Virtual Anechoic Chamber using GPS Signals

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Abstract

Using GPS for animal tracking applications presents many significant challenges; not least the integration of the antenna in what is usually a miniature device. This paper describes a test setup that has been constructed to allow the user to perform something close to a full antenna gain pattern test using a simple turntable and relying on the GPS satellite motion to collect all angles required for a 3D gain plot. This has proved invaluable when predicting the expected performance of various antenna/packaging options for animal tags.

1 Application

In the animal tracking business the biggest consideration is usually weight (typically dominated by the battery size) and/or size – especially when tracking birds. NAVSYS' TrackTag™ technology uses unique DSP algorithms that require only 20 milliseconds of received data rather than the number of seconds that conventional approaches require. This results in a far lower power requirement on the tag and offers exceptionally small, long-duration tags that can operate for a number of years taking position fixes every few minutes, while weighing around 20 grams. The exact duration, fix interval and weight possible are variables that depend on each other. A "ballpark" spec' however, could be 1 year duration, taking fixes every 10 minutes, and weighing 20 grams.

This is a far greater number of fixes over a longer duration than conventional GPS can achieve. The weight, although far below that of conventional GPS, limits which species the tag can be used for. Biologists often use the "4% rule" [3] in order to determine whether the tag is light enough so as not to interfere with the animal's natural behaviour and therefore invalidate any research!

The Journal of Navigation (2007), 60 : 33-43 Cambridge University Press Copyright © 2007 The Royal Institute of Navigation

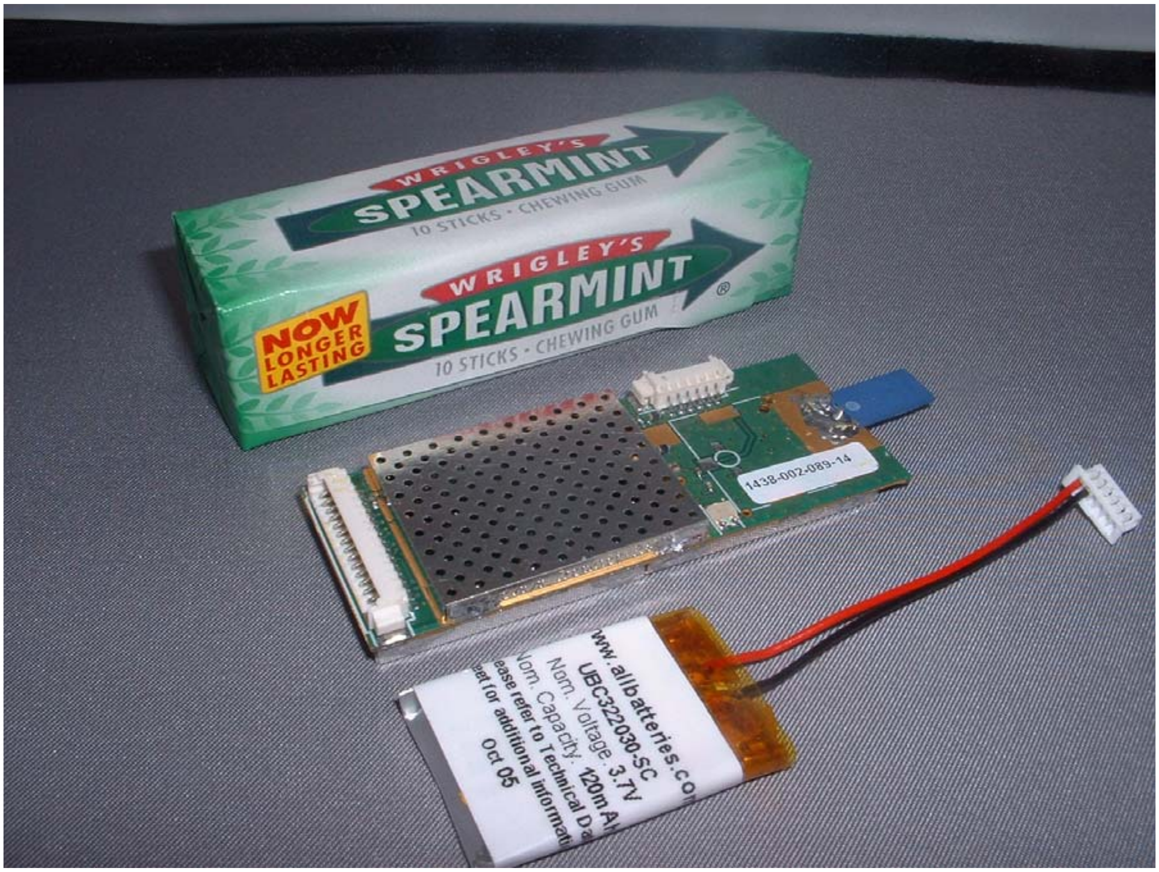

Figure 1: TrackTag^{TM}

In order to reduce the size of the tag there are many engineering issues that are addressed in the development of software and electronics. The packaging of the tag is also critical to the success of the overall design. The packaging issues vary tremendously and antenna design must be considered at the outset. Two recent examples are packaging for Albatross and packaging for Tapir tracking under the Amazon rainforest.

Packaging for the Albatross needs to be lightweight and also pressure-proof as these birds dive into the ocean. Since this housing is also used on seals and penguins (which can dive to 300m) the housing is in fact rated to 350m water depth. To minimise weight and volume this version of TrackTag uses a small ceramic chip antenna is housed within the packaging. This antenna/packaging combination had to be tested to ensure that the packaging did not interfere with the antenna reception.

Figure 2: Packaged Albatross Tag

The packaging for Tapir tags had different requirements. Weight was not the major concern. Signal integrity was the primary issue with the animal being under the rainforest canopy of the Amazon. A larger, patch, antenna with a good ground plane is used to optimise antenna gain and, again, its performance in that packaging had to be tested.

Figure 3: Packaged Tapir Tag

The method for attaching the complete tags to the animals was also a factor. The Albatross tags are glued to the tail feathers, whereas the Tapir tags are fitted to a collar. Fur seals have also been tagged and the method for attachment is often glue to the forehead. The effect of having lossy material, such as flesh, in the near-field region of the antenna is a reduction in antenna gain. This reduction in gain is often enough to prevent detection of any GPS signals. For this reason, tests have to be carried out with lossy material in the position the animal would be in relative to the tag. The variety of antenna orientations, packaging and proximity to flesh means a consistent, 3-dimensional test of the antenna performance in that environment is required.

This 3D antenna test would usually be done in an anechoic chamber. There are a few disadvantages in doing this though;

1) Expense – Use of an anechoic chamber is expensive and time consuming. This is an issue for a one-off test but in developing tags for different species means the tests are required many times.

2) Simulation of the signals – An anechoic test generates a signal in the near-field and corrections must be made to provide far-field results. The signals used are also not GPS structure.

3) Simulation of environment – A method to simulate the outdoors environment needs to be constructed.

The Virtual Anechoic Chamber test addresses all of these issues.

2 General Concept

The idea of conducting anechoic tests outdoors is not new. There has been some work done in the field of EMC testing outdoors for equipment that is too large to be accommodated within a chamber [1]. In those outdoor tests care is taken to characterise the environment in which the tests are carried out. The major difference between an outdoor test and a real anechoic test is the lack of screening. Having no screening introduces two sources of error, namely reflections/multipath and EMI (Electromagnetic Interference). These errors can be minimised through characterisation of the test site before testing is undertaken.

This paper discusses a technique for outdoor anechoic testing where the drive to go outdoors is to use the same signals that the system will use in operation. This offers data that is truly representative of how the system will behave in the real-world scenario it is being designed for.

Different design options (usually different antennas) can be compared in terms of their gain pattern using the turntable technique. Observations have shown that the expected signal power, although very stable, does vary with elevation of the satellite. This is due to the satellite's antenna beam pattern and must be taken into account.

3 Hardware Setup

Figure 1 shows the basic concept behind how the turntable rotation is coupled with the satellite motion in order to present the DUT (device under test) with as many angles as possible. Depending on the constellation geometry at the user's location, many satellites will pass overhead over a period of a few hours. The test will give the best coverage when a satellite is used which covers the entire range of elevation angles (El_{SAT}) from 0° to 90°.

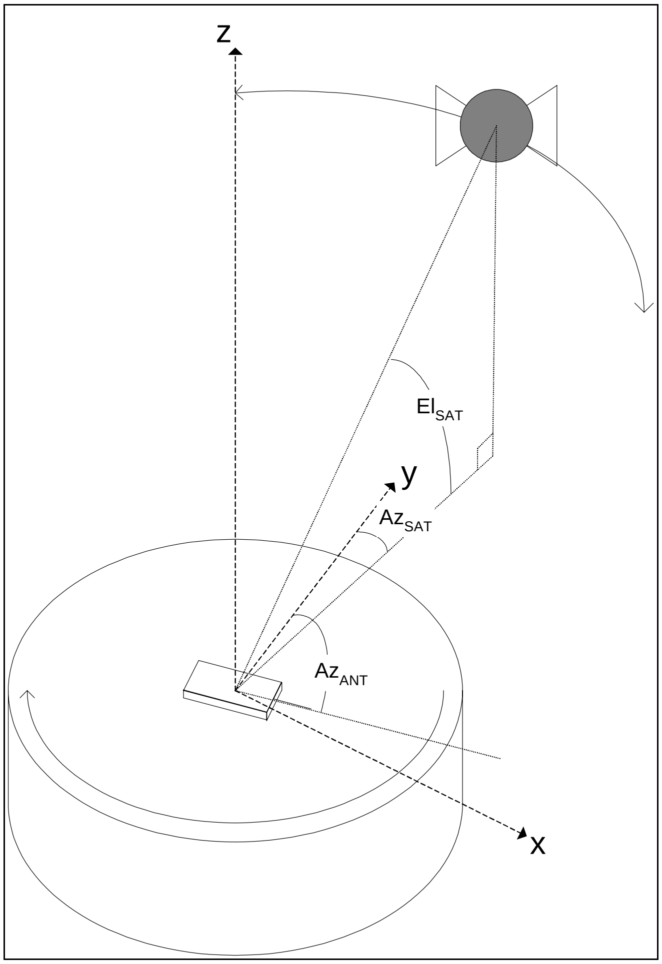

Figure 4: Hardware Setup

The turntable uses a simple DC motor to rotate. Each turn is controlled to be exactly 18°, therefore requires 20 turns for a complete rotation. Each turn's timing has to be precisely controlled and is done by synchronising the control of the DC motor to GPS time by using the 1pps (pulse-per-second) generated by a stand-alone GPS receiver to start the step. An optical sensor on one on the gears is then used to sense when to stop the turn. The turntable then remains static for 6 seconds before making another turn.

The DUT itself has to be able to either record the received signal data or send it to a system that can. There are battery powered GPS units with a Bluetooth link which could be used and avoids the need for slip rings to handle a wired system on the turntable. At NAVSYS the system is usually used to characterise miniature GPS data loggers (TrackTag^{TM}) which are therefore used to record data over a 4-6 hour test period. DUTs that cannot store the signal data can be coupled to commercially available GPS logger. The logger should record the following data at every turn;

1) Time
2) All tracked satellite C/N_0 (Carrier-to-Noise Ratio)
3) All satellite azimuth and elevation angles

This data is be found in standard NMEA format message often provided by GPS devices.

Software is available on the market, such as the NAVSYS Matlab toolbox, that will predict which GPS satellites will be in view and at what angle. This software is used to help plan the best period of time to run the turntable test and acquire data for a good range of elevations.

4 Angle Calculations

Figure 2 shows the calculated angles, taken from real data, on an “AzEl plot”. The way to interpret the plot is to imagine any points on the circumference are on the horizon (0° elevation). Any points in the centre of the plot correspond to measurements taken while the satellite is directly overhead (90° elevation). As the turntable rotates, the Azimuth angle with respect to the DUT is changing. The DUT azimuth angle (Az) is therefore calculated using Equation 1.

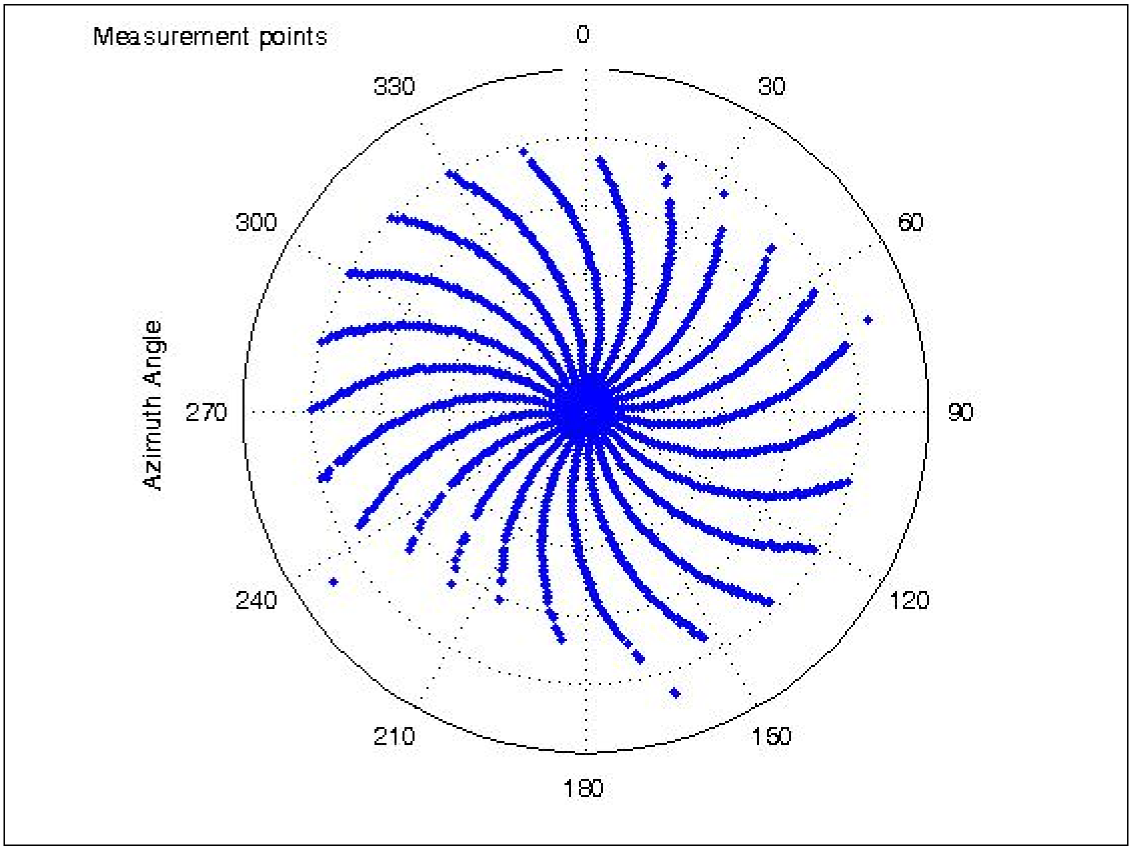

Figure 5: Measurement Angles

$$\boxed{Az = Az_{ANT} - Az_{SAT}}$$

Equation 1

The turntable/antenna angle, Az_{ANT}, is derived from the GPS timestamp of the measurement and working out how many step rotations have taken place. The satellite azimuth angle, Az_{SAT}, will be provided by the logger's GPS processing or can be calculated by post-processing using the GPS time reference and archived GPS orbital Ephemeris data. The elevation angle is provided by the logger's internal GPS processing (or can also be derived using the GPS timestamp and Ephemeris) and assumes that the turntable has been setup level.

Figure 5 highlights a limitation of the turntable approach. There are no points provided by tracked signals on, or within around 20° of the horizon. The test is limited by the site surroundings which can prevent signals being acquired at low elevations. The data shown here was taken where there were some trees and bushes encircling the turntable, hence the need to do any device comparison tests at exactly the same site. This limitation can also be made use of as it offers an insight into how well the device will work in that environment and represents the real-world antenna performance there rather than a near-perfect but unrealistic lab environment.

5 Power Calculations

Having recorded the data for the angles shown in Figure 5, a correction is required due to the variance in power received from the satellite with respect to the elevation angle. This is due to the transmission loss not being equal over all elevation angles. The attenuation due to the satellite gain pattern can be estimated using Equation 2 [2].

$$\boxed{A_{SAT} = 2.5413(1 - \sin El)}$$

Equation 2

This indicates that at 10° elevation there will be 2.1dB attenuation due to the satellite antenna's gain pattern. This therefore has to be accounted for in the turntable test. The Satellite's antenna gain is, of course, not uniform over it's main lobe which covers the Earth. The shape of the satellite's main beam can be taken into account if greater accuracy is required [2] (pp237).

Atmospheric attenuation in the frequency band of interest (1-2GHz) is dominated by oxygen attenuation. This can be approximated by Equation 3 [2], $A_{oxy}(El)$, where $a = h_m/R_e \ll 1$ and h_m is the equivalent height for oxygen, 6km. This effect equates to around 0.2dB attenuation at 10° elevation and less at elevations above. As there is little interest in the gain pattern at elevations below 10° it was decided that this effect would be ignored.

$$\boxed{A(El) = \frac{2A(90^\circ)(1 + a/2)}{\sin El + \sqrt{\sin^2 El + 2a + a^2}}}$$

Equation 3

The SNR measurements for all points taken from the satellite showing the highest elevation angle range are adjusted for the satellite gain pattern using Equation 2.

6 Turntable Results

The data collected takes the form of a sparse matrix as there are an infinite number of possible angles as illustrated in Figure 5. 3-dimensional interpolation is therefore utilised to create a surface representing the gain.

Figure 6 shows the antenna gain pattern seen while using a simple ¼ wave, monopole, whip antenna. As the device was placed on the turntable horizontally there are areas on the horizon where the gain is low. These correspond to the direction the whip is pointing. Higher gain is observed at a 90° shift in Azimuth angle. This suggests we have the expected “doughnut” gain pattern for the whip antenna.

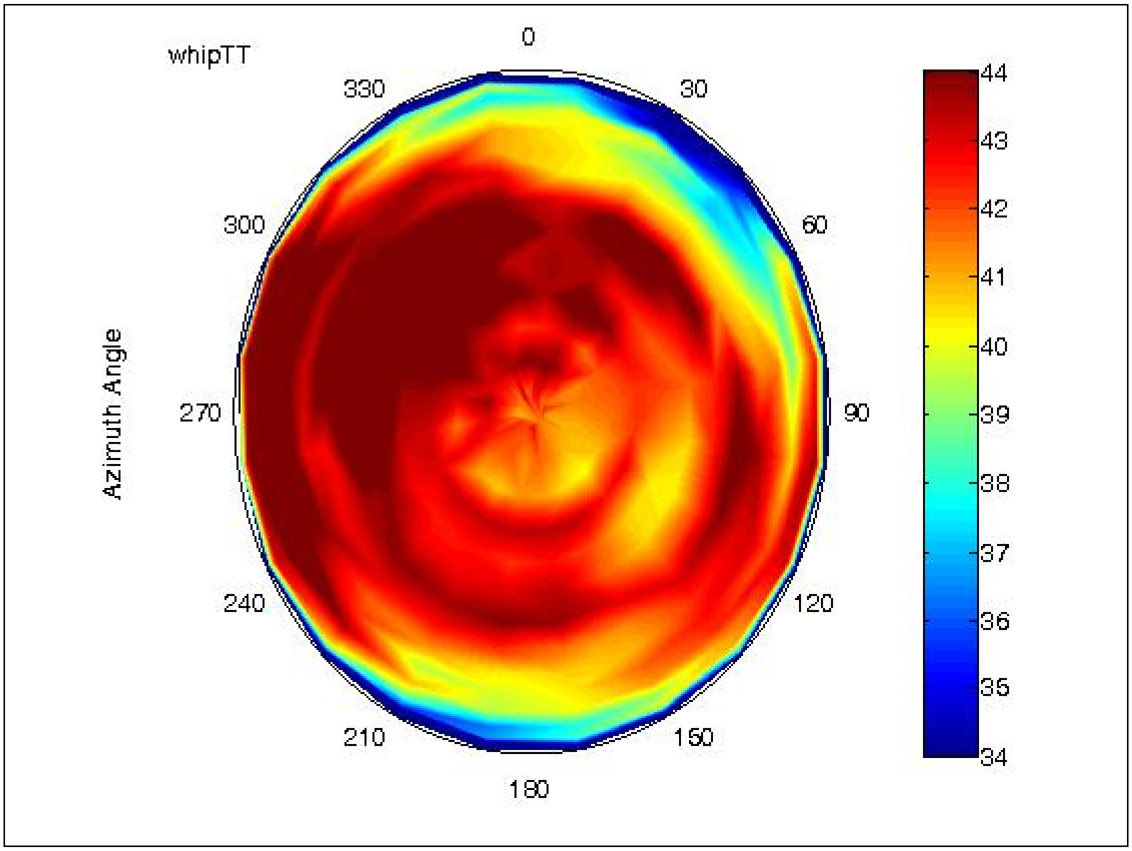

Figure 6: Gain Pattern for Horizontal Whip

Figure 7 shows the result of performing the test while raising the antenna end of the device by 30°. As expected, there is a null seen in the plot that corresponds to the null of the antenna and it occurs at around 30°.

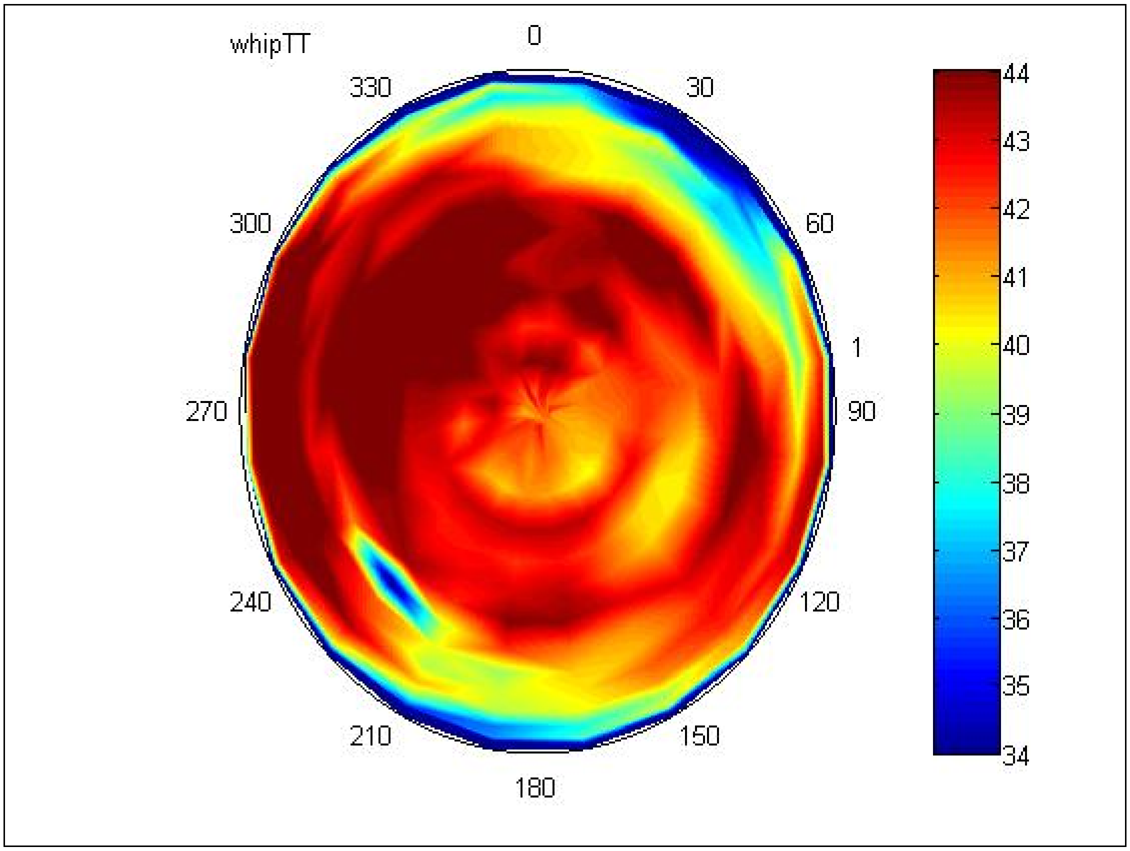

Figure 7: Whip at 30 Degrees Elevation

Figure 8 shows the result provided by the turntable test when using an active patch antenna. It shows a much more uniform gain pattern and higher gain than the whip test. There is a consistent low gain at low elevation as expected.

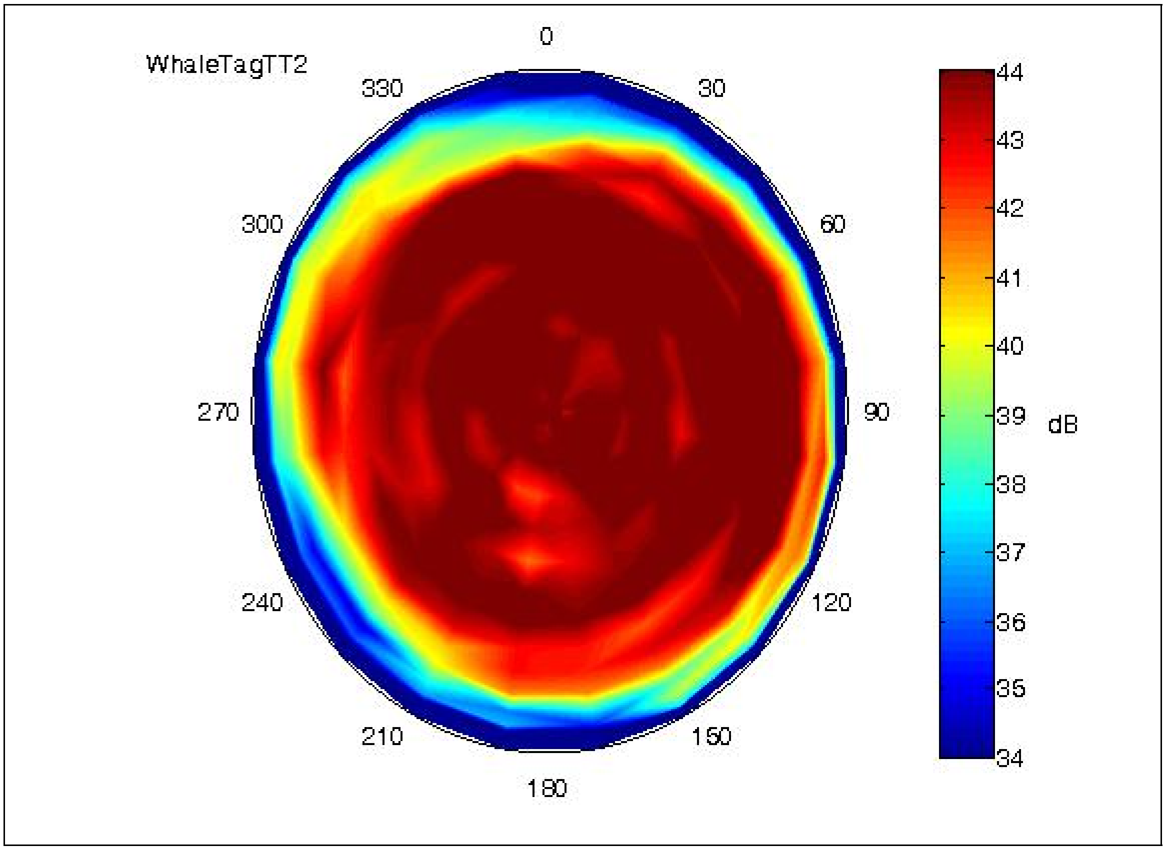

Figure 8: Gain Pattern for Horizontal Patch

The final plot, Figure 9, shows the “donut” shape expected while pointing a ceramic chip antenna directly up. The ceramic chip antenna has a field pattern similar to that of the whip in that it has a null in the axis of the antenna. For this reason, when pointing the antenna skyward, there is a null in the centre of the AzEl plot.

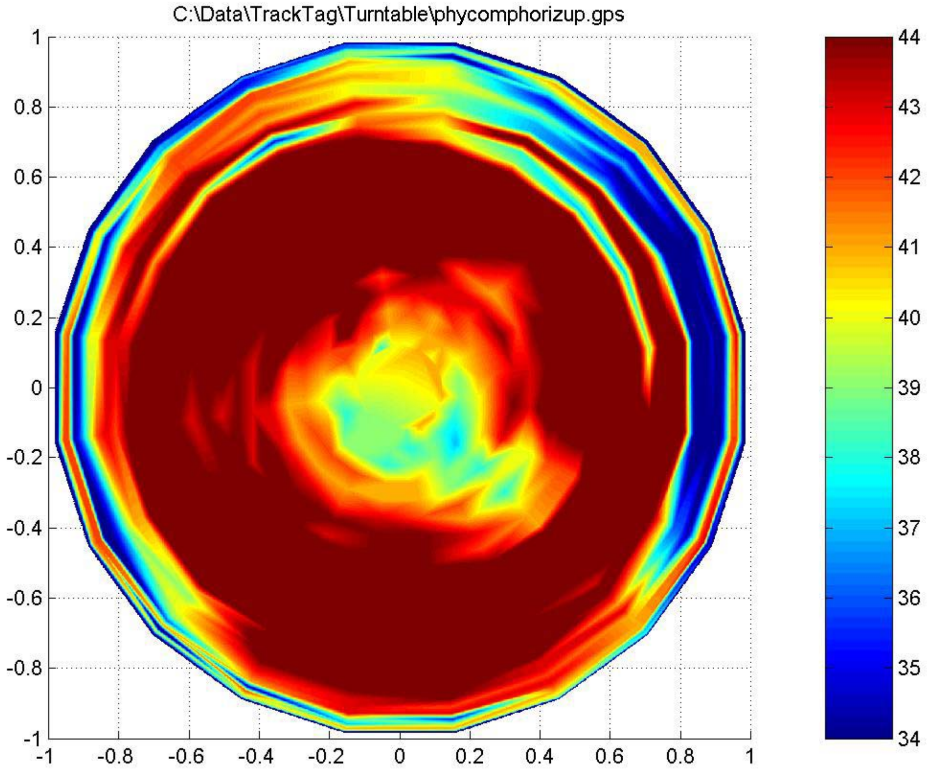

Figure 9: Ceramic Chip Antenna pointing upwards

7 Animal Tracking Field Results

The end result of these antenna tests is a tag system that can reliably receive GPS signals on the species in question and in the environment they inhabit.

Tapir tracking in Amazon

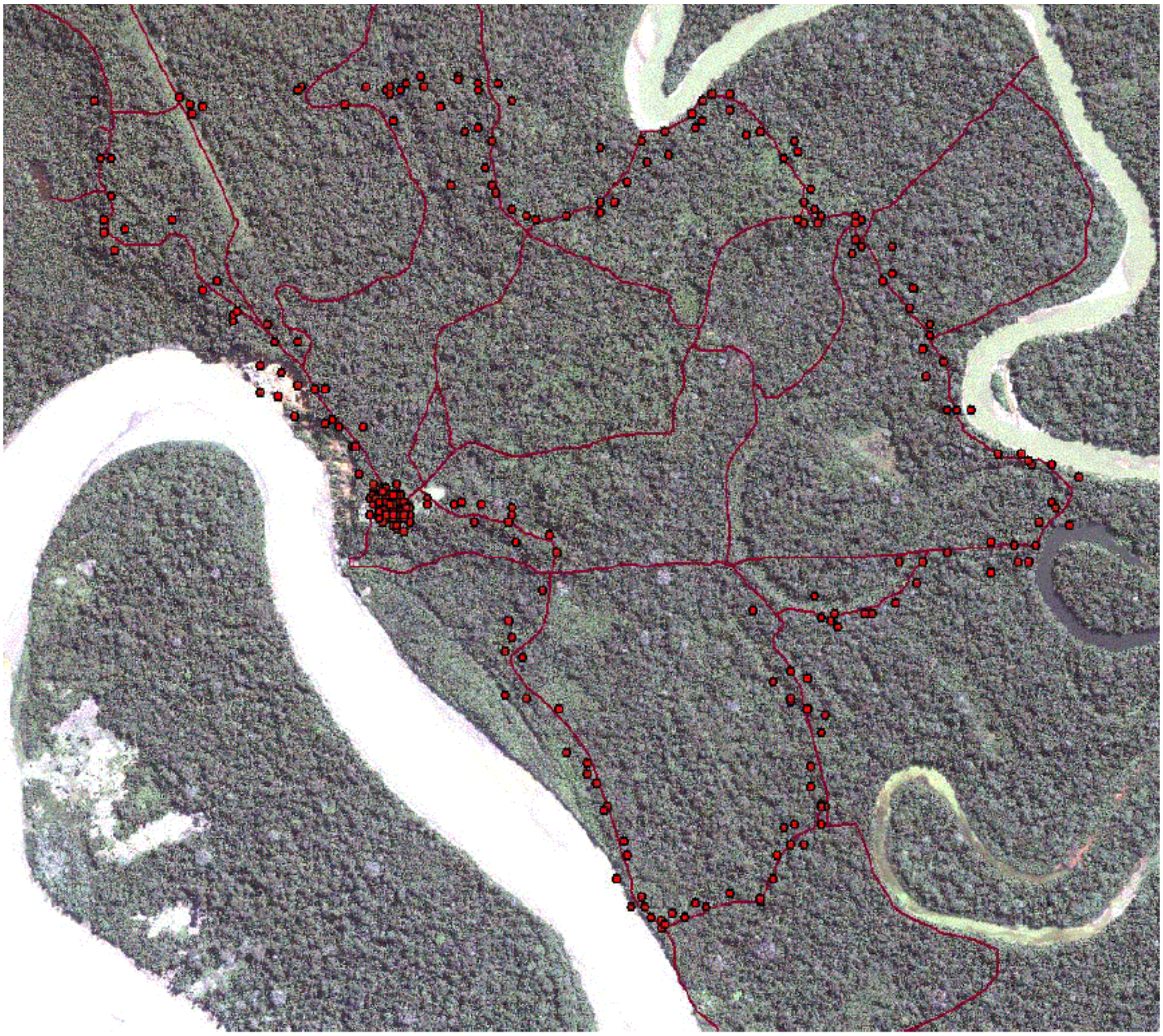

Figure 10: Amazon Rainforest Track

- This plot is actually taken as a trial by using a pet dog rather than a wild Tapir. Tapir results not yet published by customer.
- >50% navigation coverage
- Competing GPS device had long periods with no fix
- Customer conclusion - "*A success rate of over 50% under dense canopy is far beyond any existing technology and will certainly give several locations of the animal per day.*"

Albatross Tracking in South Atlantic

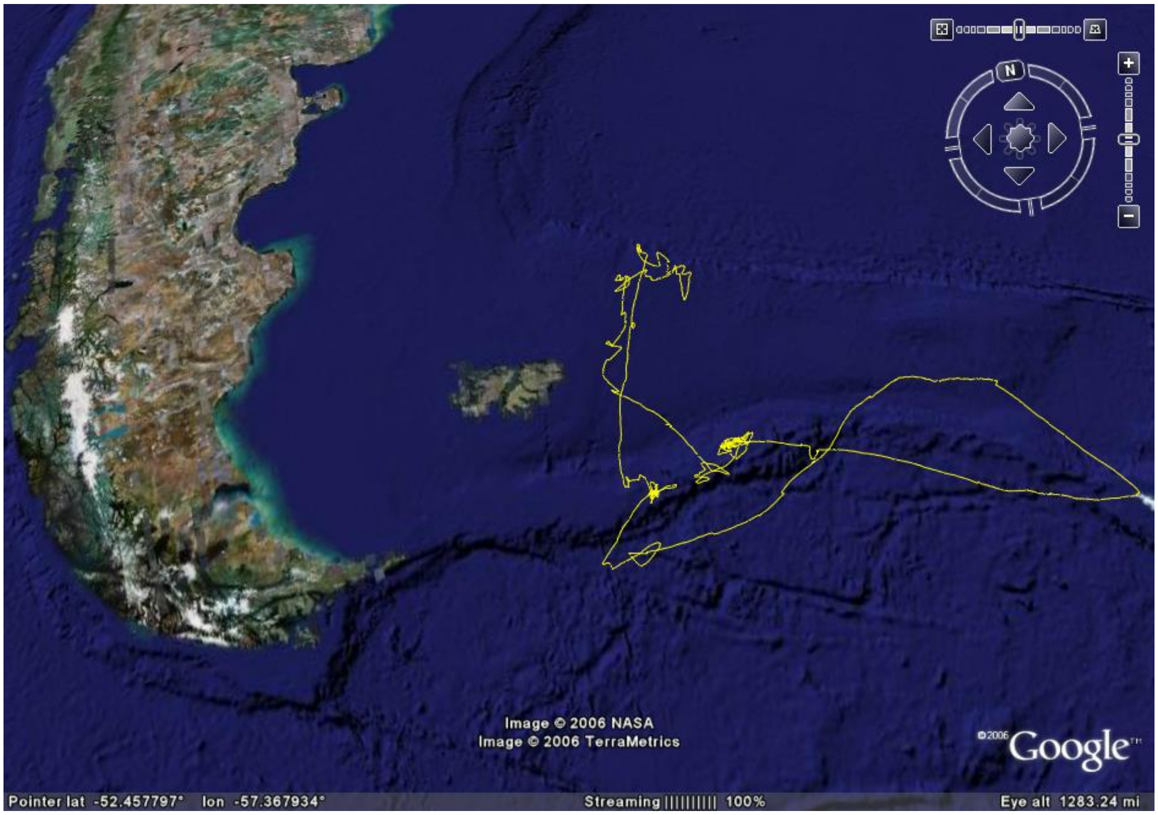

Figure 11: Albatross Track in South Atlantic

- Albatross trip covered 23 days taking position fixes every 2 minutes.
- Salt-Water switch inhibited GPS operation while bird was dived.
- Google Earth^{TM} compatible result files now available.

Leatherback Turtle Tracking in Greece

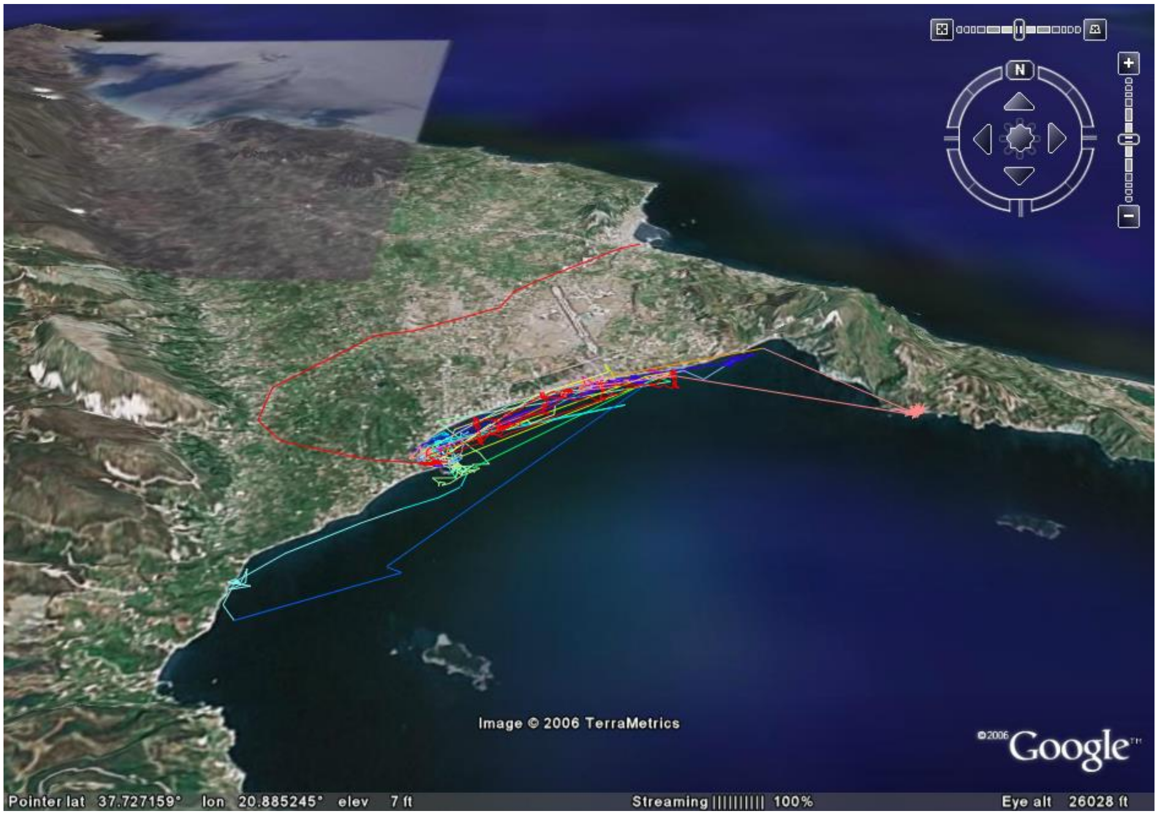

Figure 12: Turtle tracking in Greece

- Turtle trip covered 18 days taking position fixes every minute.
- Salt-Water switch inhibited GPS operation while Turtle was submerged (most of the time).
- Google Earth^{TM} result shows track for each day in different colour to aid interpretation.
- Partial track seen inland explained by the fact that the biologists initialized the tag in the main town on Zante before driving to the coast to find a turtle.

References:

[1] David L Schoch & Maqsood A Mohd PhD, *Feasibility of a Virtual Anechoic Chamber: The Ultimate E^3 Test Facility*.

[2] B W Parkinson & J J Spilker Jr, Global Positioning System: Theory and Applications Vol 1. Progress in Astronautics and Aeronautics, Vol 163. AIAA, 1996.

[3] Bander, R. B. & Cochran, W. W., Radio Location Telemetry, Wildlife Management Techniques, 1969, pp95-103.

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