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GPS APPLICATIONS FOR WILDLIFE — A REVIEW

If you have been involved with telemetry over the past two decades, you have witnessed dramatic advances in technology used for tracking wildlife. While the advancements occur continually in existing systems, only rarely does a technology come along which radically revolutionizes the way we conduct wildlife tracking research. In the early 1980s, the ARGOS system was such a development. Prototype ARGOS transmitters known as PTTs were placed on animals and used to track and recover data from caribou and polar bears. By the close of the 1980s, projects on eagles, cranes, and geese were underway. Wildlife applications utilizing ARGOS will continue their developmental course through the 1990s.

ARGOS is not the only satellite-based system revolutionizing wildlife research. The "new system on the block" is the Global Positioning System (GPS). Unlike ARGOS, with GPS the subject carries a GPS receiver which receives data from satellites and calculates the position of the subject. The transmitters are onboard a constellation of 24 satellites and the system provides near continuous positioning capability worldwide. GPS presents a potential for increased position accuracy to a level never before possible utilizing a satellite-based positioning system.

Media coverage concerning the new system has been extensive with exposure on the evening news, in popular magazines and trade journals, and in scientific literature. A number of detailed papers in the popular and technical publications explain the operation of GPS. Exhaustive explanations can be found in *GPS World*, a trade magazine devoted solely to the new technology and a review of the system can be found in the sidebar, *GPS—A System View* on page 3. In brief, the user segment of the GPS system is the receiver. The system makes no provision to transmit data (i.e. positions) from the receiver.

The early GPS receivers were too large and consumed too much power to be deployed in many tracking applications, or to operate in an unattended fashion for prolonged periods of time (i.e. months or years). Military and commercial demands have forced manufacturers into intense competition resulting in a rapid integration and miniaturization effort. The process has reduced the size of the "receiver engines" to approximately 4" x 2" x 0.5" in the current configuration and in the soon-to-be-released smallest versions, the size is reduced by an additional 25-40%. While in operation, the current receiver engines still require substantial power (typically 200-250mA of current at 5.0 VDC).

We are now testing GPS receivers with current requirements of only 150mA. Newer versions incorporating 3.3 VDC silicon technology open the door to a lower voltage receiver. The power savings from current reduction and reduced voltage components are significant. Even with the new low power technology, the GPS receiver must be carefully power managed—turned on and off—to extend the operational life. In addition, GPS receiver software continues to get smarter.

Early receivers had to obtain an almanac, time and a general location to begin satellite reception and position fixing. This process could take a prolonged time to acquire the first fix from a "cold start" (i.e. 10-30 mins). Several advances have reduced "time to first fix." Receivers can initially be given the current time and previous location so as not to be operating from a true "cold start." Also, as the satellite constellation has become more constant and thus more predictable, GPS receivers can utilize more sophisticated search algorithms to acquire satellites more rapidly. "Time to first fix" from a "warm start" under optimal conditions today is often on the order of 45 seconds. These receiver "engines" provide not only the capability to receive the satellite signal, but also store digital orbitography information downlinked from the satellites, known as "ephemeris data." The processor is able to measure the time of arrival (TOA) of the signals received from the satellites and calculate the position of the satellites using the ephemeris data. With these parameters, a highly accurate receiver position can be determined and updated virtually second by second.

A GPS receiver pinpoints *its own location* and if it's on a target such as an elk, the animal is also positioned. Now, if we can teach the elk to read positions from a liquid crystal display and jot them down on small tablets throughout the forest, then we too will know the elk's position. Since this approach may prove an inadequate link, we may have to provide a technology that does not place so much responsibility on the cooperation of the elk.

While the GPS system does not relay positions, there are multiple approaches to data recovery that satisfy various study requirements. You may have already considered the first approach—storing the data onboard the animal and not relaying it at all (see Figure 1). In some instances, it's not possible to recover all animals and equipment, thus data could be lost. For a further discussion of this approach, see *GPS Collars With Store-On-Board Capabilities* on page 8.

A second alternative is to relay the information through a direct transmission from a transmitter on the animal to a

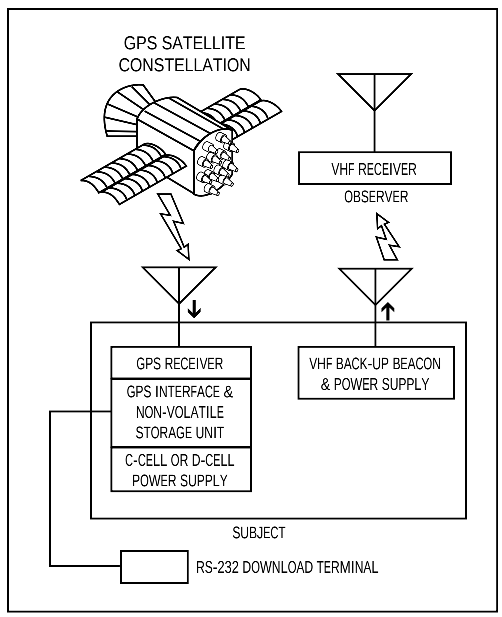

Figure 1. Block diagram of a GPS store-on-board system. GPS positions are obtained and stored in a non- volatile memory for later downlink. The unit must be physically recovered to obtain the data. This system does not have a radio frequency (RF) data link but is usually physically smaller than systems which utilize an RF link.

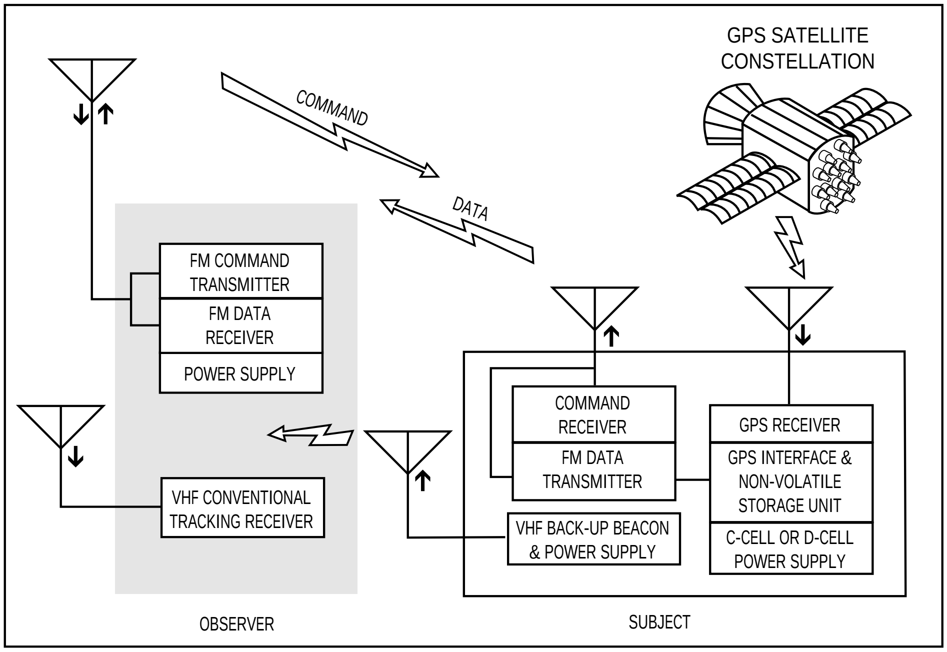

Figure 2. Block diagram of a GPS-FM system. GPS positions are obtained and stored in memory. The system can transfer information to the observer across an FM data link on command.

receiver carried by the biologist. Any modulation format could be considered for this application, including FM (Frequency Modulation), AM (Amplitude Modulation), and PM (Phase Modulation). The difficulty in this approach is the range limitation and the fact that either you and your receiver, your receiver and data acquisition system, or a repeater, must be within radio range in order to recover the information. Often the only practical alternative is to use aircraft to search for the animal. The unit onboard the animal must be queried to recover the data. Large volumes of data can be recovered, but the costs and danger of flying in small aircraft remain (see Figure 2).

Yet a third alternative which is fully operational is the use of a low polar orbiting relay satellite constellation to recover GPS data. The NOAA/ARGOS system is currently being used for this purpose and it represents a highly reliable way of recovering GPS positions. GPS information is incorporated into the ARGOS data stream and uplinked from the animal. ARGOS then becomes a data transfer system as opposed to a positioning system. As a plus, the ARGOS positioning can be used to back up GPS positioning (see Figure 3).

In fact, we used this approach to help the U.S. Geological Survey track glaciers using a predecessor to the GPS system. Navy Transit satellites were used to obtain a position which was then relayed using ARGOS. In other applications, the U.S. Forest Service has used LORAN (Long-Range Aid to Navigation) to obtain positioning information and relay it back from animals to central stations. This system has achieved only limited success relative to early, and perhaps overly optimistic, expectations. These early systems were expensive, bulky, power hungry, and essentially represent trial runs for relaying position information.

As we mentioned earlier, ARGOS itself is a positioning system with data transfer capability. The system utilizes the doppler shift of uplink transmissions as received at the satellite to position transmitters attached to targets. There are several reasons why adding a GPS receiver to an ARGOS project can be advantageous:

1) The GPS system allows for more consistently accurate position fixes than ARGOS. Even with Selective Availability (SA) turned on, GPS is typically accurate to about 70 meters or better. The specification for GPS with SA is accuracy of <100m error 90% of the time.

The ARGOS system provides different levels of accuracy depending upon numerous factors such as overpass elevation, number of uplink messages received, distribution of messages received over the course of the overpass, and ARGOS transmitter oscillator stability. Typically, with four good transmissions getting through, most ARGOS position fixes of animals will be within one kilometer. With five or more good transmissions getting through, *some* of the position fixes will be within 150 meters of a stationary target. ARGOS calculates position using the doppler shift of the carrier (calculated from the measured carrier frequency) of multiple uplink transmissions received throughout the entire overpass. The ARGOS system assumes the transmitter to be stationary and at sea level. Therefore, altitude errors of as little as 100 meters and/or velocity errors of as little as 1 meter/ second can directly translate into position errors (see

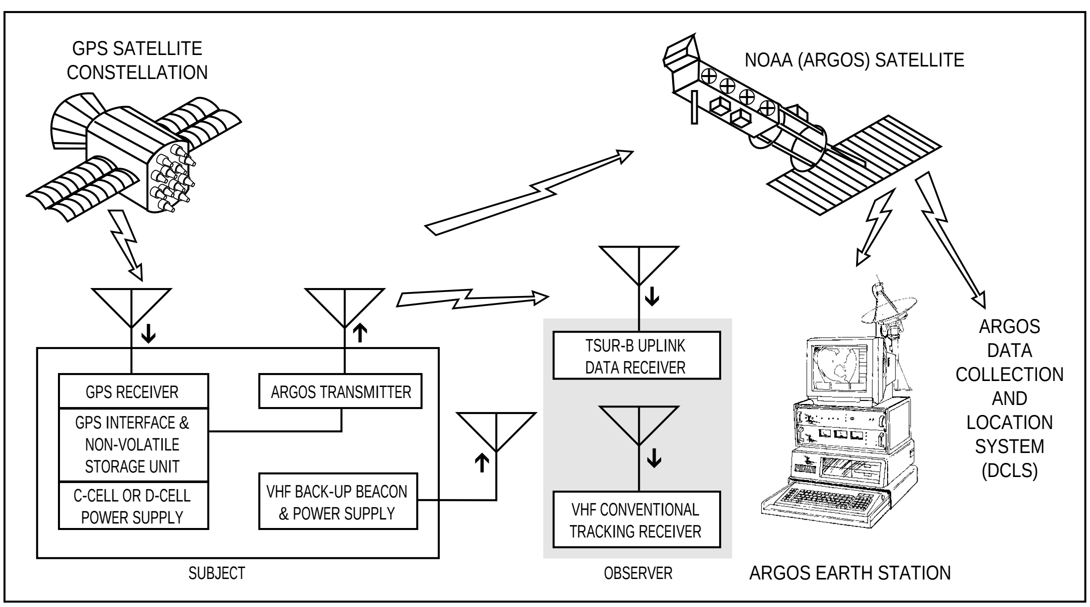

Figure 3. Block diagram of a GPS-ARGOS system. GPS positions are obtained and stored in memory. The system transfers the data through the ARGOS-NOAA satellite system.

Telonics Quarterly, V6, N2, Fall 1993, "GPS Update.")

2) GPS allows for 24 hour coverage, with position updates occurring in rapid succession (i.e. one location update/second). A position fix can be made at any time and several positions taken in rapid succession can be analyzed, selected, and/or averaged to help assure accuracy.

With ARGOS, position fixes can only be made when a NOAA satellite is in view, and only when the PTT transmissions are successfully received. Depending on your location, periods of up to four hours may go by with no satellite in view.

3) The GPS system allows for extremely accurate time stamping of position fixes. GPS receivers obtain a time signal from the GPS satellites. Therefore, you can know very accurately WHEN a position fix was obtained even if no ARGOS satellite was in view at the time to relay the GPS position back to the user. The position fixes obtained, including their time stamps, are simply remembered until an ARGOS satellite is available for relaying the data.

4) With GPS, YOU can establish the interval at which position fixes are acquired. It can be every 15 minutes, every hour, every four hours, or every day. The sample interval you choose has everything to do with the needs of your experiment, and nothing to do with the availability of ARGOS satellites.

When used with a GPS receiver, ARGOS becomes essentially "just" a satellite relay system. But it presents several advantages in this role. ARGOS is carried onboard the NOAA LEO (Low-Earth-Orbiting) satellites, typically 600 mi (800 km) above the earth. Low power transmitters (100 mW to 1W) can be used to uplink information to NOAA-10, -11, -12 and -14 polar orbiting satellites with ARGOS DCLS (Data Collection and Location Systems) onboard.

To send this information to a geostationary satellite (22,300 mi; 36,000 km) above the earth's surface, a transmitter output of 10-40 watts is required, thus making a small portable transmitter and power supply impractical. Even the proposed commercial LEOs (i.e. ORBCOMM and STARSYS) require higher power levels (5W) and more complicated transmitters and receivers on the target. All things considered, ARGOS is currently the only practical satellite relay system for obtaining GPS positions from animals. In fact, if the GPS receiver fails, the ARGOS position can be used to determine where the target is and recover the unit. No other system offers such advantages and capabilities.

GPS—A SYSTEM VIEW

The Global Positioning System (GPS) began in 1973 when the Department of Defense decided to develop a 24-hour system with worldwide coverage capable of providing three dimensional positioning principally for military applications.

The GPS constellation of 24 satellites orbits the earth approximately every 12 hours at an altitude of approximately 20,200 km. On 26 June 1993, the twenty-fourth satellite of the GPS constellation was launched, achieving System IOC (Initial Operational Capability). The system is now fully operational although military users still wish to replace some Block One satellites with Block Two to achieve Full Operational Capability for military use.

Developed at a cost of $10 billion (or more), the satellite-based positioning system was based on an initial design calling for four satellites to be in view of any position on the earth's surface at any time. A Joint Program Office was created to develop, test and acquire a space borne positioning system to be known as GPS or NAVSTAR (Navigation System using Time and Ranging). The system's concept is based upon the idea that a receiver's distance from a satellite is determined by measuring the time it takes for the signals to reach the receiver from the satellite. Measuring the time delay from four satellites allows 3-D position fixing (latitude, longitude and altitude). The existing system has an accuracy of 10-20 meters, which exceeds the design accuracy of 100 meters.

The initial design for the space segment (the first segment) of the system was predicated on using two downlink frequencies (L1 at 1575.42 MHz and L2 at 1227.60 MHz). L1 frequency was designed for non-military users and carries both the CA (Coarse) and P (Precise) codes. The L2 frequency carries only the P code. Commercial (non-military) users utilize the L1 frequency only. The military is able to reduce atmospheric errors by utilizing a two-frequency approach in their receivers.

The second segment is the operational ground control. This includes five tracking stations distributed throughout the world. The master control station is at the Consolidated Space Operational Center in Colorado Springs, Colorado.

The third segment is the GPS receiver. It is designed to track, measure time of signal arrival, demodulate, and utilize navigation messages. There are three types of receivers. Multi-channel receivers utilize parallel, identical channels which receive signals from several satellites simultaneously. Sequential receivers track one satellite at a time, each for about one second. Multiplex receivers sample four to five satellites in short sequences (i.e. one bit length).

The military maintains the most precise system operation exclusively for military operations, and degrades performance accuracy for commercial or non-military applications by an approach called Selective Availability (SA) which was initiated on 27 March 1990. Selective availability essentially involves jittering the clock frequency to degrade the accuracy of commercial performance to approximately 100 meters. The P-code contains encrypted information to remove the clock frequency jitter from the military GPS receiver calculations, recovering the system's accuracy.

Interestingly, commercial users have developed an independent alternative to this induced SA error, called DGPS ("differential" GPS). In this mode, the error introduced by jittering the clock frequency is minimized by establishing an observed error of a receiver at a known location, and applying that observed error as a correction factor to a receiver at an unknown location. By using differential GPS, most of the induced SA error can be removed.

GPS allows you to determine position on the surface of the earth, in an aircraft, or in a space vehicle. It has been clear for some years that if this position could be relayed to a receiving site, then GPS could be used to locate the position of objects to be tracked such as ocean buoys, meteorological balloons, commercial truck and rail traffic, and animals. If combined with a telemetry system, the information could be relayed to another site and recovered.

GPS-ARGOS: WILDLIFE APPLICATIONS IN THE FIELD

In late summer 1995, Dr. Charles ("Chuck") Schwartz of the Alaska Department of Fish & Game deployed an ARGOS-linked GPS collar on a brown bear on the Kenai Peninsula of Alaska. The collar weighed approximately 1.7 kg, including the electronics and power supply housed in a hermetically sealed container previously used for ARGOS satellite telemetry on black, brown, and polar bears.

The hermetic canister (Telonics P/N PK000123-001) used on the collar measures 4.3" x 2.7" x 2.3" (10.9 x 6.9 x 5.8 cm). This canister provides a completely hermetically sealed environment for the ST-14 ARGOS PTT, an Interface Card, and the GPS receiver, as well as a 3 C-cell size battery pack and an independent VHF transmitter and its power supply. A complete set of system specifications can be found in the sidebar, *System Specifications* on page 5.

The weight of this canister, with all components inside, is approximately 800 grams. The canister was affixed to a collar designed specifically for brown bears. The collar was 2.75" wide with an adjustment range of 26-42 inches. The weight of the collar, canister and GPS antenna was 1525 grams. With the external protective casting typically used on bear configurations, the collar weighed 1700 grams (for a 29-inch circumference neck).

In this application the ARGOS and VHF transmitting antennas are multi-stranded, stainless steel cable (our TA-5HT, 0.085 inch diameter antenna is often used). The ARGOS antenna is completely contained within the Telonics attachment collar for deployment on bears. External antennas improve signal propagation, but are subject to eventual fatigue and breakage. (As a practical matter, sophisticated, critically-tuned antennas seldom survive for long periods of time in the various environments presented by animal applications. Although "whip" antennas appear unsophisticated, their past performance history has proved these antennas provide adequate link margin over the long term when deployed on animals.)

The GPS antenna designed for the brown bear work was unique. A small flat antenna was utilized and completely encased in a radio transparent but weatherproof housing. The antenna is designed to be positioned on the back of the animal's neck with the best possible view of the satellite constellation. It is a low-profile antenna (i.e. less than 1" in height above the collar). This design helps minimize damage to the antenna as well as keeping a low profile on the animal's neck. Because the GPS antenna must be positioned on the dorsal surface of the animal's neck, the neck circumference specifications used in collar construction must be accurate to within a couple of inches of adjustment.

The first deployment on a brown bear sow with two cubs lasted for only 1.5 weeks. Although the GPS portion of the system was working well; the ARGOS portion was not providing as many uplinks for data as we had hoped, thereby limiting the recovery of the GPS data. Dr. Schwartz recovered the collar from the bear and we modified the ARGOS antenna which dramatically improved the ARGOS radio uplink data recovery.

Photo 3. GPS-ARGOS unit. Elk configuration.

The new configuration was redeployed in October 1995 on another brown bear sow in a nearby area. The system operated successfully providing four GPS positions per day for four weeks until the sow denned. Other options for the rate of GPS positioning are available within the user selectable parameters of the internal software.

Because this was a testing phase for

Photo 1. GPS-ARGOS unit. Brown bear configuration.

Photo 2. GPS antenna. Low profile antenna positioned on top of the collar to enhance view of the GPS satellite constellation.

the GPS-ARGOS collar, we obtained GPS data once every 6 hours. The unit relayed the data via ARGOS transmitting one uplink burst every 60 seconds for 8 hours per day. The collar was designed to work intensively for a period of about 5 weeks before exhausting its power supply, and was removed prior to the bear going to den. Ten additional collars in an operational scenario on brown bears are currently being deployed.

Other GPS sampling rates can be programmed and other duty-cycles can be specified for the ARGOS PTT to extend the life of the system. Larger packages based on D-cell sized power packs can extend operational life or be used to collect more frequent GPS positions. For example, the dimensions of the hermetic package (Telonics P/N PK 000663-001) used to house the electronics and a D-cell sized power pack are 4.50" x 3.25" x 2.75" (11.4 x 8.3 x 7.0 cm). This configuration was designed for use on elk. The collar adjustment range was (Cow: 25" to 31", Bull: 29" to 36") and the total weight of the unit was just under 2000 grams. More specific information on power budgeting can be found in the sidebar, *Operational Life* on page 7.

This system was designed to take a GPS position once every 23 hours, store the data and relay the information from the elk via ARGOS once every four days. Up to seven GPS position fixes can be contained in a single ARGOS uplink message using a new high compression format designed specifically to maximize throughput on the ARGOS system while simultaneously provide position resolution to one ten-thousandth (0.0001) of a degree (approx. 36.5ft at the equator). The system has been working well for approximately three months, but is designed to operate for over a year in this mode. Five collars were deployed by James Biggs of Los Alamos National Laboratory in areas where aerial monitoring is restricted and therefore an FM link cannot be used.

The current data formats are described in the sidebar, *Telonics GPS Format T02 for ARGOS PTTs* on page 6. Alternative formats are planned and will be implemented in the near future. They will accommodate the use of limited differential GPS and incorporation of additional biological data into the data stream. The fusion of GPS technology with the ARGOS system has revolutionized the field of wildlife telemetry.

GPS/ARGOS SYSTEM SPECIFICATIONS

1) Core Unit Electrical Specifications for use as ARGOS ST-14 Transmitter:

ARGOS CERTIFIED PTT	MODEL CM 10 001-004
SIZE	4.1" L x 1.95" W x 0.5" H in Sleeve
WEIGHT	116g In Sleeve
FREQUENCY	401.650 MHz (In accordance with ARGOS Specifications)
OPERATING TEMPERATURE RANGE	OPTION 004 -40 TO +70°C OPTION 005 -40 TO +60°C
STORAGE TEMPERATURE RANGE	-60 TO +80°C
PEAK CURRENT	750 ma MAXIMUM (500 ma typical) during transmission (50 ohm LOAD)
VOLTAGE	+7.0 Vdc to 11.0 Vdc
QUIESCENT CURRENT	<250 µa MAXIMUM (150 µa typical)
POWER OUTPUT	30 dbm +/- 1 db with automatic leveling control (ALC). Note: Units are designed ALC to operate in pulsatile mode as described in the ARGOS Operational Specifications.
RF OUTPUT IMPEDANCE	50 ohms
ON/OFF SWITCHING	OPTION 061: A normally open (N.O.) switch turns the PTT ON.

2) Description of GPS Receiver Engine Module (for reference only):

Performance Specifications

General	L1 frequency, C/A code (SPS), 6-channel continuous tracking receiver
Update rate	2 Hz
Accuracy	Position: 25 m SEP without SA Velocity: 0.1 m/sec without SA Time: 1 micro-second (nominal)
DGPS accuracy	Position: 2 to 5 m (2 sigmas) Velocity: 0.1 m/sec Time: 1 micro-second (nominal)
Acquisition (typical)	Cold Start: 2 to 5 minutes Warm Start: 50 seconds with time upload Hot Start: 30 seconds with time upload
Reacquisition	< 2 seconds
Dynamics	Velocity: 500 m/sec maximum Acceleration: 4g (39.2 m/sec^2) Jerk: 20 m/sec^3

Technical Specifications

Prime power	+5 VDC (-3% to +5%)
Power consumption	6-channel: 250 ma, 1.25 watts (nominal) with antenna: 280 ma, 1.40 watts
Backup power	+3 to +5 VDC
Backup consumption	≤1 micro-amp @ +3 volts and +25°C (nominal)

Environmental Specifications

Operating temp	-40°C to +85°C	
Storage temp	-55°C to +100°C	
Vibration	0.008g^2/Hz	5 Hz to 20 Hz
	0.05g^2/Hz	20 Hz to 100 Hz
	-3dB/octave	100 Hz to 900 Hz
Altitude	-400 m to +18,000 m	

Physical Characteristics

Dimensions	3.25" L x 1.83" W x 0.58" H (82.6 mm x 46.5 mm x 14.7 mm)
Weight	1.3 oz (36.4 grams)

Telonics GPS Format T02 for ARGOS PTTs

by Tim Rios

Telonics GPS format T02 is available for ST-13 and ST-14 GPS systems. The format supports a transmission of up to 32 bytes of sensor and/or GPS position data. GPS data are compressed, allowing up to 7 position fixes to be formatted into a single ARGOS message.

The T02 format has its roots in another GPS-ARGOS format (referred to as format A01 at Telonics) developed by CLS and Service ARGOS. Both the A01 and T02 formats can be used for transmitting GPS position data or various types of sensor data. The GPS-ARGOS format (A01) developed by CLS supports GPS position data consisting of up to 7 fixes per 32 byte message, with one fix being absolute in time and location and the remaining fixes being relative to the absolute fix. The A01 format has position resolution of .001 degrees and the integrity of the data is protected by a single 7-bit CRC.

The T02 format was created for three reasons. First, researchers wanted increased position resolution (.0001 degrees). Secondly, the error detection mechanism had to be improved. In the A01 format, a single bit error was enough to invalidate the entire message. Third, a mechanism for tagging the fixes with a date was desired.

The T02 format is fast becoming a standard for the wildlife field whenever GPS is being relayed via ARGOS. T02 uses an absolute fix and a variable number of relative historical fixes (0 to 6). The position resolution was increased to .0001 degrees and error detection was improved by using a separate 6-bit CRC for each fix. As long as no errors occur in the absolute fix, at least one fix can be recovered from the message. Date stamping was added to the absolute fix in the form of a Julian day of year (1-366). Virtually all units deployed on wildlife use the T02 format.

In addition to improved resolution and error detection, it is still possible to send up to 7 fixes in a 32 byte message. This was accomplished by using variable length fields for latitude and longitude in the relative fixes. Three categories, or types, were established:

1. Type 1 covers situations where at least one relative fix is between .2048 and 6.5535 degrees (latitude or longitude) from the absolute position. Type 1 has the greatest range, uses the largest fields, and limits the number of fixes per message to 5 in a single ARGOS transmission.
2. Type 2 covers a range of .0256 to .2047 degrees, uses smaller fields, and increases the number of fixes to 6.
3. Type 3 handles the case where all relative fixes are within .0255 degrees of the absolute fix. Type 3 has the least range, uses the smallest fields, and allows up to 7 fixes per 32-byte ARGOS message.

The Telonics algorithms that generate the T02 formatted transmit buffers make every attempt to minimize battery consumption and fit the most data into the fewest number of bytes. For example, Type 3 buffer formatting is attempted first since the latitude and longitude fields are the smallest. Should the attempt fail (relative fixes out of range), attempts will be made for Type 2 formatting, and finally Type 1 formatting (the least efficient). In cases where the system is unable to get a fix, previously formatted data continues to be transmitted. Internally, however, the fix buffer is “rolled”, shifting a “no fix” entry into the top of the data stream and the oldest fix out of the bottom of the data stream. When the system is again able to acquire a position fix, any “no fix” entries at the bottom of the data stream are eliminated so that the formatted ARGOS message is as short as possible.

The information presented in the following examples is actual data that have been transmitted by a Telonics ST-14/GPS system, recovered with a TSUR-B uplink receiver, and processed on a PC with the TELGPS Bit Splitter (a utility program which converts raw uplink data to a more readable form). Each of the examples below begins with uplink information and is followed by the converted form. Raw uplink data is presented a variable number of 3-digit decimal numbers ranging from 000 to 255. These numbers correspond to 00 to FF hex, the minimum and maximum values of a byte. The minimum number of data bytes in the T02 transmission is 12 while the maximum is 32 (the maximum for any ARGOS transmission).

Example 1

Typical of a fast moving subject or very long fix interval. In this case, the number of fixes (5) is the maximum for Fix Buffer Type 1.

02-16-96 16:11:22 ID ***** NS

014	221	224	202	081	129	017	125
202	000	010	194	000	022	001	240
082	144	000	172	001	192	235	160
001	112	121	000	028	255	254	192

———— Deciphered Data ————

Header Type = GPS Fixes
Fix Buffer Type = 1 (+/- 6.55 deg)

	Raw Data				Processed Fix				
	Lon	Lat	Dly	CRC	Lon	Lat	Day	Time	CRC
1	-111.8107	33.3841		07	111.8107W	33.3841N	047	23:10	ok
2	0.1377	0.0022	00	00	111.6730W	33.3863N	047	23:00	ok
3	0.2642	0.0043	00	1F	111.5465W	33.3884N	047	22:50	ok
4	0.1885	0.0023	01	07	111.6222W	33.3864N	047	22:41	ok
5	0.0057	0.0005	00	39	111.8050W	33.3836N	047	22:30	ok

Example 2

Typical in most applications where the subject is moderately active and the fix interval is reasonably selected. In this case, the number of fixes (6) is the maximum for Fix Buffer Type 2.

02-16-96 16:51:21 ID ***** NS

103	093	224	220	081	125	241	125
242	203	251	192	236	004	191	172
012	000	159	252	000	208	003	127
220	012	128	173	086	001	032	015

———— Deciphered Data ————

Header Type = GPS Fixes
Fix Buffer Type = 2 (+/- 0.20 deg)

	Raw Data				Processed Fix				
	Lon	Lat	Dly	CRC	Lon	Lat	Day	Time	CRC
1	-111.8098	33.3791		33	111.8098W	33.3791N	047	23:50	ok
2	-0.0017	0.0059	00	32	111.8115W	33.3850N	047	23:40	ok
3	-0.0021	0.0048	00	12	111.8119W	33.3839N	047	23:30	ok
4	-0.0016	0.0052	00	27	111.8114W	33.3843N	047	23:20	ok
5	-0.0009	0.0050	00	0D	111.8107W	33.3841N	047	23:10	ok
6	-0.1368	0.0072	00	2B	111.6730W	33.3863N	047	23:00	ok

Example 3

Typical of a slow moving subject or very short fix interval. In this case, the number of fixes (7) is the maximum for Fix Buffer Type 3.

02-16-96 17:21:07 ID ***** NS

079	221	224	220	081	131	001	128
020	151	229	218	005	095	127	124
029	192	026	240	050	247	250	128
255	215	223	000	191	135	140	015

———— Deciphered Data ————

Header Type = GPS Fixes
Fix Buffer Type = 3 (+/- 0.025 deg)

	Raw Data				Processed Fix				
	Lon	Lat	Dly	CRC	Lon	Lat	Day	Time	CRC
1	-111.8098	33.3872		27	111.8098W	33.3872N	048	00:20	ok
2	-0.0014	-0.0038	01	25	111.8112W	33.3834N	048	00:11	ok
3	-0.0017	-0.0033	01	15	111.8115W	33.3839N	048	00:01	ok
4	0.0000	-0.0081	00	37	111.8098W	33.3791N	047	23:50	ok
5	-0.0017	-0.0022	00	32	111.8115W	33.3850N	047	23:40	ok
6	-0.0021	-0.0033	00	3F	111.8119W	33.3839N	047	23:30	ok
7	-0.0015	-0.0029	00	0B	111.8114W	33.3843N	047	23:20	ok

OPERATIONAL LIFE

A simplified formula to calculate the operational life of an GPS-ARGOS system. Calculations based upon a complete 32-byte ARGOS transmission with repetition rate of one transmission per 90 seconds. GPS time-to-fix is assumed to average 2 minutes.

DBCR		**ARGOS SEGMENT**		**GPS SEGMENT**
(TOTAL DAILY BATTERY CAPACITY REQUIRED)	=	[ARHR (6.13 mAh/hr) + 2.4 mAh/day]	+	[FD (6.33 mAh/fix/day)]

Where: ARHR is the average number of hours of active ARGOS transmission time and FD is the number of GPS position fixes required per day

To obtain the operational life in days, divide the DBCR into the capacity of the battery pack. The C-cell battery pack is rated at 5000 mAh capacity, but should be derated to 4000 mAh capacity because of the current levels required. The D-cell battery pack is rated at 12500 mAh, but should be derated to approximately 9000 mAh. Further derating may be required for prolonged operation at -40¯C.

EXAMPLE: Assume an ARGOS transmission of 4 hr/week to recover data. This corresponds to an average daily transmission of 0.57 hrs. The ARGOS segment of the power budget is then:

[(0.57 hrs/day) (6.13 mAh/hr)] + 2.4 mAh = 5.89 mAh/day

Assuming one GPS fix every 24 hours, the GPS segment of the power budget is:

[(1 fix/24 hr) (6.33 mAh/fix/day)] = 6.33 mAh/day

Making a total of 5.89 + 6.33 = 12.22 mAh/day

Assuming the use of the C-cell battery pack, the operational life can be calculated as:

4000 mAh ÷12.22 mAh/day = 327 days

Assuming the use of the D-cell battery pack, the operational life can be calculated as:

9000 mAh ÷12.22 mAh/day = 736 days

OCEANOGRAPHY & COMMERCIAL APPLICATIONS

One of the first integrations of GPS technology for tracking applications was undertaken at Telonics in relaying GPS positioning information from non-wildlife subjects. The work involved tracking meteorological balloons and oceanographic buoys. GPS provided the position information and ARGOS was the relay link. In this case, Telonics' ST-13 ARGOS transmitter was used as the relay unit. A GPS receiver was integrated with the ST-13 and its functions were controlled through a special "daughter" card which we call a GPS Interface Card. This fully integrated package first used separate GPS and ARGOS antennas (later versions used an integrated GPS-ARGOS antenna with independent feeds).

Researchers utilizing meteorological balloons for the study of atmospheric conditions, climate, and weather phenomena could incorporate the electronics into their existing instrumentation or system (i.e. they provided power systems and packaging, and utilized their existing balloon or buoy technology). The system design provides position with errors less than 100 meters with selective availability (SA) invoked. See sidebar, *GPS—A System View* on page 3. Actual measurements of the error indicate most position determinations are less than 60 meters from the actual position. Even with SA in place, GPS positions are available around the clock worldwide, and they are the most consistently accurate positions available to users for locating weather balloons and oceanographic buoys.

Photo 4. GPS-ARGOS unit. Configuration designed for railcar and container tracking.

Along with this work in the scientific world, we began development of a system for commercial applications utilizing similar technology to service the trucking, rail, and container transportation industries. The same hardware technology has been utilized in this application, but a special data format called the GPS ARGOS Standard Format was developed by ARGOS for these applications. Approximately 100 of these devices are deployed on commercial containers and railcars to monitor location, and in the future to recover important data on the status of the cargo at regular intervals. Many of these applications are environmental in nature as the cargos are potentially hazardous and monitoring helps to protect these cargos.

The current software allows GPS fix attempts to be scheduled by Julian date and Zulu time with additional fixes scheduled as a delta number of hours from this point in time. A time-out period is established providing an upper boundary on the period of time allowed for a fix attempt. If a GPS fix does not occur within the fix time-out period (1-65535 secs), the unit will shut down the GPS receiver until the next scheduled fix attempt.

The commercial work using ARGOS has opened the door to the development of more miniaturized GPS-ARGOS systems. *(continued on next page)*

Incorporating what we have learned in these commercial applications of GPS systems utilizing ARGOS as a relay system, we began parallel development of two additional systems. The first is an onboard GPS data storage system wherein the GPS positions are stored in EEPROM on the Interface Card and recovered at a later time, and the second is development of an FM data link system capable of linking FM data back to users directly on command using a VHF frequency.

GPS — THE FM-SYSTEM

Another approach to recovering GPS information from animals would be to recover the information across a direct radio link upon command from equipment carried by the researcher. In concept, this kind of system is not new. It represents the incorporation of a command transmitter and data receiver carried by the observer, and data transmitter and command receiver in association with a GPS interface card and GPS receiver on the animal. A block diagram of the system is shown in Figure 2 on page 2.

To utilize such a system, the researcher (or observer) must carry an FM command transmitter to initiate commands to the command receiver on the subject (i.e. animal). Functions can be accomplished using commands such as "send data" or "reprogram" data-collection or duty-cycle regimes. To recover data, the researcher must carry an FM data receiver. This FM receiver must be capable of receiving the FM data transmission coming back from the animal, decoding it, and storing the information for later recovery. Additionally, the observer often wishes to carry a conventional VHF receiver as a means of receiving the transmitted signals from the VHF back-up beacon onboard the subject animal.

In this system, there is a high degree of complexity of equipment onboard the unit carried by the animal. There is an FM command receiver to receive signals from the FM command transmitter. (It's this receiver that must respond to "send data" commands from the biologist.) There is also an FM data transmitter which responds by relaying data back to the biologist's FM data receiver. In this system, a command is initiated by the researcher. The command receiver on the animal receives the command and an onboard microprocessor on the GPS interface card interprets the command. The FM data transmitter is then instructed to send the requested data to the observer in a fashion similar to FM modems or packet radio. In addition, there is a GPS receiver and, in some cases, a VHF back-up beacon (the system that works when all else fails).

The FM system has several important attributes. First, a large amount of data can be transferred across the FM data link. Second, the two-way communication inherent in this system allows modification of the duty-cycle and GPS position data collection scenario at various times by the researcher. (A command receiver with two-way communication capabilities is soon to be available for GPS-ARGOS units as well.) Lastly, the system doesn't incur processing charges associated with the use of the satellite system.

The system also has certain limitations. First, to utilize any radio frequency in most countries, FCC (or equivalent) licensing must be obtained for the radio link. Depending upon the actual FM characteristics of the transmitter/receiver, the modulation format and power output levels, the process can either be relatively simple or extremely arduous. Second, the FM system still requires that the researcher be within range of the animal and recover the data, so transportation costs and flight risks are not eliminated using this approach. In many instances, aircraft are unavailable or more expensive than satellite data recovery costs. In some instances, animals are located below restricted air-space and that prevents the researcher from getting within range to send commands or receive data. Alternatively, the animal is too far off-shore or in areas where risks are too high to be able to recover data via the FM link. Third, the observer must purchase a separate transmitter/receiver to interrogate the instrumented animals. The cost of this complex unit may exceed $10,000- $12,000 initially. Further, long data uplinks can be interrupted and may make data recovery from some animals "on the edge" of the useable operational range difficult.

In certain situations the FM approach is very cost-effective in the recovery of GPS data. There are several possible approaches to the development of a system such as the FM-link. As previously mentioned, one is to use existing packet technology, or FM/modem transmitters commercially available. This approach allows development of the equipment in a short developmental time-line, because it requires only the integration of existing receiver and transmitter technology. It has the advantage that some standard schemes to protect the data transfer are already in place in this commercial equipment.

Telonics has chosen not to take this approach. Although attractive in trying to develop a product quickly, this approach also has certain constraints, including a dependency on other manufacturers for the production of an FM data link. Rather than choosing this approach, Telonics has decided to develop all of its own data links for the FM system. We have been conducting a research and development program on the hardware for the past two years; software is also being developed to support these functions. Although the developmental cycle is longer developing each of the specific segments in-house, this is the only way to obtain *reliable* equipment for deployment on animals. It allows us full control and full flexibility for future development of the system. It also makes us less dependent on vendors of commercially available radio data links who may choose other directions in the development of their products. Those directions may not be suitable to future wildlife applications, and for further miniaturization of the product for use on smaller species.

At the present time we have completed all the segments necessary for the equipment to be deployed on the animal, and we are completing the development of the printed wiring boards and packaging for the equipment carried by the biologist. We are integrating FM receiving technology that has been used successfully in our intrusion detection systems over the past several years; therefore, we already have extensive experience with this data link which is now being modified for application in the wildlife field.

The development is proceeding as quickly as possible considering that the same people involved in development of our satellite telemetry also support development of the FM link technology. The present schedule suggests we will have an FM link to field by the end of 1996. The completion of this development offers another alternative to the GPS-ARGOS telemetry and the store-on-board approach, and represents a separate tool with distinct advantages (and some disadvantages) for GPS data recovery.

GPS Collars with Store-on-Board Capabilities

The lead article in this *Telonics Quarterly* suggests three possible ways to recover GPS position information from free-ranging animals. Two of the methods (the ARGOS satellite-link and the FM data link) involve placing data transmitters onboard the animal, thus allowing the user to recover data across a radio link without recapturing the animal.

A major drawback to both approaches (FM and ARGOS satellite systems) is the requirement for additional complexity in the form of added transmitter and/or receiver circuitry. This circuitry takes up space and adds weight. Perhaps more important, additional power is required to support these functions in order to recover the data. In a practical sense, the additional power requirement results in the need for a larger battery pack. The larger battery pack results in additional bulk and weight added to the final package. There *is* an alternative.

It is possible to *store* the GPS data *on-board* the unit in non-volatile memory for later recovery. Systems that store data for later recovery have been used for many years as Time-Depth Recorders (TDRs) in marine mammal studies. Most TDRs do not transmit data—they are sophisticated battery powered data acquisition systems.

The classical application is to record both time and depth-of-dive based on data from a pressure transducer. This approach eliminates the radio transmitters, receivers, other electronic circuitry, and larger battery packs associated with the radio relay, thus reducing overall package size.

Fusing similar data acquisition technology with a GPS receiver produces a device that can store GPS positions. The GPS receiver becomes, in essence, a sensor. If the same battery pack from a unit with a radio relay is used in a GPS receiver, more GPS positions can be taken. The power normally consumed by the radio relay is used to obtain additional GPS positions. Alternatively, if a smaller battery pack is used (i.e. C-cell-sized vs. D-cell-sized), a smaller configuration can be produced.

It is important to realize that the store-on-board GPS system still requires placing *more than a GPS receiver* on the animal. A sophisticated GPS controller/data acquisition unit with storage capability is also required. We put all these functions together on a single printed wiring board that we call our GPS Interface Card. In general, researchers trying to instrument medium-sized animals (such as wolves) have been very interested in this technology because the packages can be made smaller than units with radio links that are currently being deployed on bear, caribou, elk and moose (see photos 1 and 2 on page 4). The risk in such a system is clear. If the collar cannot be recovered, the data are lost. In most cases researchers also wish to incorporate a conventional VHF back-up beacon to help assure recovery of the unit (see Figure 1 on page 1).

Store-on-board systems are often designed to take relatively frequent GPS positions. The wolf unit shown in photo 5 is designed to operate for 25+ days, taking a position every hour. When the battery is exhausted, approximately 750 position fixes can be in storage for later recovery. The entire unit weighs only 1.1 kg. The collar width is 2.5 inches and the adjustment range is 16.5-18.5 inches. The system is powered by a C-cell-sized battery pack. Intensive data collection (frequent GPS positions) and smaller sizes (as compared to radio link units) characterize these systems.

Photo 5: GPS unit. Wolf configuration.

Smaller configurations are also being designed to offer even greater onboard storage capability and longer operational life. One unit, similar in size to the one deployed on brown bears (see photo 1 on page 4) is designed to run for six months, taking a position approximately every five hours. The unit is powered by a D-cell-sized battery pack. GPS positions are stored in non-volatile memory. Even if the battery exhausts or fails, data are not lost. Data can be recovered at a later time when the collar is retrieved.

In more sophisticated store-on-board units, a VHF transmitter is added for ease in relocating the unit. The VHF transmitter in very sophisticated units, such as the wolf and bear collars described above, offers an additional capability. The pulse rate of the VHF transmitter indicates the success of the last fix attempt by the GPS unit. A fast pulse rate (alarm mode) shows the GPS fix was not obtained in the allotted time; a slower pulse rate (normal operating mode) indicates the last position fix attempt by the GPS receiver was successful. This gives a researcher additional confidence in the correct operation of the unit on the animal. To verify operation, researchers can use conventional VHF tracking receivers to determine the pulse rate of the VHF transmitter. These units can be rechecked as often as required to make sure they are acquiring GPS updates. The alternative is to deploy the collar and pick it up months later, hoping that the unit has worked in the intervening time frame.

As mentioned, the principal advantage of store-on-board systems is that many of these packages and attachment designs are physically smaller than those equipped with a radio data transfer link, thus allowing for instrumentation of medium-sized animals. This advantage must be balanced against the fact that some animals, and consequently the attached units, may never be recovered and those data are lost.

It is also important to recognize that there is more than just sophisticated hardware in the unit. The hardware we have described is controlled by equally sophisticated software. These firmware programs are constructed to control the timing of the fixes, power manage the GPS receiver, and interface to the software inside the GPS receivers. The software also stores and time-dates the position information with GPS time and places it into non-volatile memory for later recovery. As a further extension of the system, units can be made to store information (i.e., satellite ID and pseudoranges) so that post-processing differential corrections can be made to the animal's position. Differential correction of GPS positions (DGPS) increases the accuracy of the position fixes by removing the error introduced by selective availability (SA). See sidebar, *GPS—A System View* on page 3.

In a standard GPS unit, only the position (i.e. latitude, longitude and sometimes altitude) are stored. In a DGPS unit, the information required for post-processing corrections includes the received satellite pseudoranges and satellite IDs. This information takes two to three times more memory than information associated with a simple uncorrected GPS fix. The effect is that only one-third as many positions can be stored in memory if the position is to be corrected later (i.e. post-processed) as compared to a simple GPS position.

In addition to all the other functions performed by the GPS Interface Card, sensor data can also be stored into the non-volatile memory. This information can be time-stamped and later correlated to animal movements to provide a more meaningful data set. Since there is a microprocessor onboard the GPS Interface Card, the sensor information can be collected, further processed and compressed as required by the study goals. This technological integration allows researchers to obtain highly accurate GPS positions and important biological data on a more frequent basis—in the smallest package available today for medium-sized animals.

GPS — PERSPECTIVE ON THE FUTURE

The fusion of GPS technology with radio transmitters, or with sophisticated data acquisition systems which store the GPS positions onboard the unit, is an exciting development in the field of wildlife telemetry. Although the concept of this integration has been bounced around for years (i.e. vaporware), the hardware and software are still relatively new. This technology is changing rapidly and studies utilizing the technology should be considered experimental in nature. This approach does not yet represent a standard technology for tracking wildlife in the vast majority of studies. As with other innovations, GPS technology is but one of the many tools available to the wildlife researcher to provide information on wildlife species.

What we know today as "conventional VHF telemetry" saw its beginning in the mid-1950s. At that time the concept of using radio telemetry on wildlife was new. In the beginning, each and every instrumentation of a new species was considered a new experiment. In the early days there was as much information being learned about instrumentation as there was about the biology of the animal. Many of the early transmitter and receiver designs used by wildlife biologists were large, bulky, and unreliable. They remained so into the 1970s. Technology used in the aerospace industry began to find its way into, and became incorporated in, what was then the only form of telemetry used in wildlife research.

Even at that time, there was excitement over the potential of future tools that might be developed as the biotelemetry field expanded. Researchers and designers conceived of data acquisition systems and intelligent programmable transmitters. Proposals appeared to develop such equipment, and crude prototypes appeared at various times throughout the 1970s and 1980s. Even with such serious minded efforts, technology takes time to mature.

In the early days of what is today known as *conventional VHF telemetry*, it was hard to imagine all the associated technological developments that would require refinement to achieve a reliable system for wildlife applications. In addition to understanding and developing appropriate *electronic circuitry* for transmitters that could be placed on animals, there was also the requirement to develop *packaging techniques*, to insure the units were waterproof. *Collars and other types of attachment approaches* for the wide array of wildlife species had to be developed. *Reliable power sources* which were small enough to be placed on animals and yet had sufficient energy density to operate the transmitter for an extended period of time also had to be developed. All of these technological developments proceeded at varying rates. Experience in the field, both successes and, perhaps more importantly, failures, opened the door to understanding and ultimately improving the technology.

When the first electronic circuits became more reliable and allowed the transmitter to operate for a longer period of time, then the power supplies were found to be failing prematurely. As the power supplies developed and became more reliable, packaging technology would limit the operational life of the unit on the animal. When a transmitter lasted only a few weeks, in the early 1950s, almost any packaging was suitable. The simplest packaging was suitable to protect the unit from moisture. In the 1970s, when transmitters and batteries could be expected to operate for 3-5 years, a different level of packaging technology had to be developed to assure that moisture was no longer the limiting factor for curtailing the operational life of the unit. The introduction of true hermetic packaging in the 1970s was a development that allowed long-term telemetry studies to be conducted. Refinements in battery technology, understanding of the power source, the effect of cold and hot temperatures, voltage delay in lithium systems, etc. were all lessons that equipment developers had to learn in order to produce a reliable conventional VHF telemetry unit.

Today, conventional VHF telemetry is often considered as standard a tool as binoculars to the wildlife biologist. Just as with binoculars, there is a wide array in the quality, reliability, durability, and performance of units produced by various vendors. Cheap (inexpensive) binoculars work adequately under certain circumstances, but often have poor optics, or fog, as moisture condenses on the inside of the lens. The more sophisticated (expensive) binoculars are generally more reliable. A range of technology, and choices, exists for the informed buyer of telemetry systems in much the same way.

In the early 1980s, satellite telemetry entered the scene and the use of the ARGOS system revolutionized long-range tracking studies. For the first time, biologists were able to follow the movement of caribou and other long-range migrating animals, such as whales, on virtually a daily basis and over prolonged time frames. This technology also took a considerable length of time to mature. Initial units were large and bulky (by 1990 standards), suitable only for large animal species.

By the 1990s, this technology had been miniaturized so that even intermediate-sized raptors are being instrumented and tracked with transmitting units designed to work with the ARGOS satellite telemetry system. The process of miniaturization of satellite telemetry took many years. Several factors were involved in this miniaturization—smaller electronic components, more highly integrated silicon (integrated circuits), more powerful and flexible micro-processor technology, smaller batteries with higher energy density and the capability to deliver higher pulse currents when required by the transmitter, innovative packaging technologies, and attachment procedures including implantation. Because so many technologies are involved, and because the wildlife field is relatively small in comparison to commercial markets, the entire process of miniaturization of the transmitter technology took a long time by commercial standards.

In the early 1980s, when only large and medium-size animals were being instrumented using ARGOS satellite transmitters, there was an attempt by the U.S. military and NASA to dramatically accelerate the process of reducing the size of the ARGOS transmitter. In essence this was an attempt to push the technology to develop more rapidly by throwing money at it. As is well known, money helps in development of the technology, but money alone cannot always force development of technology beyond its next limiting factor. In this case, and regardless of the very high funding level, miniaturization did not occur for years. When the technology did appear in a form suitable for birds in the mid- to late-1980s, several manufacturers had developed units. Most of these transmitter designs were developed by manufacturers who were not directly funded by the military community. What that suggests is that technological development was more closely linked to other factors, rather than to a limitation in funding.

All these technologies have built upon one another. It would have been almost impossible to develop ARGOS transmitters that could be successfully deployed on wildlife without understanding the technological lessons taught by previous experience with VHF telemetry. In the 1960s, some of us can remember when VHF telemetry was the latest technology—researchers placed bells on the necks of animals to help in recovery of the VHF unit if it failed prematurely. It is interesting that when ARGOS transmitters became available for animals, many experiments continued to use VHF beacons to aid in the recovery of the ARGOS transmitter if it failed prematurely. Today, we're using GPS technology to obtain positions on a global basis, and are using satellite technology to back-up or assure recovery of the GPS units in the event that they fail to provide positions.

GPS technology holds great promise for the future. In our opinion this technology is only now becoming suitable for incorporation into animal-borne packages. Although we can hold a commercial GPS receiver in our hand, and some receivers-engines are quite small and inexpensive, it is more than just size that governs the ability to incorporate such units into an animal-borne package. We are fortunate in that GPS technology has a large commercial market driving its development. In addition, this market has portability requirements very similar to the wildlife field. With the development of portable computing technology and the requirement for hand-held GPS position units, development of this technology has moved forward rapidly.

GPS technology today is an $8 billion per year business, soon to become a $12 billion per year business. Requirements continue for ever-smaller GPS receivers, operating on lower voltages and consuming less power, operating with poor antennas, and obtaining position fixes in shorter periods of time so that the units require as small a power source as possible. This is almost an exact overlap with the requirements the wildlife field has for a GPS system. With these developments moving at such a rapid pace, evolving GPS technology used in animal tracking will be obsolete at a rate that is unheard of in the wildlife tracking field. VHF telemetry systems 10 years old are often refurbished and reused in current studies. New generations of GPS receivers hit the commercial market every six months. The new GPS receivers are smaller, consume less power, and acquire position fixes faster than the previous generation. Everyone "needs" the latest technology for their study and the latest technology probably does work better. The down side is that GPS development is extremely engineering intensive and, as such, is costly.

All of these factors—size, power consumption and reliability—are the critical issues in development of this technology as a viable tool for wildlife work. Advances in these areas help assure that these tools may be used in the future on smaller animals.

There still remains a wide array of issues that are uniquely associated with the wildlife field that do not overlap with the commercial considerations for the development of GPS units. Wildlife species impose high levels of shock to instrumentation. Many wildlife species are often found at extreme temperatures where human-carried electronics would not be expected to operate. Many pelagic marine species which dive in saltwater (that blocks VHF and UHF transmissions and GPS downlink signals) do not expose the GPS receivers for sufficient time to obtain a position fix. The requirement to operate for an extended period of time (6 months to a year, or several years in an unattended mode) is still unique to wildlife applications and seldom a commercial requirement.

The hand-held GPS unit of today is not much more suitable for deployment on wildlife than was the walkie-talkie of the 1950s suitable as a VHF telemetry unit. In this field, the appropriate technologies available in the commercial world must be integrated into the special-use applications to meet requirements of the wildlife telemetry field. Thus it requires professionals who understand both the electronics and the wildlife field laboring in concert to assure that this integration process proceeds, and that this technology evolves from an experimental role to a fully operational role in the tracking of wildlife.

Even once this is achieved, GPS tracking technology becomes just a tool—and not the only tool—available to wildlife biologists for obtaining animal positions. There is still a role for conventional VHF tracking and there is still a role for ARGOS satellite telemetry, as well as GPS tracking technologies.

I guess what all that means is, we'll probably have a job for a little while longer, doing what we love to do...

Stan Tomkiewicz

The articles contained in this issue of *Telonics Quarterly* bring together a great deal of information about the state of GPS technology today and its application to our customers. Much of the information has been compiled from the writings of Telonics' staff members, including Roger Degler, Tim Rios, Gary Jones and Gayle Swinford.

Additional assistance was provided by Paul Beaumont, Mary Beaumont, Timo Hansen and Rick Wagner. Their efforts are greatly appreciated.

-Stan Tomkiewicz

TSUR-B — The Role in GPS Data Recovery

The TSUR-B (Telonics Satellite Uplink Receiver, Version B) has been an important tool used by researchers working with ARGOS satellite telemetry. This receiver allows reception, decoding and display of the ARGOS uplink message. The uplink message is the message transmitted by the ARGOS transmitter (PTT) deployed on the animal.

Since the TSUR-B receiver is not mounted onboard the satellite (and is not in motion relative to the transmitter), there is no Doppler frequency shift observed at the receiver. Therefore, the TSUR-B receiver is not capable of providing position of a standard ARGOS transmitter based on Doppler frequency shift (the method of positioning used by the ARGOS positioning algorithms). The receiver is, however, capable of recovering the ARGOS uplink message and decoding it as well as the ID code. Sensor data carried in the message can be recovered and directly displayed to the researcher. This information can also be transferred via a RS-232 serial port to a small laptop computer for further processing, display and/or storage. This system has been used extensively to provide calibration of sensors (i.e. mortality and activity sensors) onboard standard ARGOS transmitters. In other situations it has been used to recover the subsurface pressure data contained in the ARGOS message from marine mammals, thus providing dive profiling information from ARGOS transmitters without going through the satellite and data dissemination system.

The TSUR-B can also be used to recover the ARGOS uplink message from a combined GPS-ARGOS unit. The data recovered are the GPS positions which are being uplinked through the ARGOS system. Because the TSUR-B is a small receiver capable of being carried in the field or used to monitor from aircraft, it allows the researcher an alternative means of recovering GPS-ARGOS data from animals under field conditions. In essence, the researcher now has two means for data recovery using a GPS-ARGOS unit, through the satellite system or through the TSUR-B receiver. This information can also be used to pinpoint animals when trying to relocate them on the ground by obtaining the latest GPS position fix contained in the ARGOS message.

An additional capability, destined for future applications, is the activation of a small command receiver onboard the GPS interface card. This receiver is capable of receiving signals transmitted by the researcher to the animal as is done with the FM system. These commands could be used in future GPS-ARGOS systems to turn the ARGOS transmitter on when desired, thus allowing the researcher to recover ARGOS data at any time, or to issue other commands to control ARGOS and/or GPS duty-cycle and data collection regimes onboard the GPS-ARGOS unit.

Although the command receiver hardware is completed, the command transmitter (which must be carried by the researcher in the field) is just now being completed. Therefore, this function has not yet been implemented. You can look for this function to be implemented within the next year.

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