.

Two types of protocol were followed in investigations of the effect of the Wisconsin antenna on migrating birds. The Fifteen Minute Protocol consisted of pseudo-random changes in the antenna condition between four states: NS (North-South leg of antenna active), EW (East-West active), BOTH (both legs active) and OFF (neither active). The antenna condition changes occurred on the hour and at 15 min. intervals after the hour. Until 5/4/75, operators of the tracking radar were informed of the time of each antenna condition change, but were not aware of the state of the antenna, i.e. the experiments were performed blind. After 5/4, the operators were told of the state of the antenna as well as the time of condition change; however, since the tracking radar works automatically, there was no known way that the operators could influence the direction, speed, or straightness of a track once the track was in progress.

The By-Request Protocol consisted of changes between the Off and Both states (Off and NS on 5/1/75), initiated by a verbal request from the radar operator. In efforts to investigate possible effects of the antenna condition change itself, the radar operator acquired a bird target, ascertained that it was flying straight and level, and then requested that the antenna state be changed. In order to speed the process of changing the antenna state, current levels were allowed to increase only to 150 A during times when this protocol was being followed (see below). Although the By-Request Protocol generated many more antenna changes during bird tracks than the Fifteen Minute Protocol, and although the temporal sequence of antenna changes were different, we have pooled the results of the two protocols in order to provide adequate numbers of observations.

As shown in Figure 2, the change of antenna condition was not accomplished instantly. Shutting off an antenna leg at the time of an antenna change was accomplished by gradually and linearly decreasing the antenna current over a period of 100-110 sec. (45-52 sec. in the By-Request Protocol) from 300 A (150 A) to 75 A, at which time the current was shut off completely. A description of the exact waveform of the transition from 75 A to 0 A was not available. The transition from off to full current took place in the reverse sequence. When both antennas were involved in a condition change, the abrupt transitions from 0-75 or 75-0A were synchronized within a few sec.

The tracking radar was located within the Wisconsin Test Facility compound at a point 61 m south and 54 m west of the intersection of the antenna legs.

During all parts of the study, note was taken of the general direction, if any, from which birds seemed to be migrating. This direction was then preferentially scanned in searching for birds to track, in order to maximize the length of tracks and to track birds which would pass near the region of the intersection of the antenna legs. Since almost all birds on a given night usually travel in the same general direction, plus or minus perhaps 60°, this procedure did not appreciably affect the sample of migrants tracked. A marked effort was made, however, to acquire birds flying at low altitudes rather than at higher altitudes, by searching at low elevations and short to moderate ranges. We attempted to track those birds flying lowest over the antenna and therefore presumably experiencing the most intense effects of its electromagnetic radiation.

Tracks ended either because the operator intervened and switched the radar back to manual control, or because the radar autotrack mechanism failed to continue tracking. The former never occurred except when the track was straight and level and the bird has passed over the region of the antenna. The latter occurred for many reasons including ground clutter, range less than minimum (ca. 120 m), and switching to another, larger, target. Most tracks were 50-80 sec. in duration.

Data Analysis

Complete records of about 500 bird tracks were obtained, either by photographing the CRT display or by punching the values on paper tape. From these records the length of each track to an accuracy of 10 meters, the duration in whole seconds, the compass direction in whole degrees, the starting altitude in tens of meters, and the change in altitude in tens of meters (if any) were measured. These measurements were made by an assistant who had no knowledge of the antenna condition at any time during the study. Then one of us (RL) examined the photos and plots of the tracks for artifacts. Three distinct types of artifacts are known to occur. All are products of the radar-computer interface and basically involve drift in the signals which is correctable by calibration of the system. The artifacts are (1) range nonlinearities near 270, 1270 ... yards, (2) azimuth nonlinearities at 340°, and (3) elevation offsets which produce a particular set of gently curving tracks, symmetrical with respect to the radar. Tracks with these artifactual nonlinearities were considered to be straight. (One track was a doubtful case and was discarded.) After this step, the antenna conditions were transcribed onto the data sheets; thus the step of locating artifacts was also done blind with respect to antenna condition.

Before analysis of the tracks, the following categories of tracks were discarded.

(a) Tracks on nights when radar or interface malfunction prevented our taking reliable data (5/6 and 5/10).
(b) Tracks less than 15 sec. in duration.
(c) Tracks which did not begin with a straight segment, that is, which were curving, ascending or descending, or hovering in the first 6-10 sec. There were 10 such tracks, distributed among antenna conditions. Most were birds which were apparently in the process of gaining altitude or seeking a place to land.

(d) Tracks during which the antenna condition was uncertain. The computer system had an inherent time-of-day uncertainty of 1-2 min. which sometimes prevented our assigning tracks occurring near a change of antenna condition to a specific condition.
(e) Tracks occurring during the times when current levels in the antenna may have been changing, but which did not overlap an announcement of antenna condition change (Figure 1). We thought it unlikely that birds would respond only to the linearly ramping change in AC current, and that the continuous nature of both the bird tracks and the antenna current changes would render the results impossible to interpret, since few birds fell into this category.

469 tracks remained after discarding the above categories of tracks.

RESULTS

General Summary, Weather, and Winds

Useful data were obtained on eleven nights (Table 1). Weather conditions allowed observation under varying amounts of cloud cover; several nights' observations were ended by steady rain. Experiments on 5/4/75 ended when the motor-driven potentiometer that controlled the current levels in the antenna failed. This malfunction was in the drive motor itself and was not believed to affect the waveform or current level before the occurrence of the failure.

Table 2 lists wind speeds and directions as determined by balloon tracks. Each balloon is identified by its date and time. Winds were generally steady at the altitudes where birds were tracked (100-300 m); when this is the case, a set of inclusive altitudes, a direction toward which the wind was blowing, and a wind speed are given. In cases of wind shear, the balloon tracks are broken into two or more segments and the altitudes, directions and speeds are given separately for each segment. The points of segmentation can be considered regions of wind shear (and possible unstable airflow).

Birds Tracked during Steady Antenna Conditions

Because it is frequency-modulated, the ELF signal emitted by the antenna under "operational" conditions should be essentially constant in amplitude. For this reason, the effects on wildlife, if any, of the "steady" antenna conditions (Off, NS, EW, or Both, but at constant current) are most important for evaluating the environmental impact of the operation of the antenna.

Effects of steady antenna conditions on nocturnal migrants were evaluated by examining mean values of directions and speeds and by examining non-linearities in tracks. Directions and speeds of birds were averaged for each steady antenna condition, using all tracks whose directions and speeds were constant enough to measure. (Altitudes, of course, were measured but were a product of the searching strategy of the radar operators as well as of the behavior of the birds.) Tables 3 and 4 present means and standard deviations of directions and speeds relative to the ground for each antenna condition. Directions are measured from Polaris = 0°. Mean directions (Θ) and angular deviations of directions ($\underline{s}$) are computed as in Batschelet, 1965. With the exception of the six birds tracked in the Both condition on 5/5/75, differences in directions of tracks among the four antenna conditions are slight compared to the variation within conditions. Similarly, speeds do not seem to be affected by antenna condition (Table 4).

In addition to those birds which passed straight over the antenna, there was a certain number of birds (9%) which were tracked flying straight for at least 6-10 sec and then changing direction, speed, or altitude. Tracks of birds which behaved this way will be called "nonlinear". Classification of nonlinear tracks was subjective, but was done before antenna condition was entered onto the data sheets, making any bias toward a particular antenna condition unlikely. Almost all tracks classified as "nonlinear" had immediately obvious features which separated them from the straight tracks, such as abrupt transitions from level flight to rapid descent, curving turns taking them tens of meters out of their former path, or reversals in direction (Figs. 3-5 illustrate some nonlinear tracks). Records of most nonlinear tracks were punched onto paper tape, allowing us to analyze expanded plots and accurately measure the birds' positions.

The relatively small number of nonlinear tracks which occurred during steady antenna conditions prevented us from examining the effects of each specific antenna condition on the occurrence of nonlinearities. Therefore, we tested the null hypothesis that nonlinearities are not more frequent when the antenna is On (NS, EW, or Both) than when the antenna is Off, for all days pooled. As shown in Table 5, this hypothesis can be rejected at the .002 level; nonlinearities are indeed more frequent when the antenna is On than when it is Off. Of course, it was not possible in any one case to show that a turn or swerve was, in fact, due to a bird's flying in the field of the antenna. Nor could we, by examining the tracks, discover any pattern in the nonlinearities, other than that many birds resumed nearly their normal course after swerving (Figures 3 and 5). Some birds turned or changed altitude as they passed close to the antenna; others behaved similarly when more distant from it. We could not find a consistent relationship between the geometry of the changes in direction and the bird's position with respect to the antenna.

We draw two conclusions about the effects of steady antenna conditions, a negative one and a positive one. Birds which maintained a given direction and speed as they passed near the antenna showed no response to it -- i.e. the mean directions and speeds were not affected by the antenna condition at the time. However, turns, climbs, and other maneuvers were more probable when the antenna was On than when it was Off.

Birds Tracked during Changing Antenna Conditions

Changes in antenna condition (0-75 or 75-0 A) occurred during 74 tracks. The sudden current change might, if perceived by the birds, cause a change in their orientation which could be observed on the radar tracks. One can therefore look for nonlinearities in the birds' tracks occurring at or after the change in antenna condition as an unambiguous indication that the ELF radiation emitted by the antenna affects the orientation of nocturnal migrants. A problem with setting up such a test is that there is no *a priori* basis on which to predict a temporal relationship between an antenna change and a bird's behavior. The bird might react immediately, it might react after some delay necessary for integrating the signal, or it might react to the ramping current increase or decrease accompanying the step change in current (Figure 1).

In order to introduce as few assumptions as possible about timing, the tracks were grouped according to (a) whether an antenna change was recorded at a known time during a track and (b) whether the track was linear or nonlinear. Results of this tabulation are given in Table 6. The *p* values given at the right of Table 6 represent the probability that the proportion of nonlinear tracks observed (or any greater proportion) would occur by chance, computed using the Fisher Exact Test. Significantly more nonlinearities occurred under changing than under steady antenna conditions on 4/21, 5/3, and 5/4/75. Overall, birds were about four times as likely to change course if the antenna condition changed during the time they were tracked than if it did not. Referring to Table 1 and to notes taken during the study, we find no pattern of weather, migration, or visibility which might explain the presence of an effect on some days and not on others.

Especially in view of the fact that many of the "nonlinearities" which appeared in tracks on 4/21, 5/3, and 5/4 were changes in XY flight direction relative to the ground, with or without later resumption of the former course, it is possible that some nonlinearities were related to the action of the horizontal component of the wind. In fact, four of nine nonlinearities with antenna changing on 5/4 occurred at altitudes near which balloon tracks showed considerable wind shear (Table 2). Neither nonlinearity on 5/3 was attributable to unstable winds near regions of shear; no wind data are available for 4/21. Although it is inconceivable that changes in antenna condition affect the wind, the possibility remains that birds are more easily disoriented by antenna changes when the wind varies with time or altitude than when it does not.

In order to examine the effect of the type of antenna change on nonlinearities, the tracks on 4/21, 5/3, and 5/4 were grouped according to type of antenna change (Both to NS, Both to EW, etc.). The Both to EW antenna change was associated with four nonlinearities; all others had zero, one, or two. No pattern of initial condition, final condition, or type of change was found.

Since the strength of the electromagnetic field generated by the antenna decreases with distance from the antenna, birds flying closer to the antenna might show greater effects than more distance birds. Although we concentrated on birds which were flying low and near the antenna, there were portions of bird tracks as close as 100 m above the antenna and portions beyond 500 m. We therefore attempted to test the hypothesis that birds closer to the antenna were not more likely to respond to it, giving a nonlinear track, than more distant birds. No discrimination was made between steady and changing antenna conditions for this test. The beginning of each nonlinearity which occurred when the antenna was On or changing was located and the elapsed time in seconds from the beginning of the track was noted. Then linear tracks, matched as closely as possible in duration to each nonlinear one, were selected by a determined procedure. Duration was used as the criterion for matching because it is the one parameter which can be influenced by the radar operator once a track is in progress. Finally, straight-line distances were measured: For the nonlinear tracks, we computed the distance between the point in space where the nonlinearity began and the nearest antenna leg which was energized during the track. For the linear ones, the bird's position at the corresponding second of elapsed time was used and the distance was computed to the nearest antenna leg (thus biasing the results against the hypothesis). The antenna was given an arbitrary nominal altitude of 8 m with respect to the radar in these calculations. Birds giving nonlinear tracks were usually nearer to the antenna than their controls, but differences were slight and not significant (Wilcoxon Matched Pairs Signed-Ranks Test, $p >> .05$). Distance from the antenna did not seem to be an important factor in determining whether these low-flying birds reacted to the antenna. This conclusion, reached by a statistical procedure, agrees with our observation that many birds, flying nearly straight above a leg of the antenna when it changed state, showed no evidence of a response.

DISCUSSION

Birds which maintained a straight and level course over the antenna did not seem to be influenced by the antenna condition. Neither directions nor speeds were affected by antenna condition, although sample sizes were necessarily small. However, a number of birds (about 12% overall) did not fly straight and level over the antenna, and strong evidence was obtained that these "nonlinear" tracks were more frequent when the antenna was On than when it was Off, and still more frequent when the antenna was changing from one condition to another.

In order to discuss effects of the ELF radiation on the birds, one must first dismiss the possibility of direct effects of the antenna on the radar or on the data collection equipment. The radar and associated equipment were situated nearly directly beneath the main feeder cable for the antenna system; one must rule out direct electromagnetic effects between the two systems. We feel such effects can be ruled out on several grounds. First, the radar operates at about 9 GHz and the computer at nearly 1 MHz; even the voltage-to-frequency converter in the interface electronics produces 1-5 kHz, well out of the ELF range. Second, the effects were seen only on some nights, were not geometrically consistent with respect to antenna condition, and were otherwise not predictable. Nonlinearities sometimes occurred after long straight sections of flight, quite unlike interference by a steady noise source. Third, a balloon tracked on 5/4/75 did not change direction or speed when the antenna condition was changed, providing a partial control. Fourth, and most important, the nonlinearities in the bird tracks took place in Cartesian coordinates (i.e. XY turns at constant altitude), whereas the radar and radar-computer interface work entirely in polar coordinates. It is most unlikely that the electrical signals from the Wisconsin Test Antenna caused artifactual nonlinarities in the tracks.

The negative results on the effect of antenna condition on linear tracks do not necssarily conflict with the preliminary data of Williams et al. Important differences exist between the two studies with respect to type of radar, protocol used, direction of migration, time of year, and presumably the species of bird observed. It is especially noteworthy that the Fifteen Minute Protocol employed in the present study is similar in length to the time required for a bird to reach the vicinity of the radar from the end of one of the antenna legs. For instance, a bird flying at a groundspeed of 12 m/sec directly along the antenna would arrive at the intersection of the antenna legs about 15 min. after starting from the end of one leg. It is apparent that, if birds must integrate electromagnetic signals in order to perceive them, and if the time constant of the integration is long, then the antenna condition should be changed less frequently than every 15 min. and that data immediately following an antenna condition change should be treated separately or discarded. The original 30-Minute Protocol used by Williams et al. may be distinctly more suitable.

The data presented in this study provide evidence of responses to ELF radiation by freely-flying nocturnal migrants. The fact that the signal present at the output of the transmitter of the antenna has virtually no DC component, and the fact that responses to the signal were not predictable in spite of their high level of statistical significance, make biological interpretation of the results nearly impossible at the current state of knowledge. We feel it is quite likely, however, that further investigations of the phenomena, especially with a tracking radar, would resolve some of the problems encountered in the present study. In particular, we cannot now say whether the phenomenon of turns and altitude changes which correlate with antenna condition is really a disorientation of the birds, nor can we say whether it is merely temporary or may seriously affect their migration. The results of Southern (1975) indicate that the effects on birds in the process of beginning a migration near the antenna may be especially significant.

To conclude, we have several recommendations for changes in procedure which would increase the reliability and interpretability of any future study of effects of such an antenna on migrants: 1) Measurements of the strength of the field produced by the antenna at the altitudes in which birds fly are needed. Neither measurements nor satisfactory theoretical models are now available. 2) In investigating effects of steady antenna conditions, antenna condition should be changed at long intervals, perhaps 30-60 min. Fewer antenna conditions could be used if necessary. 3) When using a tracking radar, a sampling procedure should be adopted so that birds are acquired at fixed or random positions in space, and the birds tracked for a predetermined period of time or until lost to the autotrack mechanisms. Such stereotypy would eliminate the necessity to partition out such effects in later analysis. 4) Birds at high altitudes should be sampled, as well as those at low altitudes. 5) Accurate tracking in three coordinates should be a primary objective. The practice of identifying artifacts by eye is tedious and unnecessarily subjective.

Table 1. General Summary of Nights when Data were Gathered.

Date	Total Number of Birds Tracked	Time of Tracking		Weather Conditions
		15-Minute Protocol	By-Request Protocol	
4/21	67	2128-0054	-	Clear. Half moon visible.
4/24	89	2056-0207	-	Total overcast, but moon visible through cloud.
4/25	65	2112-0222	-	Clear. Full moon visible.
4/27	26	2122-0045	-	Total overcast, turning to rain.
4/30	22	2116-0014	-	Total overcast, turning to rain. No moon visible.
5/1	34	2104-2159	2208-0001	Partly cloudy, clearing. No moon.
5/2	59	2059-0013	-	Total overcast, turning to rain.
5/3	25	2311-0151	-	Clear.
5/4	45	2157-0028	0043-0231	Total overcast, clearing.
5/5	69	2112-0119	0134-0240	Clear. Aurora Borealis visible.
5/7	33	-	2117-0059	Light overcast, clearing.

Table 2. Wind Speed and Direction

Date	Time	Altitudes (m)	Direction Toward (degrees)	Speed (m/s)
4/24	2105	160-350	271	2.1
4/24	0155	100-350	265	10.3
		350-600	280	6.3
4/25	2112	140-600	255	4.0
4/27	2122	160-800	324	17.0
4/27	0016	145-600	303	14.3
4/30	2119	240-750	061	6.2
4/30	2332	140-700	078	7.3
5/1	2104	100-250	076	10.0
		250-460	079	8.8
5/1	0001	140-300	069	9.7
5/2	2059	130-260	015	12.1
		260-410	024	7.1
5/2	0007	110-300	003	8.0
		300-950	018	10.6
5/3	2314	170-360	208	4.8
		360-590	173	6.9
5/3	0151	140-575	170	5.4
5/4	2202	100-270	286	3.0
		270-595	355	3.0
5/4	0012	120-180	278	3.0
		180-280	339	2.1
		280-410	357	2.7
5/5	0119	110-380	264	10.5
		380-540	257	10.2
5/7	2124	90-140	204	6.7
5/7	0108	75-250	275	10.2
		250-400	282	10.2

Table 3. Mean Flight Direction as a Function of Antenna Condition.

	Antenna Condition							
	OFF		NS		EW		BOTH	
Date	θ	s	θ	s	θ	s	θ	s
4/21	353	27	347	23	359	28	355	38
	(n=22)		(n=13)		(n=10)		(n=8)	
4/24	283	27	300	26	295	53	298	35
	(n=28)		(n=16)		(n=6)		(n=19)	
4/25	288	34	295	4	290	31	295	17
	(n=15)		(n=5)		(n=17)		(n=12)	
4/27	326	13	321	12	343	31	334	20
	(n=7)		(n=2)		(n=3)		(n=5)	
4/30	100	53	--	--	295	67	053	23
	(n=3)		(n=0)		(n=4)		(n=5)	
5/1	047	34	067	44	065	1	--	--
	(n=17)		(n=4)		(n=2)		(n=0)	
5/2	351	24	355	19	026	12	349	35
	(n=18)		(n=13)		(n=2)		(n=7)	
5/3	271	46	302	43	--	--	318	26
	(n=4)		(n=10)		(n-0)		(n=9)	
5/4	288	31	288	19	--	--	291	45
	(n=11)		(n=5)		(n=0)		(n=12)	
5/5	271	33	275	30	282	35	315	17
	(n=24)		(n=11)		(n=9)		(n=6)	
5/7	299	30	--	--	--	--	291	42
	(n=6)		(n=0)		(n=0)		(n=4)	

θ= mean flight direction 0=true North

s= mean angular deviation (Batschlet 1965)
n= number of bird tracks used for computation

Table 4. Mean Flight Speed as a Function of Antenna Condition.

	Antenna Condition							
	OFF		NS		EW		BOTH	
Date	$\bar{X}$	SD.	$\bar{X}$	SD.	$\bar{X}$	SD.	$\bar{X}$	SD.
4/21	14.6	17.3	10.7	3.5	12.0	2.1	10.2	2.1
	(n=22)		(n=13)		(n=10)		(n=8)	
4/24	14.3	4.2	14.9	3.8	13.2	6.1	13.7	3.4
	(n=28)		(n=16)		(n=6)		(n=19)	
4/25	16.0	3.3	15.7	1.5	17.0	4.3	19.9	5.0
	(n=15)		(n=5)		(n=17)		(n=12)	
4/27	17.8	3.2	26.6	6.8	14.0	0.9	21.6	2.9
	(n=7)		(n=2)		(n=3)		(n=7)	
4/30	10.4	4.0	--	--	8.2	2.8	9.2	1.7
	(n-3)		(n=0)		(n=4)		(n=5)	
5/1	9.8	1.8	11.5	4.0	13.7	2.5	--	--
	(n=17)		(n=4)		(n=2)		(n=0)	
5/2	11.8	4.5	9.2	4.3	13.5	2.1	9.4	3.1
	(n=18)		(n=13)		(n=2)		(n=7)	
5/3	6.7	2.1	8.1	1.3	--	--	7.9	2.4
	(n=4)		(n=10)		(n=0)		(n=9)	
5/4	8.5	3.8	7.8	2.0	--	--	9.2	2.6
	(n=11)		(n=5)		(n=0)		(n=12)	
5/5	12.8	3.8	13.4	4.0	10.4	3.0	11.5	2.4
	(n=24)		(n=11)		(n=9)		(n=6)	
5/7	7.4	2.25	--	--	--	--	7.8	3.55
	(n=6)		(n=0)		(n=0)		(n=4)	

Table 5. Numbers of Nonlinear Tracks

When Antenna On and Off

	Nonlinear	Linear	Total
Antenna Off	6	157	163
Antenna On	28	204	232
Total	34	361	n=395

Total numbers of linear and nonlinear tracks on all days when acceptable data were taken, tabulated for Antenna Off and steady, and for Antenna On (N-S, E-W, or Both) and steady. The increased proportion of nonlinear tracks when the antenna is On has a chance probablity of occurrence of .002 (Fisher Exact Test, one-tailed).

Table 6. Numbers of Nonlinear Tracks under Steady and Changing Antenna Conditions.

	Steady		Changing		
	nonlinear	linear	nonlinear	linear	p
4/21	5	53	3	2	.01 *
4/24	4	71	1	2	.18
4/25	0	52	0	6	1.00
4/27	1	17	1	1	.19
4/30	5	15	0	0	1.00
5/1	2	20	0	10	1.00
5/2	4	35	1	4	.47
5/3	3	16	2	0	.05 *
5/4	5	25	9	3	.0006 *
5/5	5	41	3	10	.24
5/7	0	16	1	15	.50
Total	34	361	21	53	.00001 *

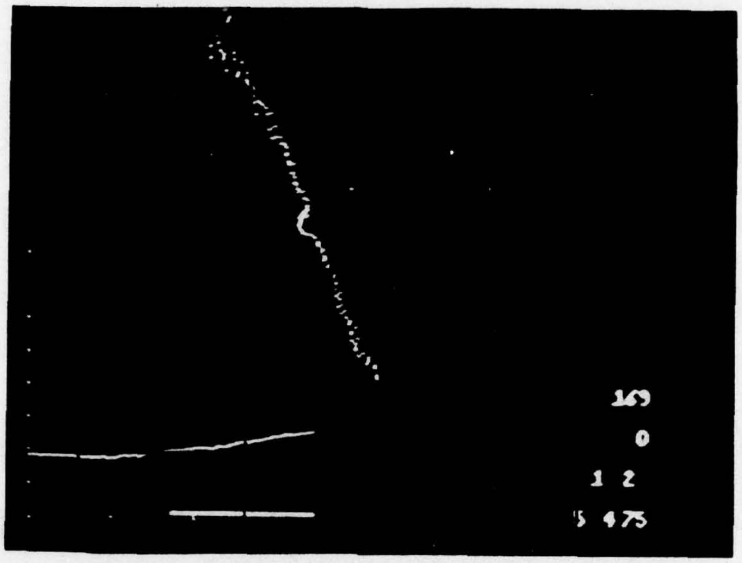


Figure 1. Photograph of on-line CRT display of XY position and altitude-time, taken after the track at 0102 on 5/4/75. The photograph appears actual size; one can *clearly see the nonlinearity* shown in more detail on Figure 3.

The dot near the center of the photograph indicates the position of the radar on the XY plot. North is at the top. Scale marks (along left edge) are at 100 m intervals. The bird target was acquired nearly south of the radar and was lost after 163 sec. toward the northwest. In the lower left corner of the photograph appears the altitude-time plot. The lowest scale mark represents 0 m altitude; the bird was acquired at about 190 m altitude. At time = 84 sec., the antenna changed condition from Both to Off; the Off condition is indicated by the bright line at 5 m altitude. Elapsed time, coded antenna condition, time, and date appear in the lower right corner of the photograph.

Figure 2. Current levels in each antenna as a function of time during a N-S to E-W antenna condition change. Solid lines indicate current levels during the Fifteen Minute Protocol; dashed lines indicate the full current level reached during the By Request Protocol.

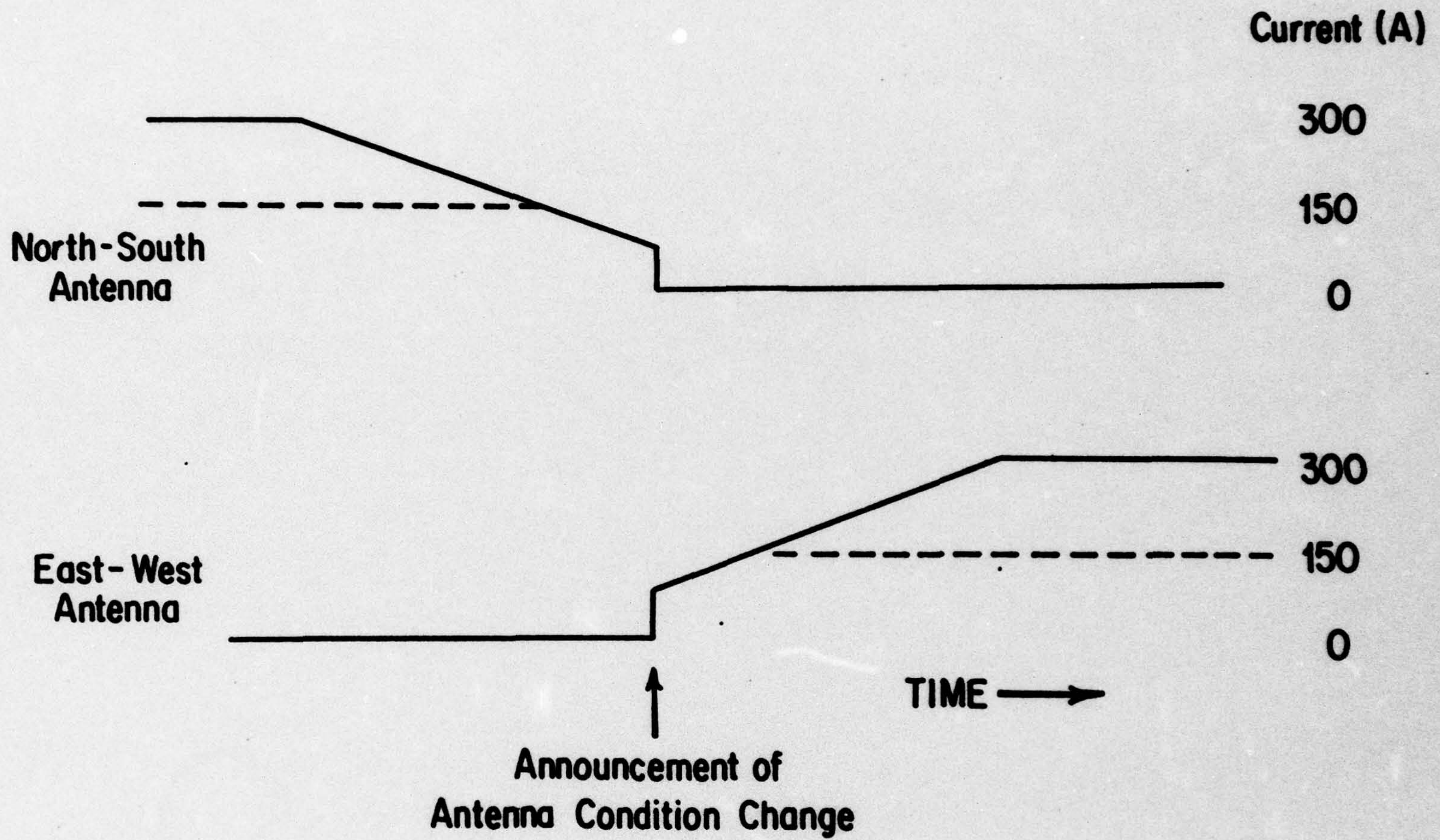

Current (A)
300
150
0
North-South Antenna
300
150
0
East-West Antenna
TIME
Announcement of Antenna Condition Change

Figure 2

Figure 3. XY plot (top) is positioned with North at top, radar (R) at center. The track is 163 sec. in duration; data were taken at a rate of one point each 1.5 sec.; and a point each 7.5 sec. is circled, starting with the first point (large circle). Arrow shows direction of movement. A diagrammatic sketch (solid lines) of the Sanguine antenna is superimposed on the plot. The bird is seen to make a slow turn to the left and then back toward the right, finally resuming its former direction just after the antenna made the transition from 75 A (Both) to 0 A at second 84 (Δ). Note that the turn began during the period of decreasing antenna current (Figure 1), not as the 75-0 A transition was made.

Altitude (above ground level) plot (bottom) is made to the same scale as the XY plot with the x axis representing the projection of the XY plot on the surface of the earth. The bird is seen to increase altitude slowly during the turning seen in the XY plot and also after the antenna current was Off (Δ). The small scale (ca. 25 m) fluctuations in the horizontal plot are due to noise in the azimuth angle recording system of the radar. Noise in the elevation angle (and thus altitude) is less by a factor of 4. As the bird moves away from the radar a constant angle error is translated into ever increasing positional errors thus the apparent increase in small scale fluctuations with range.

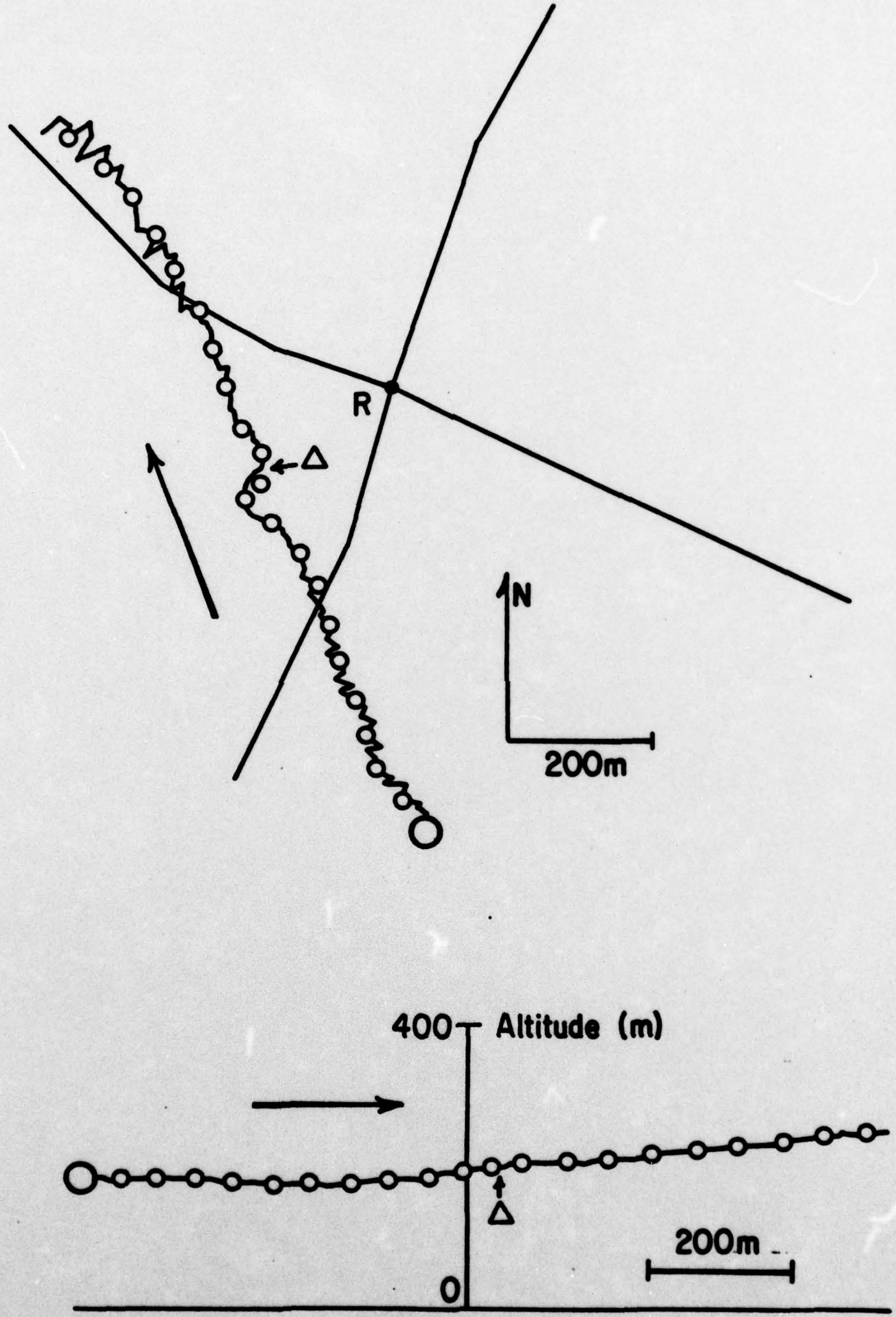


Figure 3

Figure 4. XY and altitude plots have same conventions as in Figure 3. The track is 92 sec. in duration; the antenna condition changed from Off to Both at second 12. Note the direction change occurring a few sec. after the antenna condition change, with the bird apparently changing direction again at about second 51. The altitude plot indicates that little or no change in altitude accompanied the XY direction changes.

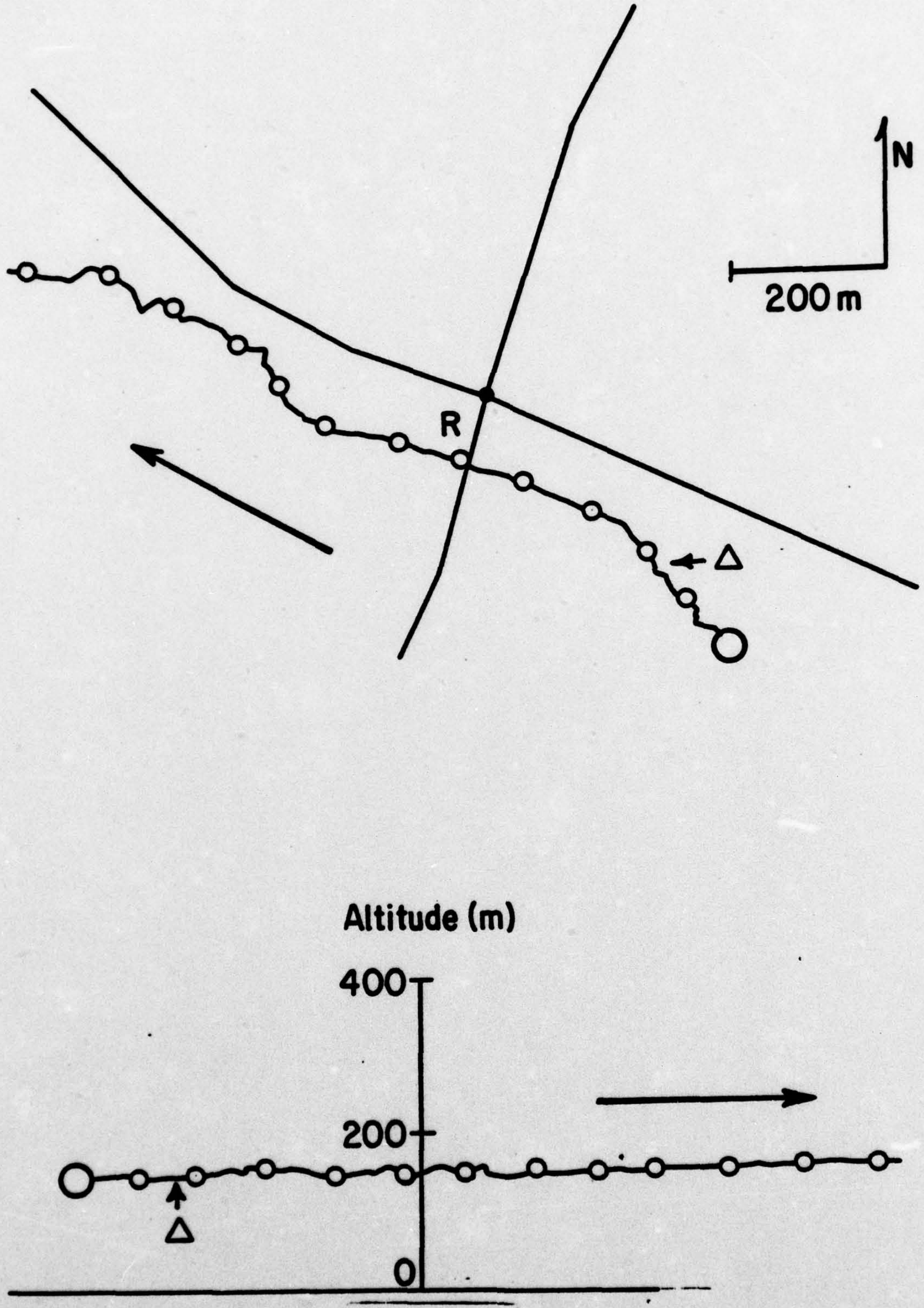


Figure 4

Figure 5. XY and altitude plots have same conventions as in Figure 3. The track is 83 sec. in duration; the antenna was Off during the entire track, having been Off since 2330. The XY direction change and concomitant altitude increase cannot have been related to the antenna signal.

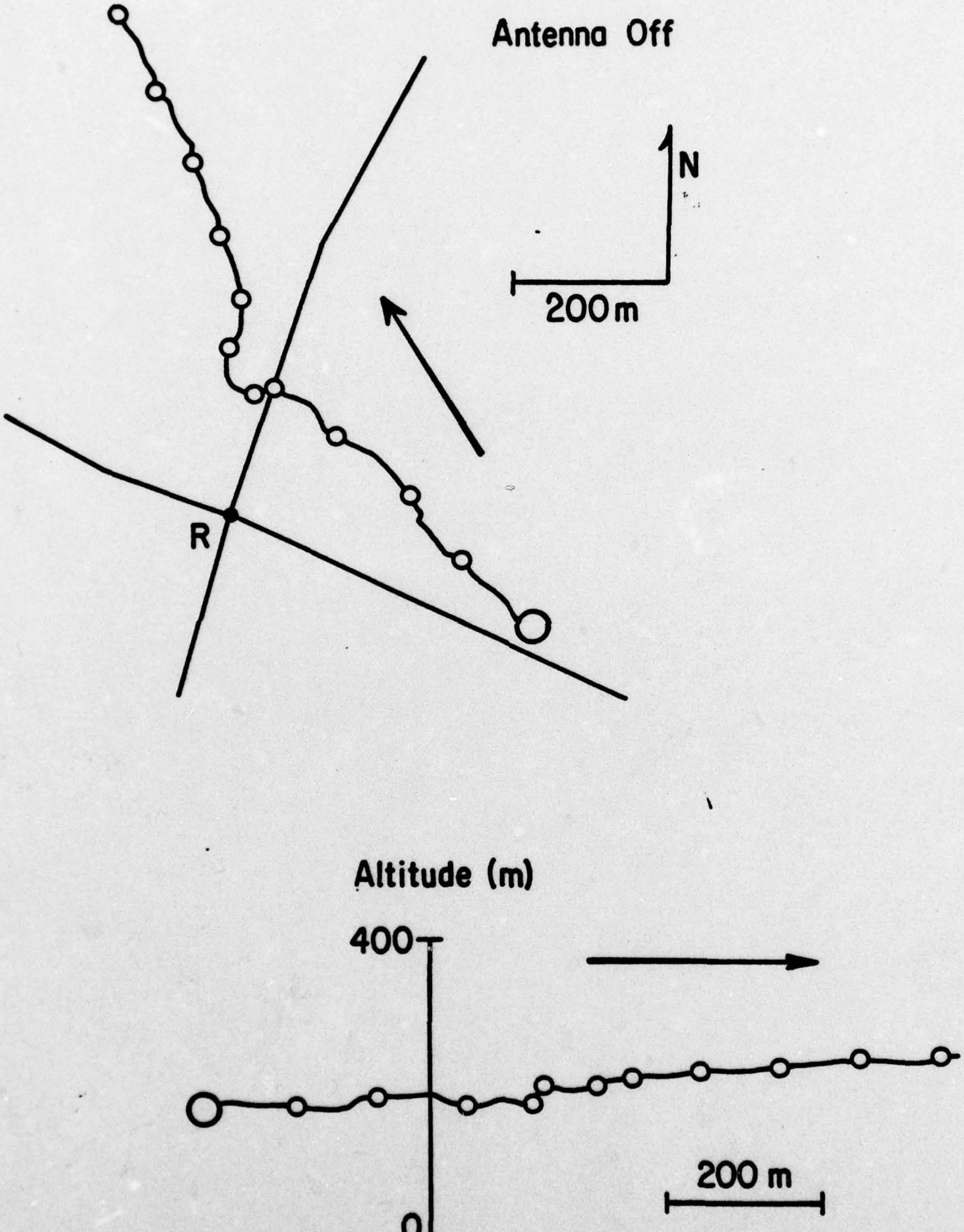


Figure 5

Part III

Observations with an Ornithar

Timothy C. Williams

Janet M. Williams

Bruce Cohen

The Ornithar radar is a mobile high resolution, short range radar designed for ornithological studies. It was used to observe bird migration within a maximum range of 1 km of the Wisconsin Test Facility antennas while these antennas were turned on and off in a predetermined sequence unknown to the observers at the radar. In addition to the radar observations we used a "starlight" scope for observations within a few meters of the antenna wires.

Methods

The Ornithar is a 3 kw peak power 3 cm (X band) radar with a vertical beamwidth of 30° and a horizontal beamwidth of 2.5°. It was operated at a pulsewidth of 0.8 μ sec and 27 RPM (Williams et al, 1974).

The radar was positioned either at a point about 100 m south-southwest of the intersection of the two antennas (main site) or at a point about 50 m south of the East-West antenna about 8 km west of the intersection of the two antennas (remote site). On one night in the fall of 1975 the radar was located 9 km south of the East-West antenna leg. At the main site four antenna conditions were used: North-South On, East-West On, Both On and Both Off. At the remote site only two antenna conditions were used: East-West On and Both Off.

Data were obtained redundantly from the PPI screen of the radar. Observers in the radar noted the relative size, direction of movement and location of radar echoes from birds. A time lapse super 8 mm camera recorded data from each revolution of the radar antenna on a single frame of film. These films were later projected onto sheets of white paper and the position of all radar echoes noted on the paper. From these data we determined the direction, speed and location of all birds detected by the radar. Analysis for data obtained during the fall of 1974 could only be performed on the data taken directly from the radar screen as the data recording cameras had an internal and undetected malfunction. For the observations during the spring of 1975 we used data from the films except for 5 May, as the film for this day was lost by Eastman Kodak during developing. Exceptionally heavy migration was recorded during the fall of 1975 and we have been able to analyse only a portion of the films taken during that period (it takes one hour to score observations for a single minute on some nights).

Altitude of flight for many birds could be estimated by the degree of spherical distortion in observed tracks (Cohen and Williams in prep.)

Observations began shortly after local sunset and continued for four hours, unless the radar operators requested additional observation time or observations were terminated by heavy rain. During the fall of 1974 each antenna condition lasted 1/2 hour. During both spring and fall 1975 each antenna condition lasted 1/4 hour.

As mentioned above, all data were taken without knowledge of the antenna condition; all scoring of raw data was also performed without knowledge of the antenna condition. For the Ornithar data no scored tracks were omitted from the analysis.

Visual observations were aided by a "starlight" scope which emitted no energy but amplified ambient light levels. This instrument in tests was able to distinguish large passerine birds at 100 yds on partially moonlit nights. The instrument was used to check for disoriented birds in the immediate vicinity of the antenna. The principal limitation of the device was a rather narrow depth of field (compared, for instance, with binoculars of similar power). Thus, best results were obtained by focusing on the antenna and checking for birds passing through the field of view. We saw no birds with the device in Wisconsin, although in tests in Rhode Island we detected birds and bats attracted to a lighthouse.

Results

Tests for large scale disruption of bird migration

We did not find any evidence that the Wisconsin Test Facility has a major disruptive effect on migration. The investigation of possible disruptive effects was grouped into three categories: Aggregation, Avoidance, and Non-specific disorientation.

Aggregation. Birds might be attracted to an ELF system antenna causing unnatural aggregations of migrants. Although the Wisconsin Test Facility has been in operation for many years there have been to our knowledge no substantiated reports of unusual aggregations of birds near the antennas. Neither radar nor nightly observations with the starlight scope during 1975 revealed an aggregations of birds at night in the immediate vicinity of the ELF antenna.

Avoidance. Birds might react to the ELF radiation as an aversive stimulus; a large antenna system could then act as a barrier. The radars detected no significant difference in number of birds passing over the area with the antenna activated or off. It might be argued that birds were avoiding the entire area of the Wisconsin Test Facility, but we recorded densities of bird targets that were at least as great as those recorded in the northeastern United States. The heaviest migrations recorded by the Ornithar at any site in the United States were recorded in Wisconsin at the main site, the remote site, and on a single night at a site 5 miles from the nearest leg of the East-West antenna. Thus, there is no evidence supporting the hypothesis that birds avoid the antenna site.

Non-specific disorientation. Lighthouses, tall buildings and television towers often kill large numbers of birds on nights with poor visibility (Stoddard and Norris, 1967; A. Clark, unpub.). Apparently the heavy mortality is at least in part due to birds being disoriented by the bright lights and flying back and forth near the structure until they strike it (A. Clark, unpub.). If birds are dependent upon the geomagnetic field for orientation, a strong oscillating field might have a similar disorienting effect. Prolonged observation with a starlight scope did not reveal any birds flying near the antenna, and dead birds were not found under the antenna wires. Neither the Ornithar nor the tracking radar revealed birds repeatedly doubling back or moving in a confused fashion in the vicinity of the antenna when it was activiated.

Effects on flight behavior other than direction.

Data obtained visually from the radar during the fall of 1975 were used to examine the possible association of antenna state and three other variables: size of radar targets displayed on the PPI screen (small, medium, and large), length of time individual birds were detected by the radar (5-10 sec., 12-20 sec., 22-40 sec.) and the numbers of radar echoes moving together (single, pair, flock). Contingency tables were constructed for each variable vs. antenna state. A Chi squared test indicated no significant departure from a uniform distribution despite an N of 4329. We also compared antenna state with number of birds detected in each of 8 sectors of the radar PPI screen (N, NE, E, SE, etc.). The Chi square value was significant at $p < .001$ for this table ($X^2 = 78$). The deviations from expected values did not, however, show any consistent trend such as fewer birds over the areas of activated antennas. Since the radar is more likely to detect birds flying at right angles to the radar beam than birds flying toward or away from it (Eastwood, 1967), the shift in numbers of birds detected in a given sector of the screen may well be due to a shift in direction of flight (see below). A test of this hypothesis would require a full analysis of the large numbers of birds recorded on films taken during the fall of 1975.

In addition to the contingency tables mentioned above, we performed an analysis of variance on several parameters obtained from the analysis of film data taken during the spring of 1975. In each case the four antenna states were used to form experimental groups for the analysis. This comparison showed no significant ($p < .05$) tendency for antenna state to affect the range at which birds were detected, their altitude of flight, or speed of movement relative to the ground (N = 1306).

Effects on direction of flight

Analysis of data taken with the Ornithar radar indicated that the antenna state was associated with a shift in average direction of bird flight over the Wisconsin Test Facility. This effect is apparent in both visual and film data obtained during both spring and fall migrations. In our opinion it is most convincingly demonstrated when sufficiently large numbers of birds are detected that it is possible to reliably determine the mean direction of flight for each 15 minute antenna condition. Each experimental condition (N-S, E-W, or BOTH) may then be referenced to the nearest (in time) control (OFF) condition. This procedure compensates for the gradual change in average direction of bird migration during a single night which we observed and is common in radar studies of avial migration (see Eastwood 1967). This type of analysis has been performed on the three nights during the spring of 1975 when we detected more than 200 birds. These data are presented in Figure 7. During the first two nights (4/21 and 4/24) we see a repeating pattern of shifting throughout the night; each time the N-S antenna was activated the mean flight direction shifted away from the OFF condition. The E-W antenna did not show a similar pronounced effect and the BOTH condition was intermediate. The direction of this shift was different on 4/21 and 4/24 and on 5/03. The first two N-S conditions showed a strong shift to the left of the control, while the last N-S condition shifted to the right of the control. (It is interesting to note that on 5/03 the low altitude wind shifted from east to north between the second and third N-S condition, while the winds were nearly constant in direction the other two nights.)

In order to test for statistical significance of these observations we followed the suggestion of Batschlet (1965) and used a Chi Square test with grouped data since to the best of our knowledge appropriate multi-sample tests for continuous data are not available for circular statistics. As shown in Table 6, these differences in mean flight direction for the three conditions were significant at $p < .01$.

Very heavy migration was recorded during the fall of 1975 and this large data base provides an opportunity for the sort of analysis described above. Funds for a full analysis of this data were not available in the present project but we have been able to analyse one night of data recorded from films and examine data recorded visually from the PPI screen. Figure 8 presents these data in the same manner as the data for the spring migration were presented in Figure 7. In this case the deviations from the control direction were smaller than observed during the spring but all antenna conditions were associated with a shift to the right of the OFF direction. On October 13, 1976 we recorded a heavy migration to the south. Although film data were obtained for only 3 NS conditions (as opposed to 5 for each of the other conditions) we were able to score 2267 tracks for that evening and these data are presented in Figure 8 and Table 7, Part 1. The average direction of migrants when the N-S antenna was on was 7° greater than the control direction. The difference between the N-S and the control (OFF) populations were tested with the Watson-Williams two sample test (Batschlet 1965) and found to be significant ($p < .01$). (It should be noted, however, that the difference is significant only if all data are used; if only those OFF conditions nearest the NS conditions are used the difference is not significant.)

Inspection of data taken visually from the PPI screen indicates similar trends for all days as shown in Table 7, Part 2, in which all data are summed and show a trend similar to that of the film data taken on 10/13/75. Although the average differences in direction are similar to those for October 13 the variance is much larger and the NS - OFF difference is not significant with the Watson-Williams test.

The analyses described above utilize all available data from all birds. Inspection of data obtained visually from the PPI screen suggests that certain populations of birds appear to be more greatly affected by ELF fields than others. Specifically we find that large, bright, fast moving targets seen in late fall (most probably Canada Geese) show greater deviations than the average.

Data obtained directly from the PPI screen during the late fall migration season of 1974 indicated that antenna state was strongly associated with a change in the average flight direction of birds. Comparisons of each ON antenna condition with the OFF ' condition were significant at $p < .01$, see Table 8. The time of year, the appearance of the radar echoes (large, fast, bright), and reports from nearby wildlife refuges all indicated that these birds were Canada Geese. Thus, a similar analysis was performed for large targets flying after the first week of October in 1975. These data were obtained on the 4 nights with moderate or heavy southward movement. All data were referenced to the median direction of migration of the control (OFF) condition on a night. (The number of large and medium sized targets detected was too small to permit analysis by 15 minute experimental periods as above.) The direction of each bird track was then expressed as falling to the right or left of the median for the OFF condition. These data are shown in Table 9. If the expected values are distributed in the same manner as the control values, p is $< .01$; if expected values are computed from the marginal totals in the usual fashion the probability is very close to .01; if only the North-South condition is tested against the off condition p is $< .01$. Figure 9 gives the mean direction of migration for each antenna condition for each of the five nights (1974 and 1975) during which we detected significant migration of large targets.

Analysis of scored data taken at the remote site has shown no consistent difference between OFF and E-W ON antenna conditions.

Discussion

Data presented in both Parts II and III of this report must be considered as a preliminary investigation of the effect of ELF electromagnetic fields on free flying migrant birds. The aim of this study was to determine whether the Wisconsin Test Facility exerts a demonstrable effect on the behavior of migrant birds and whether this effect would have a significant impact on their total migratory passage.

The ELF field appears to have a demonstrable effect on migrants. The tracking radar indicated that both a constantly activated antenna and increasing or decreasing antenna current are associated with departures from straight and level flight. The mobile Ornithar radar revealed that activation of the North-South antenna was associated with a deviation of average flight direction of 5 to 25° from the control condition.

The impact of the observed ELF effect on migrant birds is difficult to assess at present. Our studies indicate that there is no large scale disturbance to migration near the Wisconsin Test Facility. The changes in orientation induced by the ELF field are not large and there is no reason to doubt that the birds would correct their course as they moved away from the ELF field. Some tracks obtained by Larkin and Sutherland indicate that this indeed is the case. However, neither of the radar studies detected an effect of distance from the antenna within a radius of about 1 km. (The Ornithar, in fact, showed the greatest effect in fall on large birds which were detected at full range.) Neither study investigated the effects of duration of exposrue to the ELF field.

Before an adequate assessment of the impact of the Wisconsin Test Facility can be made, it would appear essential to obtain information on effects of distance and duration of exposure. Without such information we believe it would be difficult to make meaningful predictions of the possible impact of a large grid of ELF antennas, such as those proposed for the Seafarer communications system.

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References Cited

Batschlet, E. 1965. Statistical methods of analysis of problems in animal orientation and certain biological rhythms. AIBS Monograph, Washington, D. C. A.I.B.S.

Eastwood, E. 1967. Radar Ornithology. Methuen and Company, Ltd., London.

Emlen, S. T., 1975. Migration: Orientation and navigation. In Avian Biology, vol. 5, Farner and King Eds. Acad. Press. N. Y.

Griffin, D. R. 1973. Oriented bird migration in or between opaque cloud layers. Proc. Amer. Phil. Soc. 117: 117-141.

Griffin, D. R., and C. D. Hopkins, 1974. Sounds audible to migrating birds. Anim. Behav. 22: 672-678.

Keeton, W., 1974. The orientational and navigational basis of homing in birds. Advances in the Study of Behavior. 5:47-131.

Larkin, R. P., J. R. Torre-bueno, D. R. Griffin and C. Walcott, 1975. Reactions of migrating birds to lights and aircraft. Proc. Nat. Acad. Sci. 72:1994-1196.

Naval Electronic Systems Command, 1972. Sanguine System Final Environmental Impact Statement for Validation and Full-Scale Development. Technical Annexes, Annex B, "Data for Assessing the Environmental Impact of Sanguine on Man's Social Environment."

Southern, W. E. 1973. Orientation behavior of ring billed chicks (Larus delawarensis) exposed to Project Sanguine's electric and magnetic fields. Final report ONR Contract N00014-72-A-0050-0002.

Southern, W. E. 1975. Orientation of Gull Chicks exposed to Project Sanguine's electromagnetic field. Science 189:143-145.

Stoddard, H. L. and R. A. Norris. 1967, Bird casualties at Leon County, Florida, TV tower: An eleven-year study. Bull. Tall Timbers Research Station, (Tallahassee, Fla.) 8:1-104.

Sunde, E. D. 1968. Earth Conduction Effects in Transmission Systems. Dover Publications, N. Y. pp. 110-112.

Valentino, A. R., 1971. ELF Earth Return Circuit Electromagnetic Fields and Their Simulation, IIT Research Institute Technical Memorandum E6185-4.

Williams. T. C., J. M. Williams and T. J. Klonowski, 1974. Flight patterns of birds studied with an Ornithar. Proc. A conference on the biological aspects of the bird/aircraft collision problem. U.S.A.F. Office of Scientific Research.

Table 6. Comparison of North-South, East-West and Both Antenna Conditions. All data referenced to vector mean of the nearest control (off) condition

Spring 1975

	Experimental means relative to control			
	Less than or equal to -5°	Within $\pm 5^\circ$	Greater than or equal to $+5^\circ$	Totals
North-South	5	0	5	10
East-West	0	8	1	9
Both	3	5	1	9
Totals	8	13	7	28

$\chi^2 = 14.8$ $p < .01$

Table 7

Deviations of flight direction from mean control (OFF) direction, 1975

October 13, 1975

ANT STATE	MEAN DIR.	DEV. FROM OFF	N
OFF	218	+ 0	582
EW	221	+ 3	778
BOTH	222	+ 4	633
NS	225	+ 7	274

All data from main site, Fall 1975

ANT STATE	MEAN DIR.	DEV. FROM OFF	N
OFF	165	0	562
EW	169	+ 4	688
BOTH	170	+ 5	613
NS	173	+ 8	624

Table 8. Mean direction of birds observed at Wisconsin Test Facility

October 22, 1974 - 2000-2300 hours

Condition	No. targets observed	Mean vector	r
Off	25	137°	0.86
East-West	34	108°	0.83
North-South	5	174°	0.65
Both on	<u>12</u>	<u>118°</u>	<u>0.89</u>
Whole night	76	125°	0.78

<u>Batschelet (1965) - 2 parameter test</u>

<u>Off vs East-West</u>	<u>North-South vs Off</u>	<u>Both on vs Off</u>
F = 19.6, P<.01	F = 34.7, P = <.01	F = 23.0, P = <.01

Table 9. Direction of flight of large targets expressed as deviation from the control (off) direction for each night Fall 1975

	Direction		
	Less than control	greater than control	Totals
North-South On	7	31	38
East-West On	16	25	41
Both On	16	22	38
Off	24	24	48
Totals	63	102	165

Change in Average Direction of Migration with Antenna State
mean direction for each 15 min. experimental condition
relative to the nearest control (OFF) condition

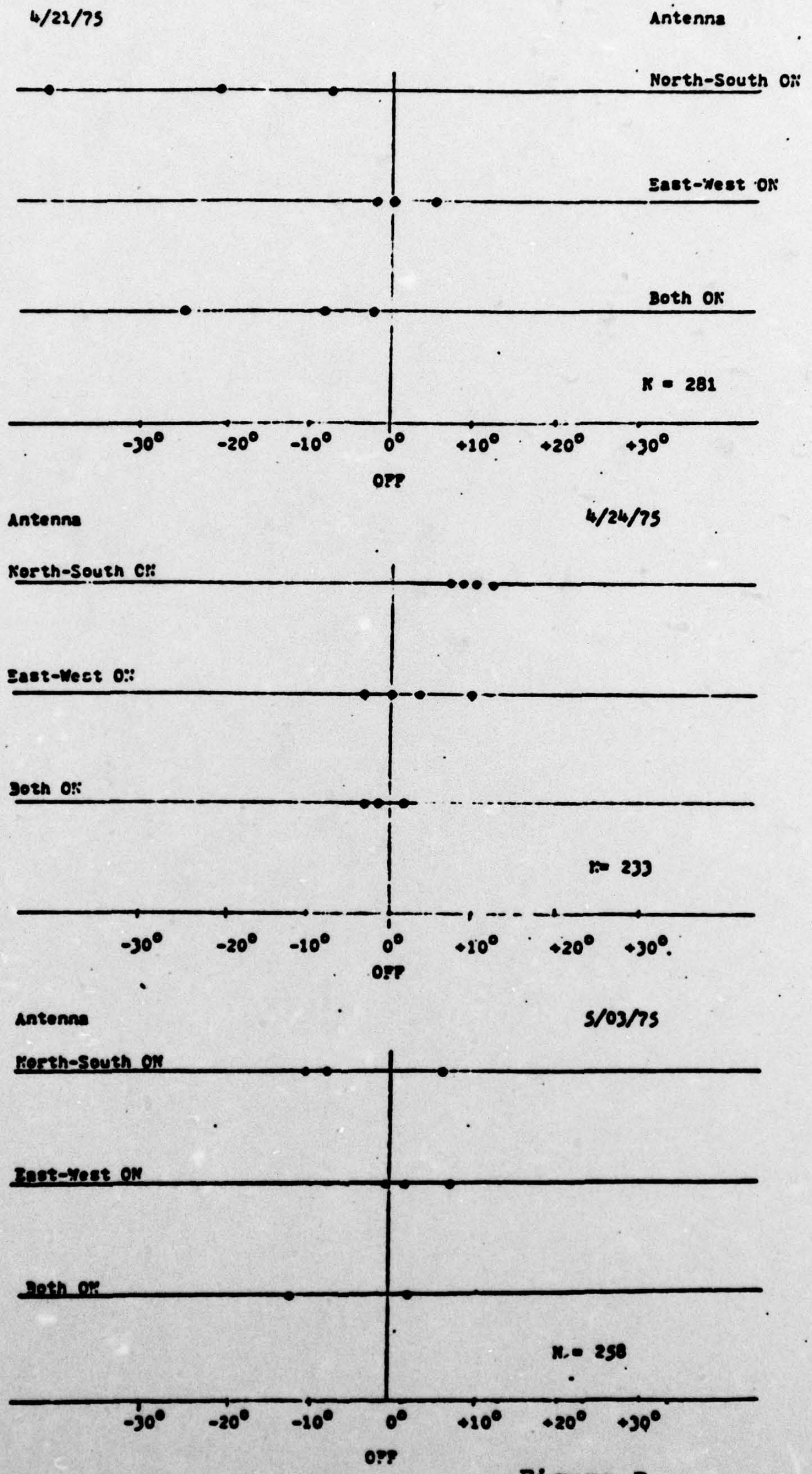

Figure 7

Change un Average Direction of Migration with Antenna State
mean direction for each 15 min. experimental condition
relative to the nearest control (OFF) condition

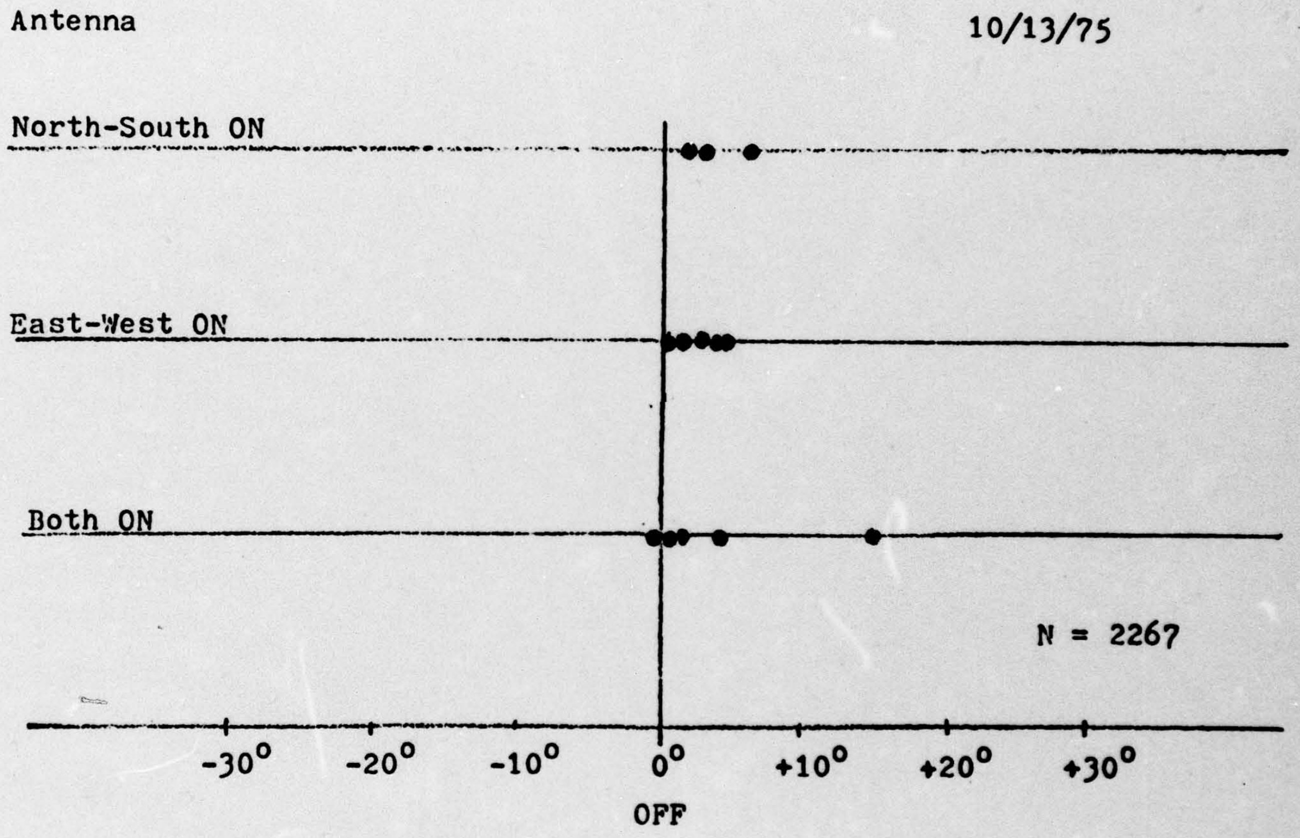

Figure 8

MEAN DEVIATION FROM CONTROL DIRECTION
LARGE AND MEDIUM SIZED TARGETS LATE FALL
(Angular Mean Direction for each Night)

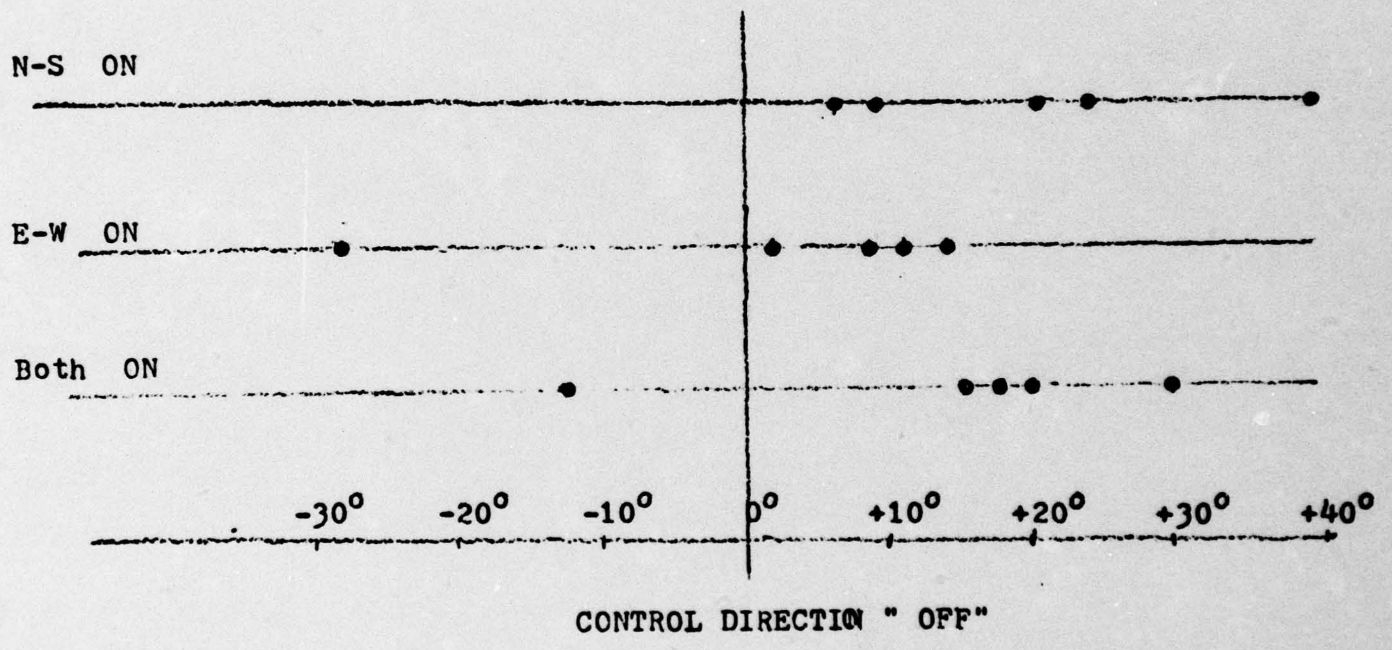

Figure 9