In Cheeseman, C. L. and R. B. Mitson, editors, Telemetric Studies of Vertebrates.

Symp. zool. Soc. Lond. (1982) No. 49, 1–18

State of the Art of Biotelemetry in North America

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SYNPOSIS

In telemetry from animals, the state of the art is in applying existing technology from a variety of sources to the problem. Currently, primary emphasis is on factors that increase the quantity and quality of the data collected. Factors influencing the reliability and quality of transmitters and receivers, such as batteries, attachment design, component selection and encapsulation design, are discussed. Also covered are new design techniques that enhance the quality of data on a second level, such as tags that telemeter temperature or pressure and the automatic or remote data collection systems. A short summary of the state of the ar in satellite tracking of wildlife is also given. Finally, future directions in telemetry are discussed.

INTRODUCTION

The use of telemetry started in earnest in the early 1960s after the transistor became readily available. Since that time the use of telemetry has extended to projects all over the world and has undergone an evolution in equipment design and in technique of use. This chapter will outline the current state of the art in North America and indicate some of the probable future directions of progress.

During the last ten years, much of the work in radio telemetry has moved from laboratories funded to do both the development and the field work, to groups that are using radio telemetry in fieldwork but are buying their equipment from commercial sources. As a consequence they are buying known equipment or equipment from catalogs, so much of the impetus for new development is gone. In addition, most of the commercial providers of the equipment are small business operations with little funding available for engineering development, and they usually have very small engineering staffs. Thus although there continues to be improvement in equipment design, it is occurring at a reduced rate.

TRANSMITTERS

Design

A wide range of frequency bands are being used for radio tracking. The greatest use is in the 150–151 MHz and 164–165 MHz bands. According to U.S. regulations only two bands are authorized for general use in wildlife tracking: they are the 40.66–40.70 MHz and 216–220 MHz bands (Federal Communications Commission, 1976). Many groups, however, operate at other frequency bands with special use permits. Biomedical devices may also be operated under wireless microphone provisions.

Most transmitters follow the general design shown in Fig. 1. Depending on the frequency used, the crystal is operated at its third, fifth or seventh overtone mode. If the output frequency is below about 85 MHz the crystal is operated at the output frequency and the second stage is used as an amplifier. If the frequency is above 85 MHz the second stage is used as a frequency doubler or tripler. In either case the first stage is tuned to the crystal overtone frequency and the output stage tuned to the desired output frequency.

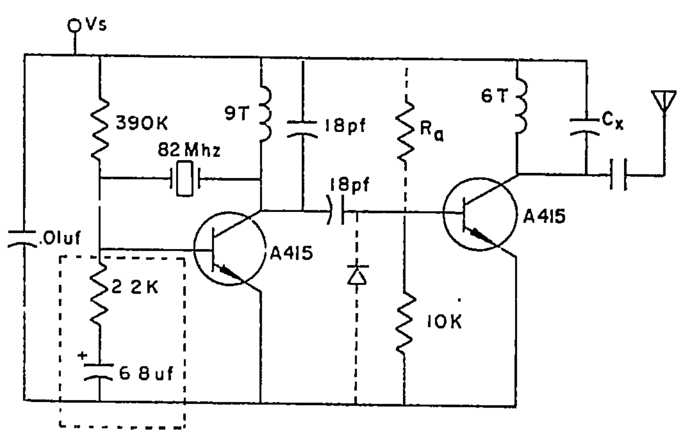

FIG. 1. Common transmitter circuit. Values shown are for 164 MHz. Resistor and capacitor enclosed in dashed lines form pulsing circuit. Resistor R_a and diode are used in some low voltage circuits.

At lower voltages (1.4, 2.8 V), the second stage is sometimes operated closer to class A mode than to class C by the addition of biasing resistors. A diode is also sometimes used in the base of the second stage to reduce base storage time. In all cases it is desirable to operate the first stage collector peak voltage as close to twice the supply voltage as possible. The second stage then acts as an impedance transformer with little or no voltage gain. Matching to the antenna is done by tapping the output coil down from the collector. For a quarter wavelength antenna the coil is tapped near the center. Most transmitter design is done by "cut and try"; very little theoretical evaluation of the potential design is done. This is partly because the technical capability to do so is not available, but probably a more important reason is that the nonlinearity of the devices and the conditions imposed on them by the user render the theoretical design almost useless on an animal. The transistors used are small signal radio frequency types such as the 2N918. Transistor selection is not critical if the device has adequate gain at low current levels. Most telemetry groups have a favorite transistor type that is used in all their designs.

Tuning and Testing

In most cases the transmitter is tuned for maximum output after assembly, by using a receiver, or some other device that can measure the relative output of the transmitter in conditions as close as possible to those in which it will be used in the field. The goal is to take as many factors into consideration as possible. The present author uses a short antenna connected to a preamplifier, the output displayed on an oscilloscope from which a measure of transmitter power is made. It should be emphasized that building transmitters of this type is as much an art as a science, and that generally the greater the experience the better the transmitter. For example, with experience one can recognize how the transmitter should be tuned to compensate for the effects of encapsulation (potting) and packaging.

Each group probably has its own system of component selection and testing; in our case, all crystals are checked for reliable operation in a test circuit. This indicates that the crystal has a low series resistance and that it does not have spurious emissions near the desired response. We use this test rather than the actual measurement of spurious emission because it is faster and easier. Most of our selection criteria are the result of experience. Transmitters are tested at each stage of construction; if they do not behave normally they are not used. Those selected for use are subject to further checks by running them for at least 24 h, after which they are temperature-cycled and checked again. If a large number of transmitters are used they are further checked for frequency drift *vs* temperature to ensure that frequencies will not overlap. This consists of a check of frequency at three different temperatures within the likely temperature range. Almost all frequency drift occurs because of changes in the crystal, and it is also found that crystals of the same manufacturing batch have a similar temperature drift characteristic.

Since the design of all transmitters is about the same, their performance from the various sources should also be similar. In fact comparative tests made by several laboratories indicate that this is the case.

Reliability

Thus, the major emphasis in design is on making the transmitters more reliable, and this improved reliability is really the major change that has occurred over the last ten years. The improvements in reliability can be grouped into component selection, potting, and testing. Improvements in batteries or power sources will be discussed later.

The most significant factor in transmitter reliability is the encapsulation, or potting, of the transmitters. It is thought that more transmitters fail because of poor potting material or technique than for any other reason. Unfortunately the materials which are the best in terms of reliability are also often the most difficult to use. The goal in any potting is to protect the transmitter from conditions in its environment and it is also important that the potting material be compatible with the attachment materials and the components. As an example, in our early work we used dental acrylic because it was convenient and readily available. Our first problem occurred when transmitters failed after about three weeks in the field. After much testing we found that the solder flux being used reacted with the potting material, causing a conductive bridge across the transistor leads. This was corrected by carefully cleaning the transmitter after assembly. A second problem occurred when transmitters again failed prematurely, this time while on ducks, owing to breakage of the P.V.C. (polyvinyl chloride) tubing used over the harness wires. The cause was found to be leaching of the plastizer from the tubing by the dental acrylic, causing the tubing to become brittle and break with a subsequent breaking of the harness wires. Since that time we have exclusively used resins designed for electrical encapsulation. These resins have several advantages. They are usually less costly and are specified in greater detail with important parameters such as conductivity and moisture absorption indicated. To ensure the adequate penetration of parts a low vicosity material is necessary and this requirement is what makes most people avoid electrical resins. It would be much more convenient to use a paste-like material such as dental acrylic that would not run off. These materials are desirable because molds are not required and because a minimum amount of material can be used, reducing weight. Unfortunately, however, it is extremely difficult to get adequate waterproofing using paste-like materials. Several techniques are used in potting transmitters to ease the mold problem. For the larger transmitters, the entire package is made in the shape of a cylinder; potting can then be done inside a tube or syringe barrel. Another technique is to pot in two stages. In the first stage the electronic parts are covered with an electrical resin, and then harness or attachment parts are added using a paste adhesive, thus making the mold simpler and more universal. Use of translucent materials aids in the inspection of the quality of encapsulation.

Some manufacturers enclose all parts in metal cans which can be solder-sealed and for reliable operation these should be evacuated and backfilled with dry nitrogen. The problem of what to do with the leads as they emerge from the package is still present, although less critical. This technique has the additional advantage of not changing the transmitter tuning by potting. Either technique is reliable provided adequate quality control is used. The importance of quality control in encapsulation techniques cannot be overemphasized. It is the single most important cause of transmitter failure.

Power Sources

Batteries

Most battery powered transmitters in North America now use lithium cells as power sources. They have a greater power to weight ratio and perform much better in cold temperatures. A wide range of sizes is currently available (Table I), although small sizes with sufficient current capability are not readily available. Additionally at least one U.S. company now makes custom lithium batteries at about twice the cost of off-the-shelf types (Battery Engineering Inc., 1980). For good reliability, only hermetically-sealed cells should be used. Some provision also must be made for cell expansion in cold weather or the expansion will crack the potting. In small transmitters (under about 8 g) mercury batteries are still used. Silver oxide batteries have fallen into disuse because of the high and unstable price of silver.

Solar

Solar power transmitters are being used in a number of studies. Although we have no accurate figures on the number being used, we estimate that less than 10% of the transmitters are solar powered.

TABLE I

Summary of the most commonly used batteries

Battery number	Type	Voltage	Weight (g)	Life days (mA)	Height (mm)	Diameter (mm)
			Lithium			
BR 1/2 A	National[a]	3.0	9.5	31	22.5	16.8
BR 2/3 A	National	3.0	13.5	50	33.4	16.8
BR C	National	3.0	47.1	208	50.0	26.0
440	Power Conv[b]	2.8	11.3	42	33.2	16.2
400-(AA)	Power Conv	2.8	12.5	50	49.5	14.0
660-2(3/4c)	Power Conv	2.8	32.6	100	41.4	24.1
660 (C)	Power Conv	2.8	40.0	125	50.8	24.1
660-3(1 1/4c)	Power Conv	2.8	48.0	158	59.7	24.1
550 D	Power Conv	2.8	83.0	333	61.0	33.2
660-4	Power Conv	2.8	100.0	416	49.5	41.6
660-5	Power Conv	2.8	221.0	1042	113.0	41.6
660-5AS	Power Conv	2.8	221.0	1250	113.0	41.6
LO-37S	Mallory[c]	2.9	6.5	19	23.3	13.9
LO-32S	Mallory	2.9	12.0	40	35.0	16.5
LO-28	Mallory	2.9	43.0	146	50.0	24.4
LO-29S	Mallory	2.9	48.0	167	50.0	26.0
LO-27S	Mallory	2.9	58.0	208	60.0	26.0
LO-30S	Mallory	2.9	62.0	279	60.0	30.0
LO-26S	Mallory	2.9	85.0	375	60.0	34.0
LO-25S	Mallory	2.9	95.0	400	50.9	38.6
LO-50S	Mallory	2.9	207.0	917	114.3	38.6
			Mercury			
RM-212	Mallory	1.4	0.3	0.7	3.3	5.6
RM-312	Mallory	1.4	0.6	1.8	3.6	7.8
RM-675	Mallory	1.4	2.6	7.5	5.3	11.6
RM-625	Mallory	1.4	4.2	14.6	6.0	15.6
RM-630	Mallory	1.4	4.8	14.6	6.0	15.6
RM-640	Mallory	1.4	8.0	20.8	11.2	15.9
RM-660	Mallory	1.4	7.6	25.0	7.6	17.4

[a] Matsushita Electric, Japan.
[b] Power Conversion Inc., Mount Vernon, New York.
[c] P. P. Mallory, Inc., Tarrytown, New York.

Two areas of application seem to predominate: the first is with mid-sized birds such as grouse that can carry transmitters in the 25-g range. With solar cells life times of two years or more could be expected, whereas using lithium batteries at normal drains four to six months are typical. In fact the life of the animal or harness is most often the limiting factor. Solar applications typically use as the storage device a 20 mAh capacity nickel cadmium battery (Church, 1980), which is a rechargeable cell. Such cells are often unreliable, partly because it is difficult to control the rate of charge, or regulate the discharge cycle. Fortunately, with failures of this type the transmitter will operate at least intermittently for a period, allowing an opportunity to recapture the animal. The second application is the use of small solar-powered transmitters as ear tags on large animals, where because of growth rate, or other characteristics, neck collars cannot be used. A number of these transmitters have been tried on moose (*Alces alces*) and caribou (*Rangifer caribou*). However, keeping the orientation correct so that sufficient light hits the transmitter solar cell has been a problem. Transmitters powered by primary batteries such as lithium cells are generally considered more reliable than solar cell systems.

Power Output

Typically the power output of the transmitters just discussed varies from about 1 mW to 10 mW. In many applications a higher output power is desirable. To achieve this a different design must be used and an example of the design used by this laboratory is shown in Fig. 2, where the component values depend on frequency; nominal values for 164 MHz are given. The power output of this circuit is 250–300 mW using a 5.6 V source and this can be easily increased by increasing the battery voltage. The design is conventional; the first stage operates as an overtone oscillator, the second stage as a doubler or tripler and the final stage as a power amplifier. Tuning of this circuit is rather critical if maximum power output is to be achieved. Additionally, tuning is effected by the potting. Compensation for this and for different antennas is achieved by using the two variable capacitors which are adjusted after potting. These transmitters have been used on seals, manatees and polar bears. In the case of polar bears two transmitters were used on each animal, one high power, the other low. All high-powered transmitters operated at the same frequency; each of the second, low power, transmitters operated at a unique frequency to identify the individual animal. Thus search time can be optimized since only one frequency needs to be monitored. Once the transmission is found, all possible frequencies are scanned to identify the individual animal.

Sensors

Although various types of transducers have been added to transmitters, the number of applications remains low. The addition of temperature measuring circuits has been the most common; a typical circuit is shown in Fig. 2 where a thermistor is used. In this and most similar circuits, the pulse rate is varied as a function of the measured

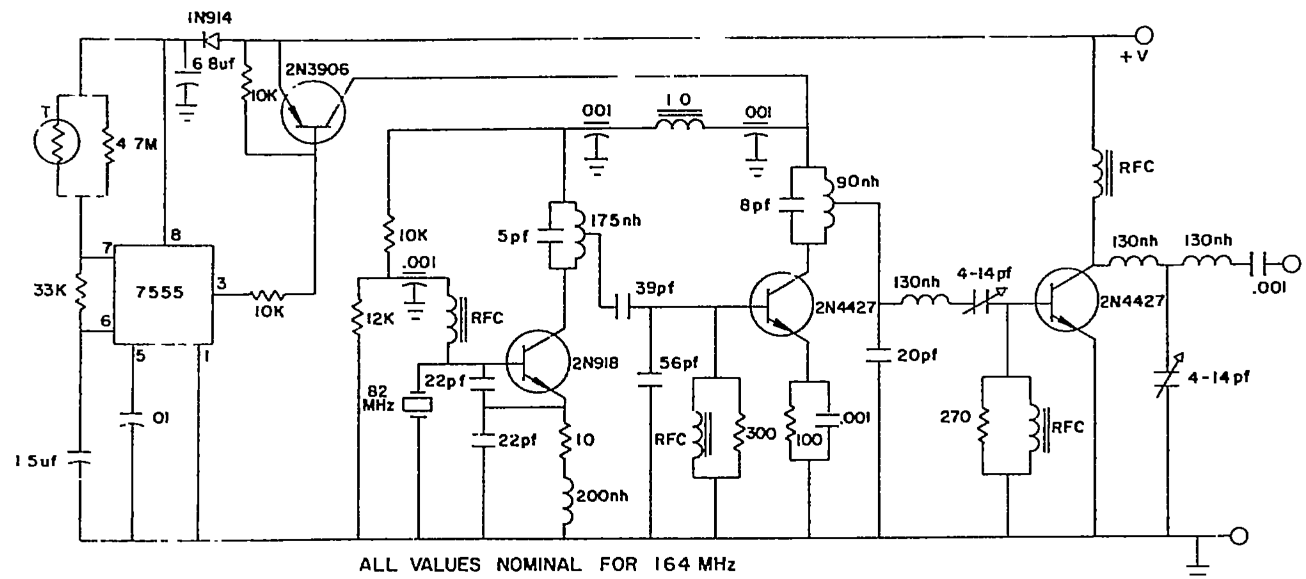

FIG. 2. Transmitter circuit used where higher power is needed.

parameter. Most do use thermistors and thus are non-linear which is a disadvantage for automatic data recording, since a separate curve must be made for each transmitter. Base/emitter junctions and other linear devices have been tried; most, however, operate at current levels which are too high for application in lower power devices.

Pressure, heart rate and a number of other functions have been measured, almost all by means of the same basic transmitter circuit. In the example shown (Fig. 3) the amplifier is a voltage to current converter; the current being converted to a pulse rate or width. To save power the bridge can be turned off between pulses as shown in this circuit. A variation of these circuits was used on elk, where an implanted transmitter sent the heart-rate signal to a collar transmitter for retransmission (Weeks, Long & Cupal, 1977).

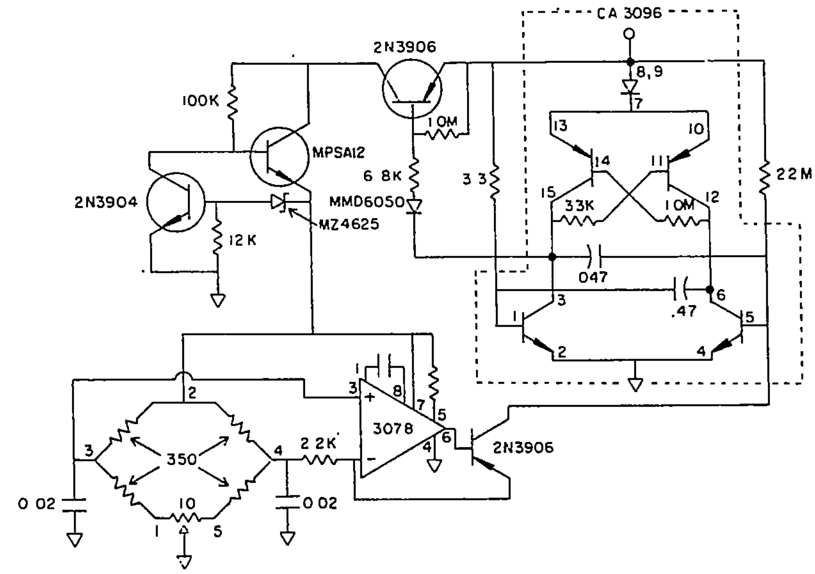

FIG. 3. Circuit diagram of transmitter used to measure pressure (depth).

The most common sensing transmitter is one used to detect the cessation of movement and it is most often used as an indicator of mortality. The circuit used by this laboratory is shown in Fig. 4, but most others are similar. A mercury switch is used as the motion sensor and is used to reset a counter. If activity stops the counter is no longer reset, and will count up to its full value; on reaching its full value the decode "out" is set, which in turn changes the pulse rate of the transmitter. The clock inhibit line is used to stop the counter until another reset is received. The delay time, which is the time

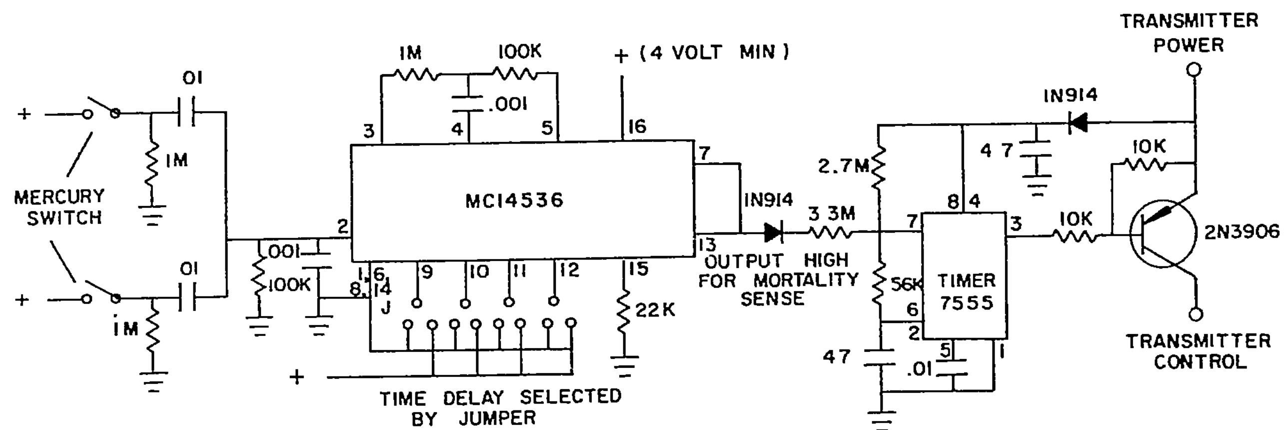

FIG. 4. Circuit diagram of mortality sensing transmitters.

from the last reset to mode change, is usually from two to four hours. Variations of this circuit are used; some have several switches mounted in different positions to reduce the sensitivity to different collar orientations. Some earlier circuits used a mercury switch or other device to momentarily change the pulse rate (Swanson, Kuechle & Sargeant, 1976; Knowlton, Martin & Haug, 1968). These are satisfactory if there is sufficient time to monitor each individual.

Transmitters for Monitoring by Satellite

Tags for monitoring by satellite have been proposed for a great number of applications. In North America, using Nimbus VI, tags have been used on polar bears, sea turtles and dolphins (Kolz, Lentfer & Fallek, 1980; Kuechle, DeMaster & Siniff, 1979). The polar bear and sea turtle experiments were moderately successful but those with dolphins were not because the dolphins did not surface long enough to give adequate transmission times. While the Argos system is currently operational, and animal transmitters have been approved as "operational platforms", no North American groups appear to have programs to track animals using Argos. This is probably because most animals can be tracked by conventional means at lower cost, while others are either too small to carry the tag needed for satellite monitoring, or have other characteristics that make the use of these tags difficult. Whales, dolphins, and long range migrating birds are examples of cases where satellite tracking would be helpful, but where application has proved difficult.

Attachment

Attachment of transmitters to animals remains one of the most nebulous and difficult areas. Attachment becomes a greater problem as more of the equipment is ordered from catalogs rather than being custom designed. In many cases an investment is made in material before the attachment is tested. Thus as problems are encountered it often becomes a case of make-do with available material.

Most neck collars are made from fabric impregnated rubber belting material with the transmitter and batteries fitted at the bottom. The antenna is usually run up the side between two layers of belting material which are riveted or sewn together. Molded urethane collars are also used. They have the advantage of ease of battery replacement, but require molds which can be expensive.

A few projects use implanted transmitters, however, few data are available on their success (Melquist & Hornocker, 1979). Our experience with white tail deer and badger indicates that implantation of transmitters is no small problem. The major difficulty is in keeping the transmitter in place, and experience has shown that the range of an internal transmitter is much less than that of an external transmitter. This is to be expected because of the need to transmit through the body tissue and also because usually the antenna must be kept short, thus reducing efficiency. A notable exception to these comments is the use of implanted transmitters on fishes where the range of internal and external transmitters is about the same for low frequencies (Winter *et al.*, 1978).

RECEIVERS AND RECEIVING SYSTEMS

Introduction

The basic design of receivers has remained the same over the last ten years or more. Most of these receivers are of the double conversion superheterodyne type. Enhancement in terms of output options and controls is varied. An example is the use of a frequency synthesizer for tuning rather than variable coil/capacitor (LC) or crystal tuning. These receivers, when used for transmitter searching, allow faster progress if a large number of transmitters are to be tuned. Precision of tuning frequency is also better than in LC types. Their primary advantage is, however, that scanning and memory functions can be easily added; for example, if transmitters are to be located by aircraft, all the transmitter frequencies can be programmed into the receiver memory. The time that the receiver is to remain tuned to each frequency can also be preset, depending on transmitter pulse rate, transmitter range and flying speed, thus increasing the probability of finding a signal. If the operator hears a signal he notes its presence or, if he wishes, he can stop the scan to localize more precisely. This results in more accurate sampling and reduces the work of the operator.

Most of the receivers have similar specifications. Bandwidths vary from about 500 Hz to 5 kHz. Experience of aural signal detection has shown no advantage in reducing the bandwidth below 3.5 kHz, probably because the ears are able to act as a bandpass filter (Hamilton, 1957). Noise figures are also reduced to the level where further reduction will yield no advantage because atmospheric and antenna noise will be higher than receiver noise. A key factor in receiver design now being recognized is the need for a wide dynamic range. This is the range of signal level that can be handled by the receiver. If it is too low, the receiver will tend to overload at high signal levels, making measurement or localization of the signal difficult. The typical dynamic range is 30 dB, although ideally it should be about 60 dB for optimum performance.

Many receivers have a meter to give an indication of signal level which can usually be output to a meter jack, so that a paper chart recorder can be used to monitor activity. A high dynamic range receiver is needed for successful operation of these activity recorders, but the interpretation of data is often difficult because the activity categories are not discrete enough. Most studies use only three classes, inactive, active, or absent. Strip chart recorders can be used, with scanning receivers to scan a number of transmitters; however, deciding which animal channel is where on the strip chart is difficult. A better approach is to use multiple pen recorders so that each animal channel will always be on the same pen. If the activity can be modulated into an on/off mode the system can be made very reliable by the use of phase-lock-loop devices as detectors because, being correlation detectors, they offer high noise rejection and a wide dynamic range. We have used this scheme in a number of applications with a 20-pen Esterline Angus event recorder to note the presence or absence of animals.

Automatic Data Recording Systems

A few automatic data recording systems are in use; they are illustrated by the following examples. The first is the Radio Tracking System at Cedar Creek (Cochran *et al.*, 1965). Its operation has been described in the literature; only a few of the pertinent points will be discussed here. This system uses two towers with antennas that rotate once every 45 s. The antennas are two Yagis spaced by two wavelengths and fed in phase. Received signals are fed to a central station where pairs of receivers are tuned to individual transmitters to determine the bearing of the animal in relation to the station. An ideal antenna pattern, stored in the computer, is matched to the signal from the animal in a correlation process; the point of maximum correlation is the bearing to the animal. With the bearing from the second tower the x, y, co-ordinates are determined, the entire process being controlled by a minicomputer. The x, y co-ordinates along with a index of signal quality are output to magnetic tape for later data reduction. The system can sample animals in groups of ten every 1.5 min and although it is quite simple in design, it has proven reliable over its 15 years of operation. Various other techniques have been tried in attempts to develop a more portable and less costly automatic location system. Most of these have employed electronically rotated antennas (Marten, Evens & Bowers, 1971). A few have been used in the field, but none has seen wide use. The principal problem is the high signal level needed to determine an accurate location. A typical signal requirement is −100 to −110 dBm – contrast this with the usual signal detection by the ear of −143 dBm. The problem with signal level is caused in large part by the short on-time of the transmitters which is typically 20–30 ms. With such short times it becomes a matter of instantaneously determining the location, thus precluding the use of any signal enhancement processes. One application where these systems have found use is in tracking ocean mammals which surface for only short periods of time. In such cases the human operator suffers many of the same handicaps, i.e. short signal duration, as the automatic system. Additionally it takes the human operator some time to determine the direction of signal arrival. When the transmitter is used in the ocean a saltwater switch is used to turn it off whilst it is submerged. When the animal surfaces the transmitter can be kept on for a longer period, because the duty cycle is already low, since the animal is submerged most of the time.

Another example of an automatic system was one built to locate fishes as they swam along experimental channels, in order to determine their response to temperature and various other pollutants (Kuechle, Reichle *et al.*, 1979). In this case the transmitters were confined to a linear dimension. To determine the location of the fishes, antennas were placed along the channels at 33-m intervals, and could be fed into a common signal cable by command from a central station. The signal level at each antenna was measured and stored, and after all the antennas were scanned, the antenna with the maximum signal level was determined. Average noise level was also measured to give an indication of signal quality. The entire process was controlled by a RCA 1802 microprocessor. This also controlled the sampling interval, receiver tuning and time keeping. Data in this experiment were output to a printer which recorded time of day, animal number, antenna with the maximum signal and an index of signal quality. In this sytem the fishes are located to ± half the distance between the antennas.

It can be seen that the automatic location systems are special applications; to our knowledge no general system exists that can be taken to a field situation to determine transmitter location. The systems currently in use can determine proximity by measuring signal strength, or they require high signal levels. The only exception is the one in use at Cedar Creek; however, it requires too much support to be considered portable.

Receiving Antennas

Antennas will not be discussed in general, for their characteristics are well known. The most widely used in North America is the multi-element Yagi. Loops are used for lower frequencies and sometimes for close-in location.

Aircraft are often used in North America to track wider ranging animals. A complete description of antenna patterns, together with mounting and operating recommendations for aircraft use, are in preparation (Gilmer *et al.*, in press). In general, high-winged aircraft are used with the antennas mounted below and to the front of the wings, pointed away from the aircraft and slightly downward. Location is determined by switching between the right and left antennas to determine whether the transmitter is to the left or right. Further resolution can be achieved by flying smaller and smaller search patterns. Experience is a big factor in locating transmitters from aircraft.

FISH TAGS

Radio frequency (RF) tags have been used to track fishes for some time. The success of RF tags depends on the conductivity of the water; as this goes up, range goes down. Figure 5 gives theoretical and measured results for several conductivities; a typical surface range for the transmitter circuit of Fig. 1 is about 3 km. The importance of the relationship of depth and conductivity can readily be seen. Another important factor in fish tag transmitters is that the tuning and antenna matching be adjusted for operation in water. Antenna loading in water is very different from the loading in air and must be compensated.

Acoustic tracking is used where the underwater attenuation is high, precluding the use of RF tags. This includes all salt water and fresh water with conductivity of about 0.50 S/m (mho/m) and above. Between 0.01 and 0.05 S/m, which tags (acoustic or RF) should be used, depends on the depth of the transmitter (see Fig. 5).

Ranges for the acoustic transmitters in fresh water are typically 0.5 to 1.5 km but depend on the output power and the losses due to absorption. Higher power transmitters have been used: for example we have used transmitters which develop sound pressure levels of 165

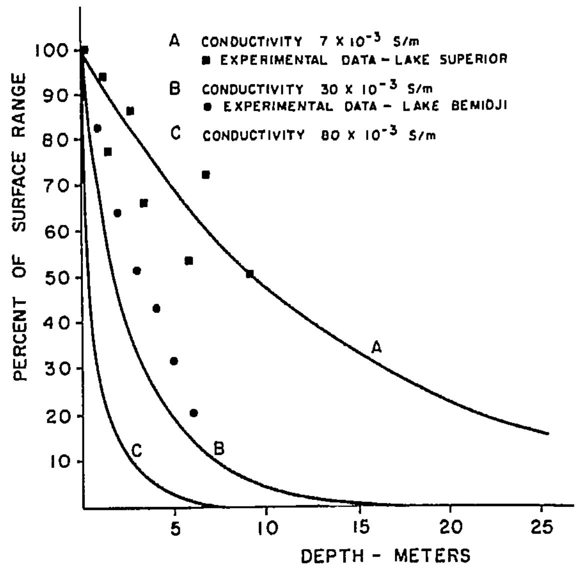

FIG. 5. Percentage of surface range versus depth for several water conductivities. Solid lines are from theoretical calculations.

dB re 1 μPa at 1 m which yielded ranges of about 3.5 km. The pressure level of tags in the USA is normally 145 to 155 dB re 1 μPa at 1 m.

Location is usually by means of directional hydrophones. A few applications have used a three-hydrophone array and time of arrival to determine location (Kuechle, Thomas *et al.*, in press). Location can be graphically determined or a hand-held programmable calculator can be used. The latter system is restricted to fixed locations because accuracy depends on the three hydrophones remaining in a fixed position.

Potting of transmitters is done by inserting the electronics in a plastic case, filling with oil or other inert substance and sealing the cap, or by complete encapsulation using epoxy resins or urethanes. There is a preference for urethanes because of their good acoustic transmission characteristics. A good description of acoustic tracking is given by Stasko (1975, 1977).

FUTURE DIRECTIONS OF PROGRESS

Transmitters

Little change in transmitter design is expected. Most designs are reliable and operating near optimum output levels. More forms of modulation are likely to be added to transmitters, especially if they give better indication of what the animal is doing. There is also some interest in having all or many of the transmitters on the same frequency with some form of coding to identify individual animals. The primary limitation upon developments in animal transmitters is size and weight restrictions, although cost is also a factor.

Receivers and Receiver Systems

Receivers will probably undergo some improvement in reliability and ease of operation. Improvements that will yield greater range are unlikely. Most improvements will probably occur in the recording of data, perhaps on digital cassettes, so that data can be easily transferred to a computer for analysis. Some advances in unattended location systems are likely but no significant move toward the recording of physiological data is expected, although most of the technology is available. One great hindrance to the improvement of equipment and techniques is that very few laboratories are actively engaged in engineering research and, whilst commercial organizations do some design and development, most have very small engineering staffs with little time available for development.

ACKNOWLEDGEMENTS

The original work reported here was supported by the National Science Foundation, Division of Polar Programs, U.S. Fish and Wildlife Service, Jamestown, North Dakota and U.S. Department of Energy.

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