Miniature radio frequency transponder technology suitability as threatened species tags

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Murray E. Douglas

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CONTENTS

Abstract

This report presents the findings of an investigation into the availability of miniature receiver, transponder and paging technology and its suitability for Department of Conservation applications, particularly animal security tags.

Security from unauthorised use can be improved, and radio radiation, radio interference and power consumption can be reduced, if code sensitive active transponders are used for threatened species radio tags. Other conservation applications such as trap monitors, quadrat markers, security tags and safety beacons are also possible. A review of animal tracking systems revealed recent advances in this technology. This included a small long-range transponder (board only c. 51 mm x 15 mm x 4 mm, weighs 3.6 g, life 2–5 years on 750 mAh battery) for vehicle tracking that can be adapted to activate a conventional VHF animal tag, made by a New Zealand company, Locator Systems.

Novel miniature harmonic radar transponders for short range (20–200 m) tracking are low cost but have expensive readers. Low frequency implantable passive transponders (range < 1 m) are in wide use for marking individuals (>36 billion discrete codes) have automatic readers capable of remote monitoring and in specialised types, sensing activity and temperature. New small satellite position transmitting tags (25–30 g) that can provide global automatic tracking (0.9 km mean maximum resolution) using ARGOS™ satellite system, are available at greater cost (c.$3000) per tag. These have optional sensor (activity, temperature) inputs and a power saving timer for improved life expectancy.

1. Introduction

1.1 AIM

This report was requested by the Department of Conservation which has had responsibility for the management and conservation of New Zealand's endangered species since its establishment in 1987.

The purpose of this review is to investigate the availability of miniature receiver, transponder and paging technology and assess its suitability for Department of Conservation applications, particularly animal security tags.

Associated products that may be useful for other purposes are described in less detail. Passive and satellite transponder technology are only briefly summarised in this report because they are well known and described elsewhere, (Fagerstone and Johns 1987, Howey 1992, Taillade 1992, Keating 1994, Becker and Wendeln 1997).

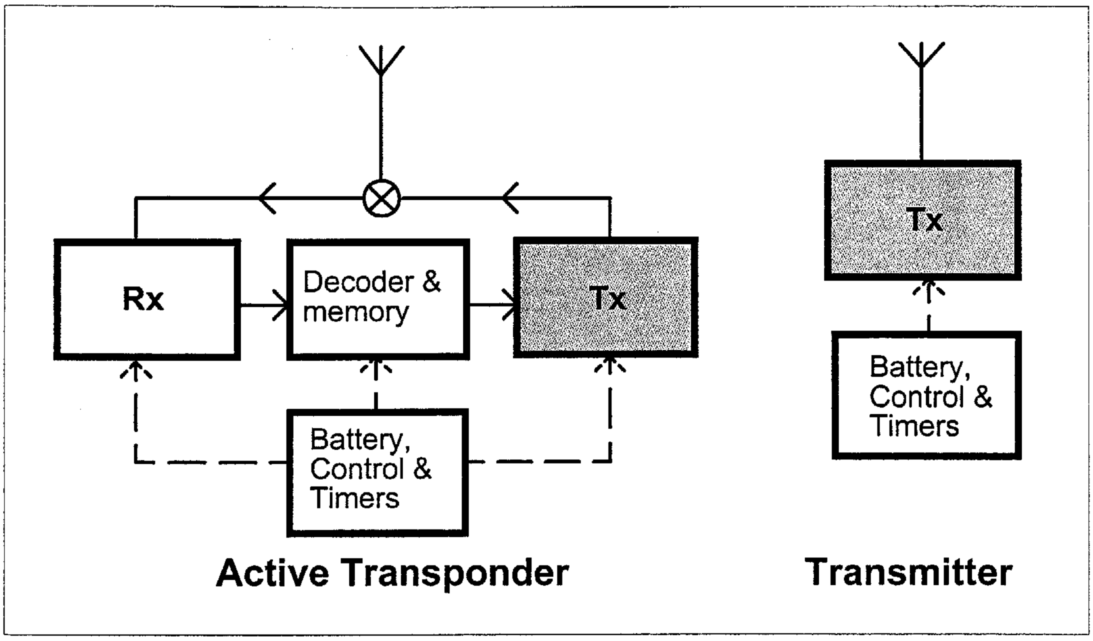

FIGURE 1. COMPONENTS OF A SIMPLE RADIO ACTIVE TRANSPONDER SHOWING TRANSMITTER (Tx), ADDITIONAL RECEIVER (Rx), DECODER AND A WILDLIFE TRANSMITTER.

1.2 DEFINITIONS

In conservation management and research, **radio tag** refers to a miniature radio transmitter (Fig. 1) used to mark wildlife, or as a safety beacon for field personnel. In New Zealand these tags are mainly **Very High Frequency** (VHF, 30-300 MHz band) radio transmitters that pulse a radio signal between 30-60 pulses per minute. Animals or people marked with these radio beacons can then be located or tracked using a receiver and directional antenna. Radio frequencies at **High Frequency** (HF, 3-30 MHz) are mainly used for long distance voice communications where some of the **skywave** signals are reflected back to earth from the ionosphere (Fig. 2). Transmitters at HF require very large antennas.

Transponders (Fig. 1) are 'a transmitter-receiver facility, the function of which is to transmit signals automatically when the proper interrogation is received' (Van Nostrand's Scientific Encyclopaedia, 1968: 1884). They differ from **repeaters** (which receive and then re-transmit the same signal) by their triggering signal often being coded and bearing no similarity to the transmitted signal. A form of transponder is the personal telecommunications message **pager**. When signalled to by a master transmitter on another frequency, the device transmits a beep, to indicate a message is awaiting, or in some models even receives a short message on a small Liquid Crystal Display (LCD). When referring to transponders that also transmit, the term **out-of-band** refers to the totally different frequency bands of the received signal (trigger) to the paging device's transmitted signal.

An **active transponder** is powered from batteries contained in the unit whereas a **passive transponder** is powered from the received signal energy. Improved miniaturised rechargeable battery technology has led to some passive

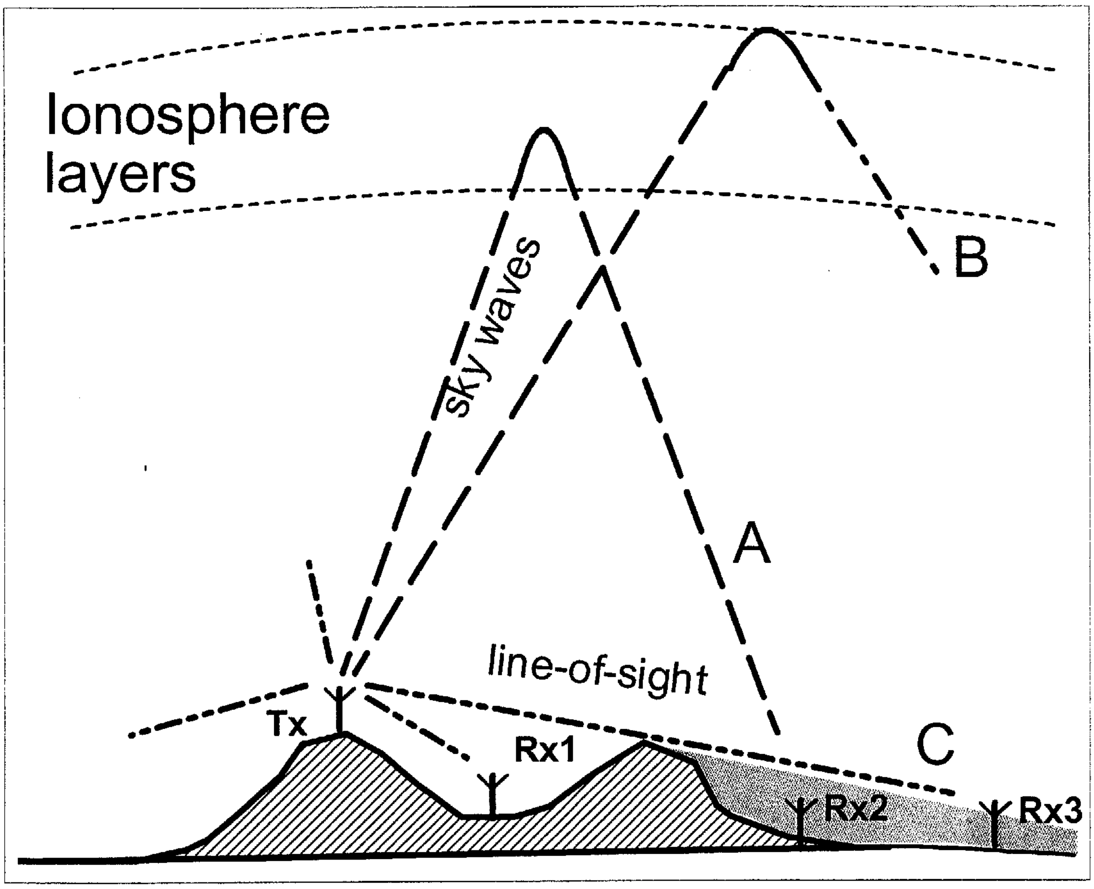

FIGURE 2. RADIO SIGNAL PROPAGATION: EXAMPLE OF HF SKY WAVE PROPAGATION (A & B) FROM Tx TO Rx1-3 AND VHF LINE-OF-SIGHT PROPAGATION (C) FROM Tx TO Rx1 AND Rx3. Rx2 REMAINS IN TOPOGRAPHIC SHADOW TO VHF SIGNALS.

designs with micro-miniature batteries that are recharged from repeated transmissions from the reader. Passive transponders may be designed for operation at **Low frequency** (LF, 30-300 kHz) and HF through to VHF, ***Ultra High Frequency*** (UHF, 300-3000 MHz) and **radar** frequencies (**Super High Frequency**, SHF, 3-30 GHz). The **wave-length**, (L, where Lm = 300 / fMH,) at these super high frequencies is very short.

Most low power circuits are constructed using **Complementary Metal Oxide Semiconductors** (CMOS) as timers and simple logic circuits. These may be assembled with **micro-controllers** (computer-in-a-chip that also has some memory and output or input control lines) as a customised chip **Integrated Circuit** (IC) or as small **thick-film** units assembled with screen-pasted and oven hardened resistors and capacitors. Power savings can be achieved in electronic circuits by changing the **duty rate**, the ratio of time on to time off.

1.3 BACKGROUND

Miniature radio tags are in wide use throughout management and research studies of wildlife carried out by staff of the Department of Conservation. Larger radio tags are being used also as personal safety beacons for trampers and Department of Conservation staff working in remote and sometimes hazardous

hazardous terrain. Generally these transmitters are low-powered, radiating less than 1 mW, so do not require licensing. An internal timer pulses the radio carrier wave (CW) on and off thus extending the battery life and allowing smaller packages, suitable for attachment to animals. The single-side band (SSB) telemetry receiver detects and amplifies these transmitter signals and produces a series of slow ‘beeps’. The location of the transmitter's position can be estimated by taking several cross bearings using the direction of the loudest signal from one or more receivers with directional antennas.

VHF animal radio tagging and tracking in New Zealand has now become common place. Historical allocations of the frequency band has led to most animal radio tagging (whether for deer recovery operations, pig-dog tags, or monitoring research animals) using a narrow 1 MHz band at 160 MHz, shared by industrial telemetry applications and marine band radio. Furthermore, the first 8 channels, at 25 kHz spacing, are designated licensed high power channels. Most animal trackers operate low-powered (< 1 mW) transmitters, without the requirement for licensing, on the first 8 channels and then up to 190 others above this at 10 kHz or 25 kHz channel spacing overlapping into part of the VHF FM marine band. The same telemetric equipment and band of frequencies are sometimes used by the Department's staff during monitoring and management of endangered animals. This shared use presents a security risk and on occasions radio interference from these other users.

Code-activated transponders can improve security by preventing unauthorised use of individual transponders and avoiding radiating ‘tell-tale’ signals from devices during periods when they are not being tracked. Furthermore, there may be improvements in power consumption and reduction in interference that could prove advantageous over conventional radio tags.

2. Methods

2.1 SEARCH METHODS

Modern developments in micro-miniature technology have led to a proliferation of commercially produced miniature electronic receivers and transmitting devices. Locating products and promising developments from throughout the world has been difficult. Some companies working on this technology are reluctant to divulge details for commercial reasons. Also, technological advances in this area are so rapid that suitable new products will no doubt appear even before this report has been published.

Three approaches were used to search for materials described in this report:

- Literature searching of key wildlife telemetry journals, publications and the Internet.
- Direct contact with leading technologists in radio and wildlife telemetry
- Contacting New Zealand and foreign electronics manufacturers.

The findings of this review have been analysed to illustrate features of the respective systems with respect to size, suitability and, if known, power consumption and approximate cost.

3. Findings

3.1 ACTIVE TRANSPONDERS AND PAGERS

3.1.1 Technology Experts

Three key New Zealand radio engineering advisers from industry were consulted regarding technological advances in transponder and receiving designs.

Colin Jennese, 32 Tawhai St, Lower Hutt, provided information on current receiver designs and how these may be used in a transponder.

Ted Barnes, formerly of Physical Sciences, DSIR, Lower Hutt provided general advice and suggested several receiver and paging ICs which could be used.

Barrie Carruthers, Ag'Tronics Ltd, New Plymouth was consulted for advice as he has an extensive knowledge of radio frequency designs when using thick-film technology.

3.1.2 International Products & Companies

Six key international companies were contacted by mail and this drew no worthwhile leads for active transponders but led to a number of passive transponder developments (see 3.4). Local agents for international companies had more worthwhile products to offer:

- A new miniature paging device has been manufactured by SWATCH™. It is a wrist-watch that can receive messages and display up to 15 digits on a small display, enough to hold an international phone number. It is called 'Beepup' and cost (at September 1997) $265. In continuous page mode operation it lasts less than a week on small disposable lithium batteries.

- Motorola produce a number of small pagers for consumer use. Some have complex menus and functions which makes adaptation for our use more complex. One of the smallest pagers is the 'Mini Page' which runs from a 1.5 V battery, has a small 16 digit LCD display that can display numbers transmitted to a telephone number via the general VHF paging network on 157.9250 MHz. The Telecom Mobile distributors claim these pager can be activated from '95% of the places where New Zealanders live, work and play' but additional portable paging transmitters may be needed for more remote applications especially in mountainous terrain. The battery consumption is approximately 0.5 mA and this low power consumption possibly could be reduced further for extra low-power applications by changing the pager's receive duty cycle. Repeat or longer transmit times would then be needed to activate the unit. At September 1997 the cost of the unit (including GST) was $99 for the pager and $0.99 per message at peak hours, $0.40 after hours.

3.1.3 Locator Systems Ltd, New Zealand

Zajae International, Wellington, is a small NZ company that is developing a miniature active transponder for use in security applications. During 1995 the company Locator Systems Ltd was formed to promote a number of other electronic products as well as a version of the device for car security. The transponder tested initially for animal tracking is an out-of-band device, triggered by receiving a HF signal with transmission on VHF. This VHF signal can be conventionally radio tracked using an existing VHF-single side band (SSB) receiver.

The company has contracted various parts of the project out to NZ and overseas engineering companies and at September 1997 had a working prototype. The proposed system consists of several parts:

- The design and thick-film manufacture of the miniature active transponder chip that works like a pager, triggering a VHF transmitter for tracking.
- Protocols for securely gaining access, for group or individual transponder activation, via an optional locally controlled or national paging network.
- Manual field radio tracking or an optional Master Tracking System (MTS) which can get transponder bearings and pass these through repeaters for display on a computer screen.
- Compatibility with Supervisory Control and Data Acquisition (SCADA) systems for remotely encoding data to standard existing data networks.

Because of the commercial potential of this project, the company is reluctant to divulge detail of the technical specifications of the transponder device. The following general details no doubt will change during future product development.

Transponder size

The size of the end product will depend upon application considerations such as output power required and life before replacement of batteries. The 70 MHz Radio Frequency (RF) receiver board, is 50.8 mm x 15.3 mm x 4 mm, weighs 3.6 g (without battery) and has the sensitivity of a standard commercial receiver of −117 dBm. The unit is pulsed for lower current consumption and can be interfaced with a suitable CMOS timer, or micro-controller. For animals the size of Kakapo a ‘match box’ sized, c. 50 mm x 35 mm x 15 mm, unit is proposed where overall size and weight is reduced to a practical minimum by redesigning the thick-film circuit board and using disposable lithium battery technology. A break-through in the design of light rechargeable lithium-ion batteries by Sony Energytec Inc. (Challis, 1996), could make re-charging a future option once commercial supplies of suitable batteries are available.

Activation

The triggering range of the device depends upon the radio system used. The pager can be designed for activation by a VHF coded radio transmission from an existing paging or commercial radio transmitter (as for the ‘Mini Pager’) or, by local activation via existing portable transceivers. A more portable paging transmitter with built in security coding and antenna array can be used for remote site activation if necessary. A lower frequency, such as HF, would be better for activating the unit in close proximity to the ground, in bush, or rough terrain, due to the signal being less affected by terrain than VHF. If VHF

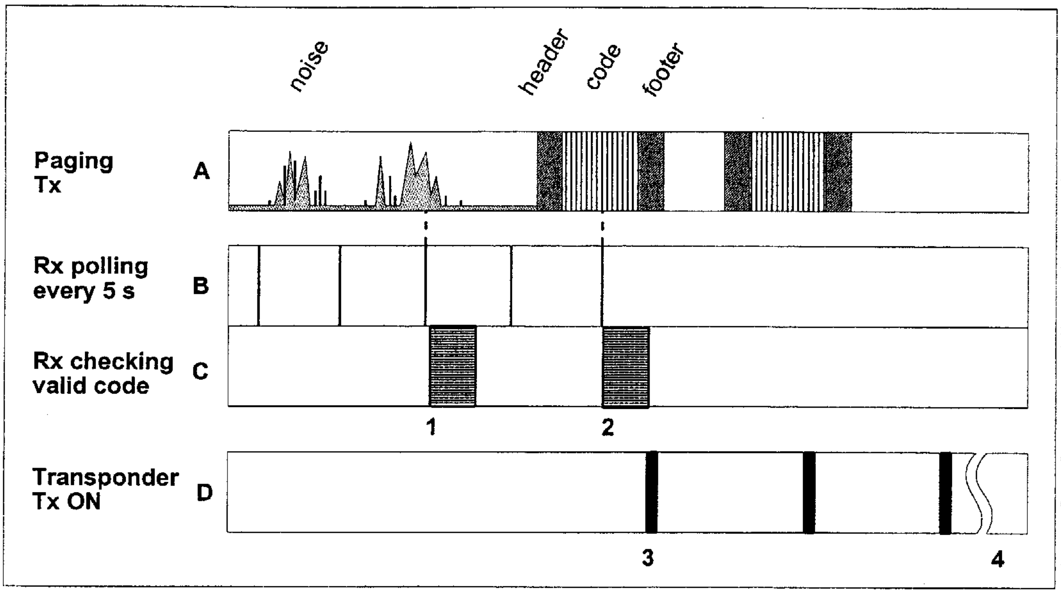

FIGURE 3. TRANSPONDER ACTIVATION TIMING. TRANSPONDER'S RECEIVER (Rx) POLLING EVERY 5 s (B) RESPONSE TO NOISE (C, 1) AND VALID PAGING TRANSMITTER (Tx) CODED SIGNAL (C, 2). TRANSPONDER'S TRANSMITTER ACTIVATED (D, 3) AND PULSES UNTIL TURNS OFF (D, 4) AFTER A SET DELAY.

activation is used the signal is subject to line-of-sight propagation and shadows will be present in dissected terrain, see Fig. 2

In trials during 1994, the company successfully activated transponders from a range of 100-150 km over sea and 60 km over land using a portable Telecom VHF paging transmitter (157.92 MHz). The second generation device has its own custom designed receiver which can be adjusted to use any frequency from 40-120 MHz.

Listening rate and triggering

The pager listening rate determines the response time to a transmitted signal. This can be adjusted to have a fast response (e.g., every second) or a slow response (every minute). Power is consumed by the device during the on time of this listening period (1.5 ms) so fast response times have higher power consumption. When the unit receives any RF signal within its receiver band width it is triggered and listens for about 200 ms for the code information. The number of times the unit is triggered per day (by transmitters turning it on, or while paging other units, in-band radio noise etc.) affects the consumption of power from the battery (Fig. 3). Finalised designs are needed before accurate evaluation of battery life expectancy can be done. Based upon provisional data, obtained from the manufacturer, the following estimates of life can be calculated, Table 1.

Antenna

The transponder transmit antenna could be the same as conventional animal transmitters or increased in size where improvement in transmitter range was necessary. The receive antenna can be a small ferrite antenna built into the receiver circuit board, or could use the transmit antenna.

TABLE 1. ESTIMATED TRANSPONDER LIFE BASED UPON USE OF 80% 750 mAh BATTERY LIFE. THREE DIFFERENT DESIGN AND ACTIVATION SCENARIOS BASED ON ESTIMATES OF FIELD USE. A STANDARD TRANSMITTER WITH A MEAN POWER CONSUMPTION OF 200 μA (ON) IS ASSUMED.

DESIGN AND ACTIVATION SCENARIO	1			2			3		
Receiver listening rate (seconds)	1	5	15	5	5	5	5	5	5
No. of times receiver triggered per day	1	1	1	0.1	1	5	1	1	1
Transmitter ON time (days per year)	7	7	7	7	7	7	1	7	30
Total device current (μA)	27	15	13	13	15	24	11	15	27
Safe life (years) to 80% 750 mAh battery	2.5	4.5	5.2	5.2	4.5	2.8	5.8	4.5	2.5

Security

Code activation is intended so that only a user supplied with an unique key for the encrypted paging signal will allow remote activation of the devices. Security will be improved by encryption coding techniques but like all security systems is only as safe as the method of storage and transportation of the key code from supplier to user. Each device would transmit only after receiving its appropriate activation code. Coded transponders would be more expensive to design but have the advantage of establishing transponder identity (ID) for single unit or group activation.

Once a transponder is activated, the VHF transmitted signal is then insecure in that unauthorised persons can then locate the active device using conventional tracking methods. A pre-set timer within the device can be adjusted so that the device transmits for a set period of time (minutes to hours) after reception of the activation code, so reducing risk of unauthorised tracking. More complex micro-controller designs could use a real-time clock to enable delays for sharing a single frequency when using multiple units.

Reception

Reception range of an activated transponder will largely be determined by line-of-sight VHF propagation. In the tests done during 1994, the triggered VHF 50 mW transmit signal was tracked from a ground hand-held antenna and receiver. Aircraft can increase this detection range for land-based transponders or, alternatively, a satellite channel could be used with higher powered versions of personal beacons. The hand tracking ranges of conventional 1 mW transponders would be the same as present animal radio tags.

Tracking

Where complete coverage is necessary conventional manual tracking is proposed, using hand-held or vehicle mounted antennas. The location of a tag can be estimated from site bearings obtained simultaneously from known receiver sites. Accuracy of bearings received will be affected by topography, spacing of receivers and the Radio Direction Finding (RDF) methods used.

Locator Systems' proposed Master Tracking System (MTS) is a system of directional antenna arrays and computer controlled radio repeaters. It will operate in conjunction with existing telecommunication networks and is intended for displays of tracked devices overlaid onto digitised and mapped Geographic Information Systems (GIS) data.

Transponder output power

Ground systems in New Zealand can work up to 1 mW without licensing. A higher RF power (c. 200–500 mW) is needed for satellite detection at extra cost to battery life, size and requirement for licensing. A transmitter which has high frequency stability and is able to be tracked by satellite (see 3.3) is not envisaged in this design because of increased size and cost.

Battery size and Life

Both duty cycle and the peak power of the transmitter affects power consumption. Shape of the device is largely dependent on the types and size of cells used and their capacity. Improvements in battery technology have been slow relative to other areas in electronic technology, however a very recent break-through in light, rechargeable lithium-ion batteries could improve future designs. Using the prototype design data (Table 1) with a 750 mAh battery, a c. 40 g package, suitable for kakapo, would last 2–5 years, depending upon configuration selected.

Reliability

Only a prototype has been produced and its reliability has not been tested. No production models of the wildlife transponder design have been completed, although the manufacturer has been successfully using the core transponder parts in another product for several years. Reliability of thick film devices is generally high, once the burn-in phase has been completed and provided successful environmental housings are designed.

Applications

An electronic device that can be individually and remotely triggered by a coded signal has wide application in the electronics industry in general. Although the device is being developed initially for safety and security equipment, the ability to remotely activate a device over RF has a number of possible applications and features that could be useful to DoC. Some of these are:

- Animal tags for securely marking endangered animals
- Reduced radiation output can be used where transmitter channel sharing is needed.
- Equipment Security, e.g., expensive field items, vehicles etc.
- Personal Safety Beacons for DoC staff, hunters and trampers.
- Reduced power remote switching, where low use but long life is needed, e.g., repeaters, data-acquisition equipment.
- Trap monitoring for detecting trap data or activation.
- Long life survey quadrat markers for location of sites in bush.

Costs

The present design is at a stage where it can be improved with a small amount of development. Present estimates of unit cost are under $500 each unit for 100 units, but this price could be reduced with greater numbers produced. Costs associated with any further reduction of the package size or power consumption would mostly occur at the development phase. The per item cost (once in production) is unlikely to increase significantly.

3.1.4 Discussion

Conventional pagers, such as the Motorola 'mini-page' are impractical as animal transponders because of their complex menu functions, high current consumption and relatively large size.

Locator Systems developed a prototype car transponder in December 1996. The level and method of security encryption used in the modulated paging signal of this transponder would make signal mimicry or tampering by unauthorised code breakers extremely difficult. Random code breaking would be unlikely due to the large number of possible codes.

The range of the device depends upon factors such as the proximity to paging transmitter stations, frequency used for paging activation and terrain of pager location. It is expected that there will need to be comprehensive tests done on pager detection range for VHF or HF frequencies. Problems with activation in some terrain may require portable sites to activate local units reliably. In most cases the deployed transponders will be in a limited area and the portable paging transmitters would not be expensive as they could be incorporated into existing HF land mobile or VHF tracking equipment.

Reception range of the activated transponder is similar to present VHF radio tracking, although if the full 50 mW power is used, longer range detection of devices may be achieved. With VHF this is largely line-of-sight. The detection of activated transmitters can be improved by increasing the altitude of the receiving station above the ground — optimised by using aircraft or satellite, but at higher cost.

The Master Tracking System would be expensive to implement and probably will not happen until there is wide commercial use of these devices such as for equipment and vehicle security. The MTS field tracking ability accuracy will depend upon the number of field receivers deployed in any one area and the topography. Cost would increase with the number of field units required.

The transponder design is considerably more complex than that of a simple transmitter, but when production models are completed the reliability of the total circuitry is likely to be very high. The same precautions as for conventional tags would be needed for package waterproofing. Care would be needed in properly evaluating the reliability of activation in dissected terrain, its sensitivity to noise and thus resultant power consumption. Users would need to be trained in the system use and its limitations.

Since 1995, parts of the company have been sold and they are mainly working on two major commercial developments: vehicle tracking and power authority meter monitoring. The animal and personal beacon transponder applications have not been fully developed. At a small one off cost the manufacturer can split and improve the board layout for miniaturisation of the existing design for animal tracking applications. Presently the company is awaiting DoC interest before proceeding to production phase with a final wildlife transponder product.

3.2 MICROWAVE RADAR TRANSPONDERS

Microwave radar transponders are widely used in the military and aircraft industry for radar identification of aircraft and equipment. A similar system has been devised for radar tracking of birds in Aberdeen (French and Priede, 1993). The battery powered unit is attached to the animal and provides a clearly identifiable return signal when scanned by high-powered ground radar. A small marine radar system was fitted to a Landrover vehicle for multi-site operation. The active transponders are quite large in size — 35 mm x 60 mm — and weigh 60 g, with a mean current consumption of about 0.3–5 mA, depending upon the duty cycle required. Location estimation can be made from the bearing and the supplementary visual information, allowing position estimates to the nearest 30 m resolution. The frequency of operation is 1–2 GHz, so only line-of-sight operation can be supported. Range is determined by the power of the radar unit and the quality of the transponder micro-slot antenna. A pulse-coded reply is used to identify individual units and delayed response is used to reduce reflection noise from other objects. Transponders cost approximately $1200 each and $8000 for the radar station.

Other short-range devices are being produced, such as the CONFIDENT™ system, by TagMaster AB in Sweden, where a 2.45 GHz signal can read the code five times, at 4 m range, for vehicles passing at speeds up to 160 kph (Transponder News, 1997).

3.2.1 Discussion

The advantage of radar active transponders is that an estimate of range is provided with each radar sweep. French & Priede (1993) state that 'This may be a particularly useful alternative for marine animals where VHF systems cannot respond rapidly to a momentary surfacing animal'. A serious practical limitation is the large minimum size available at present, but future miniaturisation improvements may further reduce transponder and radar size. High data rates are possible at these frequencies for more complex automated data applications. If lower frequency activation is used it may not work reliably in dense vegetation, typical of New Zealand study areas. Serious disadvantages are that activation requires line-of-sight during each radar sweep; and the high cost and size of radar receivers.

3.3 SATELLITE TRANSMITTING TERMINALS

3.3.1 Systems

Doppler

Satellite VHF and Ultra High Frequency (UHF) links are available for higher powered transponders. Many complex digital systems exist for industry and the military using satellite transponders at medium power.

More low-powered specialised devices for scientific applications are currently being manufactured by companies for use with the French ARGOS satellite tracking system. These are mainly transmit only devices, called Position Transmitting Terminals (PTT). They have been in use since the early 1980s, mainly to monitor the position of balloons, scientific equipment, and large animals such as bears, whales and eagles.

The PTT position is calculated by the Doppler shift principle. As stated by Kenward (1987) 'A frequency shift in each received signal indicates the satellite's speed relative to the tag, and the tag's position is computed from the ratio of this speed to the satellite's true ground speed'. Each date and time-stamped transmission is then sent to the ground telemetry station at the end of each orbit cycle and relayed to Toulouse, France. The PTT short transmission bursts are received by the satellite and distance calculations are done by in-flight and ground station computers from the known orbit position of the satellite. After positions are calculated the data is relayed from Toulouse to customers directly by modem or FAX.

Accuracy depends upon the PTT location and the quality and number of fixes during any satellite pass. ARGOS have classes Z, B, A, 0, 1, 2, 3 with an estimated accuracy for class 0 of >1 km. Accuracy for class 1 is ±1 km, 2 is ±350 m and 3 is ±150 m (Guinn and Lee, 1996). In most wildlife tracking the most common location estimates are level 0-1 and occasionally level 2. During a study of Canadian snow geese, J.-F. Giroux, pers. comm., (Department of Biological Sciences, University of Quebec) found these classes had lower accuracy than stated by ARGOS at 0 ±8.5 km, 1 ±2.5 km and 2 ±900 m.

Newer PTT designs have sensor data transmissions as well. The PTT needs to have a very stable signal and a moderate power level to reach the orbiting satellites, so long life package sizes are still quite large. In recent years the sizes have been reduced and their capabilities increased, e.g., the ST-10 (Telonics Inc., Mesa, Arizona) weighs 48 g, is 8 cm x 3.3 cm x 1.8 cm, has an output power of 0.4 W, and is equipped with dive and temperature sensors, memory and salt-water switches (Burger, 1993). During 1994, efforts were being made to further reduce the weight to 25–30 g by using a single battery and having shorter transmit periods. For example, the Microwave Telemetry PTT used on peregrine falcon 'weighs 28.5 g with a lifetime of 1 year at 8 h on every 5 days duty cycle' (Howey, 1994). There is also the NTT International Corporation Ultra-small transmitter, T-2050, which weighs 25 g.

Global Positioning Systems (GPS)

Improvements in miniaturisation of GPS and methods to improve their accuracy have led ARGOS and a German company, OHB-System GmbH, Bremen, to launch satellites that can calculate Doppler fixes, capture environmental data as well as (GPS) fixes from ground based PTTs. The OHB-System is called Satellite for Information Relay (SAFIR) and has the following features:

- Transponders or 'micro-stations' are linked via the satellite system to the user using special computer transponder terminals called 'macro-stations'.
- Two types of radio position data may be obtained from the station: GPS or Doppler.
- Other data may be captured by the remote stations and unloaded to the satellite.
- Macro-stations can deliver and receive messages via the satellite to other macro-stations like Internet.
- Maintenance costs are expected to be reduced as users pay only for satellite user time and a small fee for reservation time.

Remote transponders, once deployed, work on a pre-programmed timing schedule to transmit signals to the satellite receiver. The micro-stations are designed with a built-in GPS receiver and analogue and digital input options for sensors. A packaged unit functions as a data logger that may be pre-set to different hardware options depending upon application. All communications with the unit are done (from any position in the world) via the satellite link using a macro-station user terminal. Data can be transferred at a rate of up to 160 Kbytes per 14 minute contact with a user terminal.

After time has been reserved on the satellite, the access time depends upon the location of the remote station and the number of SAFIR satellites in operation. Accuracy of the position fixes depends upon the method of location used. Doppler is fastest as the processing is done on the received transmission by the satellite and ground-based software, not by the PTT.

A GPS fix is done by the PTT processor and consumes some power while its receiver is searching for the satellites, almanac data, and calculating its position. The GPS satellites are controlled by the USA Navy and they have purposely imposed an error on the GPS satellite signal (Selective Availability, SA) to reduce its accuracy to c.100 m. If SA is switched off the accuracy improves to c. 15–18 m. A calculated fix is transmitted as a data stream to the PTT satellite for later transfer to a macro-station.

3.3.2 Costs, applications

The cost of PTT units varies with manufacturer (c. $3000) and what on-board monitoring options are installed. Some companies charge for booking the satellite time in advance and for time monitored. A new range of low level VHF satellites are planned by ORBCOMM/MICROSTAR™, Dulles, Virginia 20166, USA, and these may reduce costs because of their lower orbit altitude (785 km), superior sensitivity and lower power of PTT required. PTTs have been used in New Zealand for monitoring ocean movements of albatrosses, sea-lions and large petrels. GPS tags have been used in Europe and America on deer, moose and bears.

3.3.3 Discussion

The use of expensive satellites and the increased circuit complexity of transponder designs makes satellite transmitting systems a higher cost option than land-based systems. However, as long as sufficient satellites are available then this system has an advantage of greater flexibility in rough terrain compared to ground based systems. The disadvantage of this system lies in its complexity and the additional RF and DC power required to reliably access the satellite receiver; which increases package sizes, weights and unit costs. Although autonomous GPS models can give mean position estimates of <100 m, the reception of three or more satellites signals is needed, along with time taken for regular correction and satellite identification data updates, and this takes longer and consumes more tag power than comparable single Doppler transmissions. As at September 1997 the SAFIR system is not finally operational for consumer use.

Unit prices of satellite tags and service costs of the systems may reduce in the future with greater use of such systems, cheaper satellites and new satellite launch methods.

3.4 PASSIVE TRANSPONDERS

Passive transponder technology can be categorised by application and frequency band type, (Table 2). Most are designed for short range location and ID in a wide range of applications including implantable animal tags; Electronic Article Surveillance (EAS) e.g., retail stock labels, shipping containers; Industrial Scientific & Medical (ISM); vehicle access and movement e.g., rail-car tracking; and personnel access and production control (Transponder News, 1997).

TABLE 2.TRANSPONDER FREQUENCY ALLOCATIONS AND USE (TRANSPONDER NEWS, 1997[1], REECO™ [2], RILEY *et al.*, 1996[3]).

USE	FREQUENCY	TYPE
Animal tags	125 kHz	[1] injectable, magnetically coupled, LF
Retail stores EAS	1.95, 3.25, 4.75, 8.2 MHz	[1] HF
ISM Australia	13, 27 MHz	[1] HF
ISM Europe & Africa	430-460 MHz	[1] UHF
ISM North & South America	902-916 MHz	[1] UHF rail car, tolls
Rescue, animal tags	917, 1834 MHz	[2] Harmonic UHF
	2350-2450 MHz	[1] Active transponders, UHF
	5400-5600 MHz	[1] Allocated for future use
Animal tags	10 000 MHz	[3] Harmonic radar

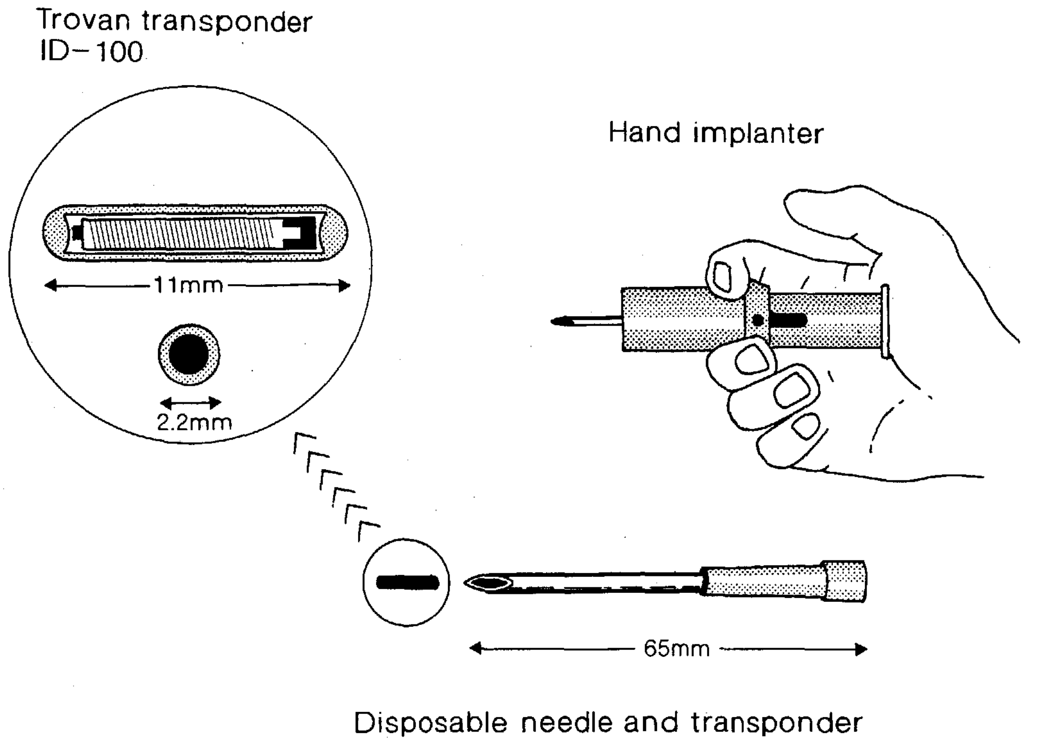

FIGURE 4. TROVAN PASSIVE INTEGRATED TRANSPONDER (PIT), MODEL ID100 AND HAND IMPLANTER WITH STERILE DISPOSABLE NEEDLE APPLICATOR.

Initially, radio frequency ID tags were based on magnetic coupling techniques. The limitations in semiconductor design methods that existed in the early stages of their development, and the desire to operate at frequencies below the minimum licensing frequency (135 kHz), resulted in tags that could only be read singly and over short distances. However requirements for greater operating distance are now resulting in new technologies coming to the fore. Major applications are starting to appear in the 433, 915 MHz band and above. With increasing range, it is necessary for the receivers to read several transponders at the same time, as the chances of finding more than one transponder in a given three-dimensional volume increases. One of the major developing areas is in EAS security, particularly as shoplifting has created a demand for low cost solutions (Transponder News, 1997).

3.4.1 Low Frequency (LF)

Passive Integrated Transponders (PITs) have been used since 1985 for marking wildlife (Fagerstone & Johns, 1987), security tagging, automatic ID and marking of live-stock and slaughter animals (Parmenter, 1993; Geers et al., 1997). The transponder is small (c. I l mm x 2.2 mm, Fig. 4), and has a unique number (one of >36 billion possibilities) that when energised reports back to a receiver (Fig. 5). The transponders are permanent, have no battery, do not wear out and as commercial devices are encapsulated in a small glass tube or in a plastic credit card. A syringe applicator (Fig. 4) can be used for implanting the glass varieties into animals for security marking or tagging.

The transponder has a micro-antenna that receives the LF (125 kHz) signal from the `reader' or transceiver. The transponder is powered by the high RF energy

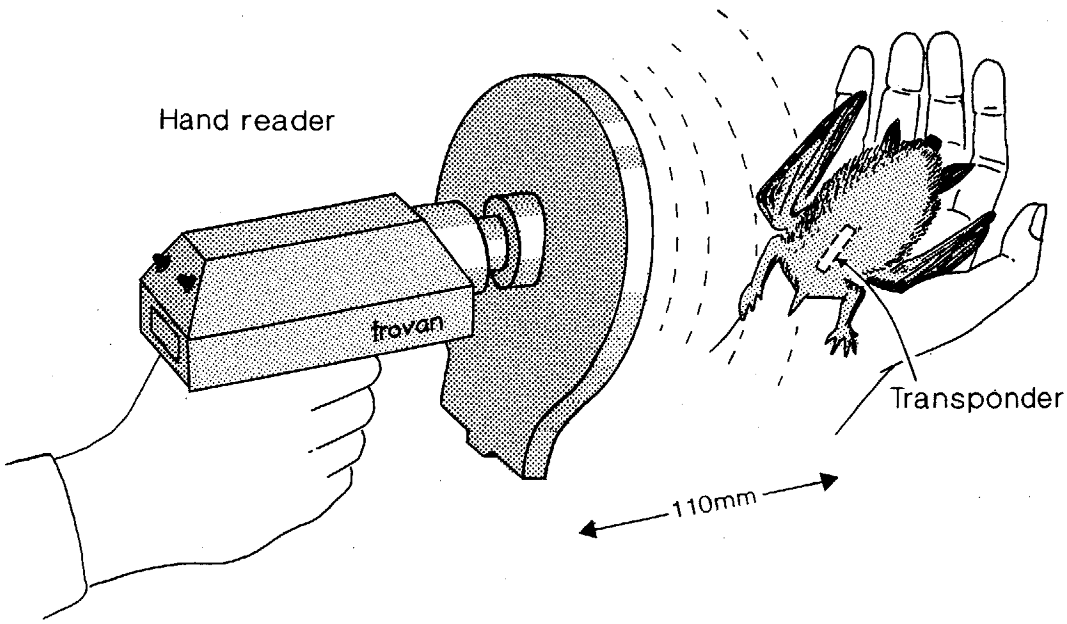

FIGURE 5. TROVAN HAND READER AND SHORT-TAILED BAT, SHOWING TRANSPONDER IMPLANT SITE.

field to transmit back, at a similar frequency, the serial data containing the ID code. This is decoded and displayed by the reader on a LCD display along with date and time. The reader/decoders come in various sizes ranging from hand-held portable to fully computerised static. units with large loop antennas (Prentice et al., 1990a, 1990b; TrovanTm Electronic Identification Systems, National Central Animal Registry Ltd, New Lynn, Auckland). They are manufactured by AVID (USA), Data Mars (Switzerland), Destron/ID (USA), Euro-ID/Trovan (Germany), NEDAP (Netherlands) and TIRIS (Germany). At present there is little compatibility between various manufacturers' designs, although a new ISO standard (ISO/11785) will ensure new readers will read standard as well as non-standard designs (Geers et al., 1997).

Read range for hand-held readers (e.g., Trovan LID500) is limited to <11 cm for small transponders (Trovan ID 100, 11 mm x 2.2 mm) to 25 cm for 18 mm units (1D200). Range can be extended up to 72 cm (ID100 <25 cm, ID200 <45 cm) when using the larger transponders with higher power readers that have external circular antennas (Trovan product brochure).

PITS have the advantage of low cost (c. $9 per transponder and c. $1000 for a hand reader) and high security due to their small size, which allows them to be hidden from view, and their individual coding. However, their low range limits them to near contact or hand-held applications and they cannot be used for location and direction finding. There is also little hope for significant ¡mprovement in range because of the risk of radiation exposure to animals, humans and electronic equipment if power levels are increased. The automated readers were bulky and until recently, had moderately high power consumption (100 W, Trovan PSU-HP). However, these specifications have recently improved making localised monitoring in remote field situations such as nests, feeders and weighing stations more practicable (Becker and Wendeln, 1997).

Recent improvements have included transponders with sensor capability as well as multipage transponders which have larger memories (Geers *et al.*, 1997). These devices have an application specific integrated circuit which includes temperature sensors, activity accelerometers, memory, microprocessor and logic circuitry. The implanted transponder can be programmed via a second receiver for setting the transponder ID and temperature calibration curve. The unit is 40 mm x 5 mm which includes a small lithium battery, lasts six weeks and has a read range of 50 cm. These devices require multiple computer controlled transceivers (Geers *et al.*, 1997.

3.4.2 Microwave passive transponders

The simplest of these devices draw their energy from the received signal via a micro-slot or short whip antenna and like PITs they only have a short range. The energy from the interrogation signal is reflected at a harmonic frequency, generally by frequency doubling, (secondary radar principle) back to the sending antenna which also receives. The signal is detected by the receiver and directional antenna and the operator hears the signal as a continuous tone in the earphones when the antenna is pointing towards the device.

RECCO System

The RECCO™ system (RECCO AB, Lidingo, Stockholm, Sweden) was invented by the Royal Institute of Technology, Stockholm for rescuing people buried in snow avalanches. The Model 300 transceiver has a 4 beam hand-held antenna array built into a receiver box measuring 34 cm x 34 cm x 12 cm, transmits 5 W at 917 MHz and receives on 1834 MHz (Fig. 6). The range varies from about 4–30 m depending upon transponder size, antenna configuration, orientation, other objects in the path and proximity to the ground.

A complete transponder, or ‘reflector’, consists of two components — a special type of sensitive diode and an antenna wire in a loop or foil strip whip. They can be very small — 10 mm x 3 mm with a antenna 25–50 mm long (range 2–6 m) — or larger with foil strips on each end of the diode — 120 mm total length (range 20–30 m).

Harmonic Radar

Riley *et al.*, (1996) used a 25 kW radar (3.2 cm wavelength) tracking unit, ‘harmonic radar’, for tracking bumble bees (*Bombus* spp.) and honey bees (*Apis mellifera*) in United Kingdom. The radar dishes (1.5 m diameter and 0.7 m paraboloids) extend the range for which the transponder (a Schottky diode mounted in the centre of a 16 mm dipole antenna, and in parallel with a 3 nH inductor, weighing 3 mg, 1.5% of bee’s weight) can be detected and displayed from 50–250 m with ±7 m resolution.

3.4.3 Discussion

LF passive transponders are individually coded and inexpensive but have limited read range so are useful for hand monitoring applications or restricted sites such as nests, feeders etc. Although range can be extended to some extent by

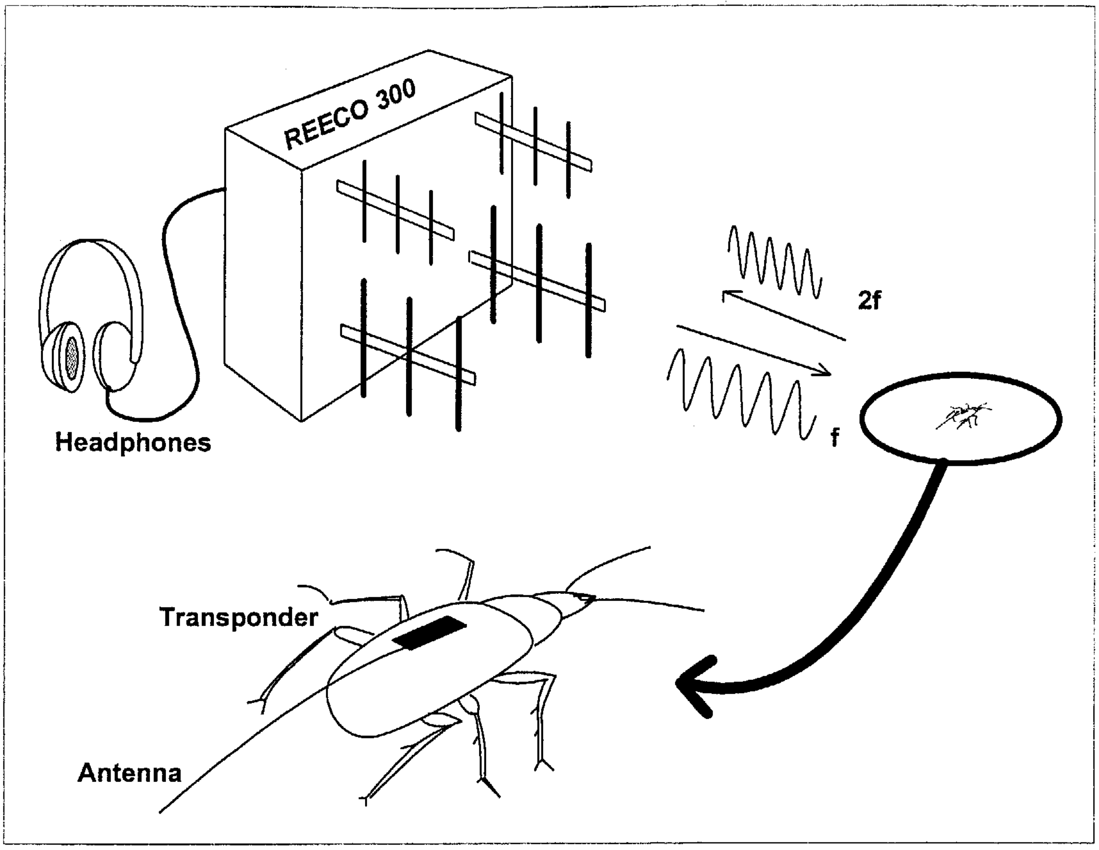

FIGURE 6. REECO™ MODEL 300 HAND-HELD TRANSCEIVER UNIT WITH HEADPHONES AND EXAMPLE OF A SMALL TRANSPONDER (HP2835 DIODE AND 3 cm ANTENNA) GLUED TO THE BACK A CARABID BEETLE.

using high-power readers and multiple switched circular external antennas, extending the range beyond a few meters is both costly and impracticable.

The main advantage of the passive microwave transponder is the reduction in size which enables small animals to be tagged and the low cost of transponders, c. $5. Conversely, the lower output power and simple design reduces its range and ability to distinguish individuals. The short range of the low powered device limits applications to portable use where location and visual inspection is needed. Cost of the REECO transceiver unit is quite high, c.$12 000. The price of the parabolic radar unit is unknown but is likely to be more expensive than the hand-held UHF unit.

4. Programmed transmitters and receivers

Miniature VHF radio tags have been in wide use since the early 1970s. Their size has been progressively reduced by the use of smaller components and batteries, e.g., Holohil Systems, Carp, Ontario bat transmitters (model BD2B, 14.8 mm x 8 mm x 3 mm, 0.65 g, life 14 days).

Recent miniaturisation of micro-controller ICs presents alternative methods to increase security of standard wildlife transmitters both at the transmitter and receiver ends. Transmitters can be programmed at manufacture to 'sleep' and turn on only when surveys are to be made. An example is model LB-70 (Telonics Inc.) which measures 22.2 mm x 12.7 mm x 8.7 mm (not including packaging and batteries) and is able to be configured to final weights of >10 g.

Alternatively, by using a computer controlled receiver, several coded tags can use the one frequency and be identified by their code. The Electronics Laboratory, Department of Conservation, is currently developing a data-logging receiver tag, called 'MateID', that can be used for identifying transmitters within a 0.3–1 m range. Alternatively, coded transmitters can be pulsed very slowly and position estimates can be obtained from a Doppler antenna array attached to a special receiver and computer which plots tag ID and location (Angerbjorn & Becker, 1992; Zelcon Technic, Pty Ltd, Glenorchy, Tasmania). Although these automatic DF arrays have been available for a number of years they are typically insensitive to low-powered animal tags, with short pulse length, and the high DF receiver cost (c. $40 000) has led to few wildlife applications.

5. Conclusions

Miniature passive transponder devices available from some commercial companies, or active transponders like that currently under development for Locator Systems, are of most value as transponders for animal tagging. IC manufacturers are also improving size, range and intelligence by using microprocessors and customised functional chips. Unfortunately, some of these products currently have insufficient read range, or are too expensive, to be suitable for our use. Despite this, significant recent advancements have been made so that an active transponder design that would meet the Department of Conservation requirements can be assembled.

Improvements have also been made in reducing the size of satellite tags and increasing their functionality, and in the computerised location of small coded tags using Doppler antennas. These products are readily available but quite expensive so their use has been restricted.

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