

HOW HIGH DOES the WHISTLING SWAN FLY?

W. A. Good
J. W. Hamblen

HOW HIGH DOES THE WHISTLING SWAN FLY? This was the question put to APL by W. J. L. Sladen, of The Johns Hopkins Pathobiology Department. He is well known for his studies of the Antarctic penguin and, more recently, his work on the migration patterns of the Whistling Swan. The name comes from its whistling wings, not from its voice. Some 50,000 of these magnificent birds arrive in the Chesapeake Bay area each November and return to Alaska every March—a round trip of 8000 miles! For several years Dr. Sladen and his colleagues have been banding and tracing the migration paths of these swans, establishing the major flyways from the Bay, over the Great Lakes, through North Dakota, and on to the tundra at the border of Alaska and Canada.

Even with the flyways established and seasonal warnings issued to the airlines, a number of mid-air “strikes” with swans are reported by planes each year. Usually the damage is minor. An exception was the case of a Viscount airliner which crashed near Ellicott City, Maryland, in November 1962 after a collision with a twenty pound Whistling Swan. Since that time the need for both migration and altitude patterns of the swans has been increasing for the purpose of informing the airlines of the bird hazard during the migration season. Hence the question: How high does a swan fly?

In connection with the Whistling Swan migration studies carried on by the Pathobiology Department of Johns Hopkins University, APL was asked to participate in the telemetry aspects of the program. Required as a pickaback rider on the swan was an airborne radio transmitter which would send location signals for 50 miles, measure altitude, perform for three months, survive the salt water environment, and still weigh under three ounces. This article relates some of the technical and operational facets of this ecological/engineering problem in the growing field of biotelemetry.

Hard facts on the swans' flight altitude are scarce. The Viscount collision occurred at 6000 ft while the swan was terminating his west to east migration jaunt. Had he really flown higher than this? Canadian radar studies on flocks of birds show some above 10,000 ft. In England the ornithologist Peter Scott cites an airline pilot observation of a Bewick Swan at 12,000 ft. The bar-headed goose of the Himalayas has been observed flying, and honking, at over 27,000 ft, where the air density is about one-third of that at sea level.

The small telemetry transmitter was introduced to the Whistling Swan program several years ago by W. J. L. Sladen and W. W. Cochran.¹ These “radio birds” have been tracked from a light aircraft for many miles. In one case the swan had flown non-stop for 600 miles in ten hours for an average speed of 60 miles per hour. The following plane had to land twice for refueling during that jaunt! The three ounce transmitters could be heard for a distance of 40 miles when the plane used a sensitive receiver and a directional antenna. Even though the “bugged” swan was never seen visually by the trackers, its specific radio frequency and pulse rate left no doubt about his identity.

¹ W. J. L. Sladen and W. W. Cochran, “Studies of the Whistling Swan, 1967-68,” *Trans. 34th North American Wildlife and Natural Resources Conf.*, Wildlife Management Institute, Washington, D. C., 1969, 42-50.

Thus one advantage of radio tracking is its ability to follow the specific patterns of known individual birds. This degree of precision is not possible with the other methods, such as radar and banding.

Since Dr. Sladen desired the flight altitude, the authors naïvely reasoned that it shouldn't be too difficult to add an altimeter device to the existing transmitter and quickly determine the flight altitude of the birds. The result of over six-months' effort did produce the altitude-transmitter units, but it was a much more difficult task than we had predicted. The following paragraphs will tell a little about the technical aspects and a few of the trials encountered in the transmitter and the altimeter developments.

The transmission of measurements from one point to another is the highly developed science of telemetry intended for use with aircraft and missiles. However, these telemetry systems were not developed with the swan project in mind. Here it was necessary to return to fundamentals and design for very low weight, long life, and simplicity. Many of these simple techniques are interestingly described in Mackay's book.²

The main effort in this paper was placed on the transmitter and its altitude device and upon improving the tower receiving antenna system. A few ideas for the future are also included.

Transmitter

The initial goals placed upon the APL design group for ten transmitters were as follows:

1. Weight (maximum)—90 grams.
2. Operating life (minimum)—6 months.
3. Primary function—to provide angle tracking plus one or more of the following telemetering data channels: (a) Altitude (first priority), (b) free air temperature, (c) heart rate, and (d) body core temperature.

Transmitter weight and operating life requirements have a major impact on overall system considerations. The resulting solution was the employment of pulsed cw as the modulation format. This places minimum power loading on the swan-borne power supply as well as permitting use of simple narrow-band receiving equipment with a beat frequency oscillator which allowed usable signal levels down to approxi-

mately -125 dBm. Thus, the selected "modulation" was compatible with items 3(a) and 3(b) above, but placed a severe constraint on design approaches to the implementation of items 3(c) and 3(d).

A careful review of the problem indicated that within the time scale available and the various constraints, APL could provide a transmitter design that would provide the tracking capability and a simple altitude measurement.

The modulation employed consists of a pulsed RF carrier in which the pulse period is controlled by an RC arrangement. An altimeter switch device functions to change the time constant of the RC arrangement from a slow pulse rate of approximately one per second when below the altimeter switch setting to twice that rate when the transmitter is above the altimeter switch height.

Circuit Details—Figure 1 is a schematic diagram of the transmitter employed. Y1 is a 14.8 MHz crystal operating in the fifth overtone mode, thus providing a frequency of approximately 74 MHz. The circuit components associated with Q1 function as a tripler output stage, providing an output frequency of 222 MHz. The transmitter employs two transistors and delivers approximately 1 mW of peak power to the antenna. The pulse duration is approximately 60 msec and the pulse rate is one pulse per second below altitude switch value (S1 open) and two pulses per second above the altitude switch value (S1 closed). In Fig. 1, S1 represents the altitude switch which, upon closing, places R4 in parallel with R3; R3, R4, and C4 determine both the

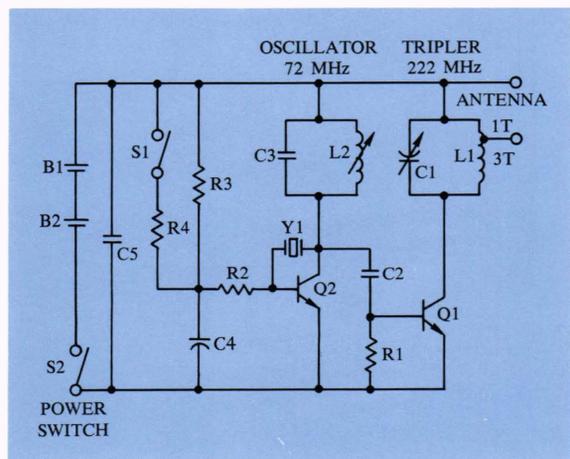


Fig. 1—Transmitter schematic.

² R. S. Mackay, *Biomedical Telemetry*, John Wiley & Sons, Inc., New York, 1968.

time between pulses and the pulse duration. B1 and B2 are Mallory RM-1 type mercury cells having a capacity of 1000 mA-hr and supplying approximately 1.4 volts. When the transmitter is operating on the slow pulse rate, a life expectancy of 4 months is anticipated. This duration fell short of the 6 months specification, but is still quite adequate for the 2 to 3 months migration journey. The duration would be reduced by approximately 2 months if the transmitter were to run continuously at the fast rate, as might be caused by the accidental entry of salt water into the switch contacts. Even in this case the transmitter is still useful for radio tracking. The complete transmitter, less harness, weighs approximately 90 grams and is 1¼ in. high × 2 in. long × 1½ in. wide. The inner case of the transmitter, as shown in Fig. 2, consists of a thin

fiber glass box which is later filled with plastic foam to provide secure mounting of components at minimum weight. The transmitter component parts, as shown in Fig. 2, are mounted on a small fiber glass circuit board with cutouts at one end to accommodate the mercury battery power supply. Table 1 shows the weight of the various components of the transmitter. Note that the power supply is the single heaviest component and the circuitry is one of the lightest components. Thus, using microcircuitry instead of the conventional parts would save only a few grams. Indeed, the power supply is the critical element in the weight. The two tubes attached to the bottom of the transmitter facilitate fastening the unit to the swan. Teflon cloth tape is employed to harness the transmitter to the swan. The transmitter is positioned between the bird's wings just back of the neck as shown in Fig. 3. This permits unrestricted motion of the fowl's wings while in flight and keeps the transmitter out of the water as much as possible. The choice of teflon cloth came about from past experiences with cotton tape when it was observed that large ice formations were clinging to the cotton tape. The teflon cloth seems to have solved this problem completely and no ice formations around the bird's harness have been observed since its employment.

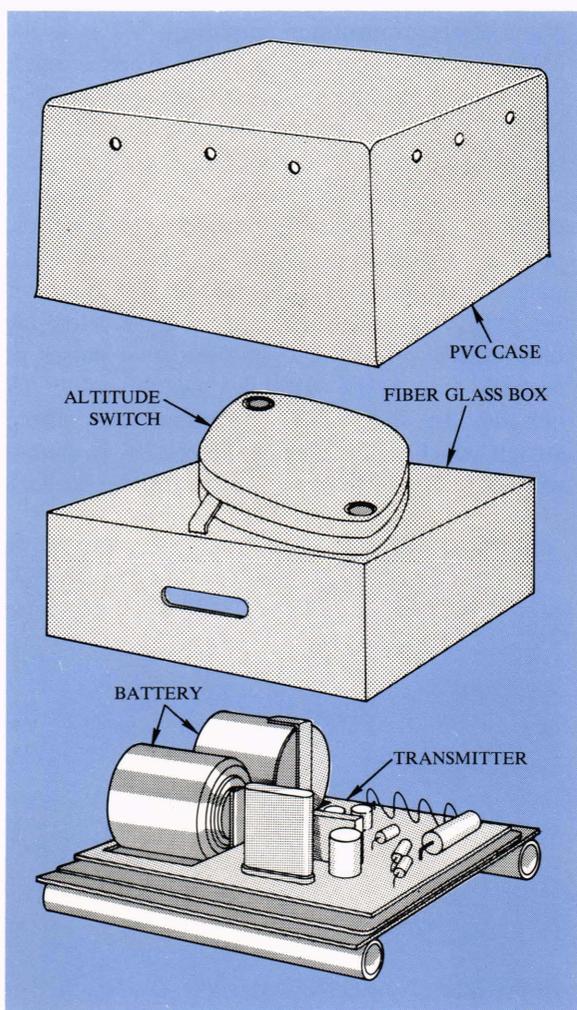


Fig. 2—Transmitter parts.

TABLE 1
WEIGHT OF MAJOR COMPONENTS
OF TRACKING, ALTIMETER TRANSMITTERS

Component	Weight (grams)	Approx.
		% Total Weight
Fiber glass case top, base & mounting tubes	17.0	19.5
Circuit chassis complete less batteries	8.4	9.6
Power supply two each Mallory type RM-1	26.8	30.3
Altimeter	21.5	24.4
PVC cover shell	5.0	5.6
Potting & RTV	9.3	10.6
Transmitter complete ready to install	88 grams	100%

A number of factors were considered in arriving at the final pulse duration and pulse rate of the transmitter. Battery life could be increased if very low pulse rates were employed. For ex-



Fig. 3—F90 swan being held by John Hamblen.

ample, one pulse every three seconds with 10 msec pulse duration was considered. It proved, however, to be very difficult to locate a weak signal with existing receiving equipment, so a trade-off between very broad pulses and low pulse rates vs. very short pulses and high pulse rates had to be determined to satisfy the practical constraints. It was also noted that when receiving the pulsed signal an apparent loss in power was noticed with pulse widths less than approximately 50 msec in duration. This was particularly noticeable at very low signal-to-noise ratios and seems to be due partly to the square law characteristic of the human ear and partly to the bandpass characteristics of the radio receiver. Thus, the pulse rate of one pulse per second and the pulse duration of 60 msec were selected after a number of field tests. These waveforms are shown in Fig. 4. Variation in pulse period due to battery voltage and temperature (from 32° to 100°F) is about 10%.

Antenna—Previous transmitters employed by the Sladen ecology team utilized transmitters made by W. W. Cochran.³ These units employed a vertical whip antenna of piano wire approximately 12 inches in length which was mounted on the swan's back and angled to the rear at 45°. The whip had a number of drawbacks which made it desirable to find a different solution to

the antenna problem. Some of the disadvantages of the whip antenna were:

1. Adverse disturbance effects on the swans which have been known to continue pulling at the vertical whips until they succeeded in removing them.
2. Aerodynamic drag and oscillation during flight.
3. Restriction of the installation of transmitters to males because of subsequent mating problems.
4. Snagging on foliage while feeding near shore or in fields.

One interesting incident occurred when a frantic bird watcher called Dr. Sladen's headquarters and reported that one of the swans she was observing had an arrow sticking out of its back. Questioning revealed that it was one of the early style transmitters with one of the whip antennas. She was advised not to pull the "arrow" out. The idea of deploying a soft wire dipole incorporated within the attachment harness evolved after discussion with various ecologists involved in the program. The technical questions that had to be answered were what the effect would be of distorting the dipole pattern by wrapping the antenna around the body of the bird and what sort of radiation impedance factors would be involved. In short, what was the radiation impedance of a swan? Discussion with

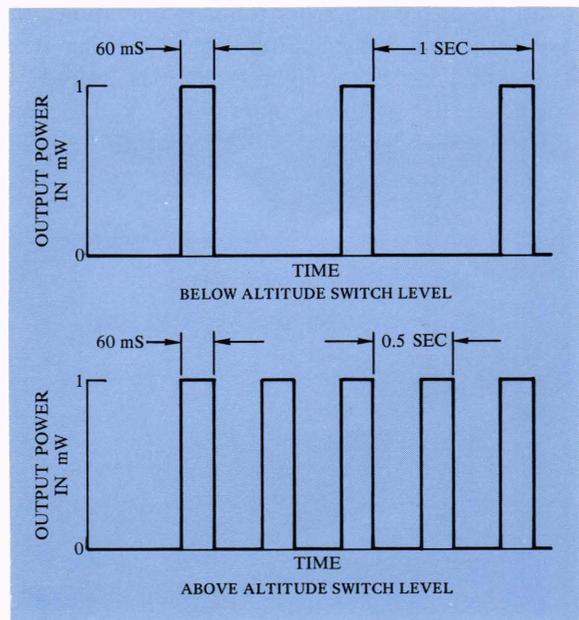


Fig. 4—Pulse waveforms.

³ W. W. Cochran, "145-160 MHz Beacon (TAG) Transmitter for Small Animals," *BIAC Information Module M15*, American Institute of Biological Sciences, Washington, D. C., 1967.

“antenna experts” produced very few concrete suggestions so it was decided to simulate a swan by filling a large plastic container with plastic foam which had been impregnated with salt water, thus simulating a warm-blooded creature (man has often been described by the medical fraternity as a rubber bag full of salt water). The test device is shown in Fig. 5 and consists of a transmitter with a soft wire antenna wrapped around a plastic foam-filled jug in a manner precisely as it would be in the swan harness installation. A series of tests was conducted while shortening and lengthening the soft dipole lengths until maximum radiation was obtained. Thus, in production the antennas were cut to the length arrived at with the “plastic swan” and no further attempt was made to tailor each transmitter’s antenna after installation on the individual swans. This technique proved to be quite successful during the pre-migration period when numerous listening tests were performed. Also flight tests employing the soft wire dipole were conducted in cooperation with the Ivy Neck Receiving Station. The tests consisted of carrying the soft wire antenna arrangement on a light aircraft and flying vectors from the Ivy Neck receiving site. Quite useful signals were observed up to a range of 75 miles, which was considerably more than that observed for the early style whip antenna.

In the actual migratory tracking operations, the Ivy Neck Receiving Station detects a rising swan and ascertains if its flight group has indeed set forth on its northerly migration. A direction-



Fig. 5—Photo of the “Plastic Swan” which is the electrical equivalent of a Whistling Swan.

finding radio-equipped light aircraft complete with pilot and ecologist radio operator is then alerted and they fly well to the rear of the swan group making the necessary maneuvers to accurately plot the flight path of the swans. A swan flight, leaving the Chesapeake area, typically takes off when the wind is out of the southeast at early morning or late evening and may fly non-stop for as much as 10 hours. Determining exact time of take-off for migration is complicated by local movement of birds as well as receiving birds resting in the water.

The “soft antenna” employed by the APL transmitters provides additional information to the listener since it exhibits strong vertical polarization from a bird resting on water and horizontal polarization from a swan in flight. Thus, a rotation of the receiving antenna helps to separate the polarizations and hence the status of the birds. When horizontally polarized receiving antennas are employed, signals from birds feeding and resting on the water as close as a mile from the receiving site are eliminated. Also, when searching for resting birds from a radio-equipped automobile, a sudden flight of a swan can be detected by signal drop-out with the antenna vertically polarized; quickly re-orienting the antenna to the horizontal position often results in a very noticeable increase in signal strength which signifies a flying bird. Thus, the change in polarization is a very valuable tool, particularly in local movement studies.

The Altitude Unit—It was hoped that an altitude device could be found which would give an output indication proportional to the height and thus provide a detailed reading of the flight altitude of each radio bird. However, no such proportional unit has been found which meets the stringent weight allowance of one-half ounce and also contains an output indicator that would easily modulate the radio signal.

After some searching it was recalled that a small pressure switch was used in the automatic controls of one of the early missile programs. A quick inquiry revealed that the tiny rugged switch was still available and at a remarkably low price of ten dollars per switch.* A disassembled altitude switch is shown in Fig. 6. The switch contains an evacuated aneroid capsule which has a

* Type ES-4 Altitude Switch, Erickson Specialties, 10915 Johnson Drive, P. O. Box 3192, Shawnee, Kansas 66203.

snap action when the external pressure drops below the design value. When the pressure is then increased the capsule snaps back to its rest position. A silver contact screw closes the electrical circuit when the capsule expands and opens the circuit when the capsule contracts. A typical switch would close at 5000 ft altitude and open at 4600 ft. The switch has a plastic case with a small vent hole to permit pressure access to the capsule. The switches are available in steps from 5000 ft to 45,000 ft. After considerable discussion three altitudes were selected for the spring migration. These were 5000 ft, 7500 ft, and 10,000 ft. The biologists would have preferred another value lower than 5000 ft, but this was



Fig. 7—Photo of swan biting the transmitter.

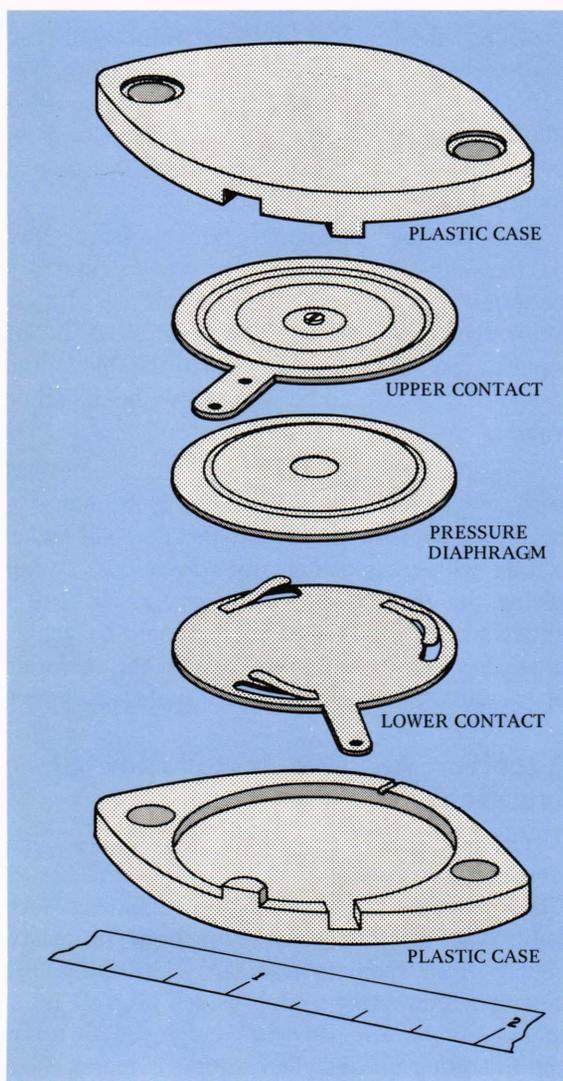


Fig. 6—Disassembled altitude switch.

not available. Hence the plan for the first experiment was simply to bracket the flight altitude values.

Considering the environment encountered by an altimeter-transmitter on a swan's back, a critical look at the packaging was taken. First, the temperature range that was arbitrarily chosen (from 32° to 100°F) seemed to present no serious difficulty. Shock and vibration wasn't really known except that the swan's flexible neck allows him to chew on the transmitter case with his tooth bill which is strong enough to crush clam shells, Fig. 7. A polyvinylchloride (PVC) plastic case was vacuum formed with 0.030 inch sheet material and thus far has passed all the swan biting tests. The PVC case was cemented to the transmitter body with a silicone sealant (Dow Corning RTV-732) which provided an excellent joint.

The most difficult problem was coping with the salt water environment. On the one hand all parts needed to be well sealed against salt water and its vapors, and on the other hand it was essential for the altimeter capsule to be exposed to the ambient air pressure. We had been told that Whistling Swans did not dive under water as ducks do so maybe the sealing would not be too difficult. The transmitter elements were carefully sealed as a separate unit so that only the altimeter switch would require a breathing seal. At first it was thought that tiny vent holes in the outside case might be sufficient to pass the air and not the water. Some laboratory tests

showed that holes of 0.006 inch diameter would hold back salty bay water to a depth of five inches before surface tension broke down and permitted entry of the water. One test unit with six holes of 0.006 inch diameter was mounted on a flightless swan. This unit survived for four days in the watery environment before the altitude switch shorted out. Then we learned that swans do “dunk” themselves when bathing and will truly dive when frightened. So the next step was to place a soft plastic film barrier between the switch and the cover to prevent entry of the water to the switch contacts but still permit ambient air pressure to the capsule. As shown in Fig. 8, a pliable tent of Saran wrap film was shaped over the switch. A test unit with the plastic barrier construction was fastened to another flightless swan for a period of fifteen days on Chesapeake Bay with normal operation of the unit resulting during the whole period. After removal from the swan, the altimeter-transmitter was placed in an altitude chamber and tested for proper altitude functioning. These tests reproduced the earlier altitude values within one hundred feet but the response lagged several minutes indicating that some of the small vent holes were plugged. The final production units employed twelve vent holes of 0.008 inch diameter to minimize the hole-plugging problem.

Ten production altimeter-transmitter units were built following the final design configuration discussed above and delivered to Dr. Sladen at the end of February to meet the normal migration departure during the month of March. Five units

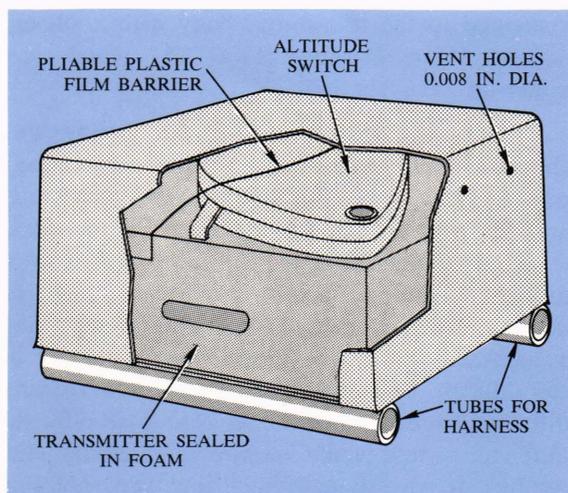


Fig. 8—Cutaway sketch of altitude transmitter.

were set at 5000 ft, 2 units at 7500 ft, and 3 units at 10,000 ft. All units were “flight tested” in an altitude chamber to verify the altitude values and to measure the high and low pulse rates.

The overall accuracy of the altitude switch is affected by three factors: the factory tolerance on the switch setting, the barometric pressure, and the component of ram pressure due to flight speed.

The factory setting tolerance of ± 1000 ft is reduced to a small value of ± 100 ft when actually measured in a pressure chamber. For example, a “5000 ft” switch might give $4800 \text{ ft} \pm 100$ ft in a series of test runs in the chamber.

Since the aneroid capsule measures absolute pressure, the derived altitude value will vary with the daily barometric pressure variation. This will usually range about ± 500 ft, but could be almost completely eliminated if the local air pressure conditions were known at the time of measurement.

The possible maximum ram pressure effect on the ambient static pressure was calculated to be equivalent to less than 100 ft of altitude. With the vent holes on all four sides of the square case it is estimated that the likely ram pressure effect would be well below the maximum value.

Considering all known factors, the overall accuracy of the altitude switch is estimated to be about ± 1000 ft around the nominal switch setting without applying any corrections. By applying the corrections a tolerance of ± 200 ft about a measured switch value should be achievable. For the initial experiments the accuracy of ± 1000 ft was considered quite acceptable.

Receiver Antenna Installation at Ivy Neck

The Ivy Neck Whistling Swan Monitoring Station is located on the western shore of the Chesapeake Bay just south of Annapolis, Maryland. The listening station functions to receive signals from radio instrumented birds migrating North in the spring and provides take-off information to the aircraft crews employed to follow the migrating groups. The station is manned day and night around the clock during the spring migration season between mid-March and early

April. A new antenna receiving system was designed by APL for the 1971 migration. As shown in Fig. 9 the installation consists of an APL-designed volute omnidirectional antenna plus an eleven element yagi directional antenna. Low-noise, high-gain, solid-state preamplifiers were designed for each antenna and located within a few feet of the antennas. Listening tests with a "swan" transmitter attached to a small aircraft yielded usable signal-to-noise ratios at a range of 65 miles with the omni-antenna and 75 miles with the yagi.

The yagi antenna has a beam width of approximately 25° and with an electric rotator system can be pointed in 6° increments. Listening tests indicate the directional capabilities are adequate but that there is room for some improvement. One possible approach would be to use two yagis as an interferometer; such an arrangement would provide a choice of two patterns. One pattern would have a beam width of 12° and one would have a sharp null along the directional axis which would allow pointing accuracy in the order of 5° , depending on the spacing of the yagis. This technique would use two receivers, one receiver connected to the sum pattern and the other to the difference pattern, thus avoiding the possibility of an erroneous pointing due to sidelobes. However, a single receiver could be switched between the patterns to obtain the same result.

While working to produce transmitter units for the unalterable schedule of the spring migration a number of new ideas suggested themselves. A few of these follow in the next section.

Future

Two major problems which should be considered for future migrations are: (a) Power supply life and (b) electronic surveillance relative to start of migration.

The first problem deals with extending the life of the power supply and, if possible, reducing its weight. As indicated in Table 1, the power supply represents about 30% of the transmitter's total weight and yields about 4 months operating time. One possible solution to this problem is the use of small (50 mA-hr) nickel-cadmium sealed button cells along with an adequate solar panel which would keep the cells charged, hopefully, for a long period of time. An experimental solar

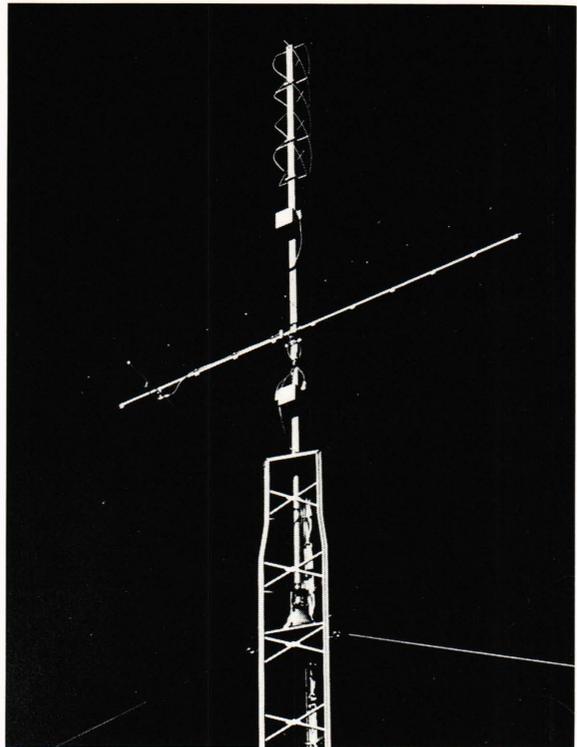


Fig. 9—Photo of receiving antenna tower showing the omnidirectional and the directional antennas

panel consisting of twelve $1\text{ cm} \times 1\text{ cm}$ cells with an open circuit voltage of 6 volts would seem to yield enough current in bright weather to provide a total recharge in approximately two days, including the operating current normally drawn by the transmitter. Such problems as overcharge and reverse polarity of the cells during a prolonged sunless period are being considered and the results of the work to date indicate that an adequate nickel-cadmium solar panel power supply system is quite feasible and should result in a very long life (perhaps a year or more) at no increase in total transmitter weight. Problems such as feathers covering the solar panel and proper harnessing have been discussed with ecologists and possible solutions, although untried, have presented themselves.

The second problem has to do with the difficulties encountered in monitoring a large number of instrumented birds during the several weeks while the birds are in process of preparing themselves for their long flight to the Arctic regions. Typically, a number of short "round-the-bay" flights are noted and it always remains a problem to cover all instrumented birds and determine

whether they are actually starting to migrate or are just restless and involved in local movement. In the past, the technique of separating the birds has been that of placing each transmitter on a separate frequency and thus separating instrumented birds by frequency. This presents the problem of covering all frequencies with the relatively simple receiving equipment currently available to the ecology community. Another attack that has been discussed is the use of a single frequency with pulse-coding techniques to identify the individual birds. This relieves the surveillance problem in one respect but could cause considerable difficulty in identification of an individual bird. Thus, work remains to arrive at an optimum solution to this problem. A review of the literature available on wild life tracking experiments indicates that most experimenters are using the frequency division principle. However, they are instrumenting a relatively small number of animals; quantities of one or two are typical. One example is the Craighead experiment with the grizzly bear in Yellowstone Park.

As indicated in the goals set forth at the beginning of the program, ecologists would like to measure physiological functions such as heart rate and body core temperature. However, at the same time the weight of the equipment and the operating life of the equipment must be maintained. That is to say they desire to increase the instrumentation but cannot allow an increase in the transmitter weight or a decrease in transmitting life. Frequency-modulated, amplitude-modulated, or any of the continuous carrier methods are almost categorically ruled out because of their increased load demands on the transmitter power supply. Thus, it would appear that the proper approach to the problem would be to employ some subtle techniques of pulse-position modulation, pulse-width modulation, or pulse-rate modulation with the existing pulse transmitters and insure the continued use of the very sensitive but simple cw receiving equipment now in use. This is indeed a complicated problem from the modulation format viewpoint with the existing ground receiving equipment. In addition to these problems, the methods of obtaining body core temperature and heart rate of a Whistling Swan in flight and the associated end instruments and modulators must also be studied. Therefore, for the next migratory period it seems most likely

that the effort will be restricted to the power supply problem with an improved altitude measuring system as first priority.

Another technique that might be used for flight altitude determination eliminates the need for a radio transmitter, but is still in the idea stage. This technique would require an altitude switch, a tiny mercury cell, a resistor, and a coulometer. The coulometer is a tiny mercury column in which an electrolyte gap migrates along the column when current is passed. The coulometer would simply indicate how many hours the altimeter switch had been closed during the migration period. In other words, it would record the number of flight-hours above the switch altitude. Of course, the bird would need to be captured after the migration so the biologist could read the coulometer value. The total weight of this device would be less than one ounce and perhaps could be mounted on the existing plastic neck collar so that an additional harness would not be needed.

Seven of the altitude-transmitters were installed on Whistling Swans in the Chesapeake Bay during March 1971. Six of the swans successfully entered into the migration pattern and their radios are being monitored along the migration route. The results of the altitude units will be known in a few months after all of the field data have been collected. Radio swan number seven refused to migrate so he was captured and relieved of his radio after a month on the water. He is now under observation to determine the cause of his errant behavior.

As far as we know this is the first attempt to directly measure the altitude of single known birds in flight. Hopefully the results of this experiment will add to the knowledge of the flight habits of the majestic Whistling Swan and in turn will assist in reducing the number of bird collisions with aircraft.

Acknowledgment

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