

Thoughts about A SYSTEM FOR TRACKING LONG-DISTANCE MIGRATIONS OF SMALL ANIMALS

THE PROBLEM:

Many biological processes involve long distance (intercontinental) movements of animals too small to carry radio transmitters powerful enough to be tracked by existing satellites (Argos, for example). The smallest radio tags compatible with the current satellite tracking systems have mass of 18 grams, limiting their use to birds weighing 400 grams or more. Most ecologically and economically important species of animals, such as birds, bats and insects, weigh less than 400 grams. One estimate is that 76 percent of bird and mammal species below this weight. Smaller transmitter packages transmit less radio frequency power for a given battery lifetime. For a small songbird, capable of carrying a one-gram transmitter, battery mass considerations commonly limit the peak power output to one milliwatt or less if a lifetime of the order of one month is needed. Such transmitters are now available and are widely used for bird studies, using hand-held receiving systems, to ranges of one kilometer or so from the ground, or several kilometers from light aircraft or elevated terrain or towers.

The basic difficulty is that the satellites currently used for wildlife tracking have orbital periods of several hours, thus satellite altitudes of, say, 850 kilometers. For such altitudes the inverse square law dilution of signal intensity requires higher transmitter power and thus heavier batteries than a small bird can carry without seriously inhibiting its behavior. An obvious solution is an elevated platform at a lower altitude. The minimum feasible orbital period of an earth satellite is 90 minutes, corresponding with an altitude in the neighborhood of 400 Km. The lower satellite would have a four-fold power advantage over the higher one; that is, it would require one fourth as much ground transmitter power as would the higher one to achieve the same results.

The Argos system, which uses satellites in the 850 Km orbit, uses the Doppler shift phenomenon for determination of the position of a ground target. This implies a strict frequency stability

specification on the ground transmitter as well as a minimum length of transmission to make a position determination. These requirements militate against the need for extremely low mass and very short, infrequent transmission pulses in a transmitter for a small bird. It would be highly advantageous if a position determination could be made by receiving only one short pulse, say one milliwatt peak from the animal's antenna, with a duration of 20 milliseconds and a repetition period of one second. On the other hand, position determination for long-range migrants in transit need not be very precise. As an example, if a trans-Pacific migrant could be located every second day with a precision of 70 Km, that would represent a breakthrough to the ornithologist.

We pose the question, "Is it physically feasible to detect and locate a transmitter at the Earth's surface, emitting one-milliwatt pulses of 20 millisecond duration at one second intervals, from a satellite at 400 Km altitude?" Alternatively, "What pulse power must be generated by the earth transmitter for a single pulse to be detected with a conservative signal-to-noise ratio by the satellite's receiver?" We address the second question, making the following reasonable assumptions:

- Carrier frequency 150 MHz; wavelength 2.0 M.
- Receiver system noise temperature 50 Kelvin.
- Satellite height 400 Km.
- Earth is a black body at 300 K, completely occulted by the antenna beam.
- Receiver bandwidth $B = 10$ KHz. Limits noise power and data rate. Precludes pulse length less than 0.1 millisecond.
- Earth (animal) antenna is isotropic, gain 0 dB; efficiency 10%.
- Satellite receiving antenna gain 15 dBi At 150 MHz the effective area is 10 M^2 .
- Required signal to noise power ratio at detector: 10 dB.
- Boltzmann's constant $k = 1.38 \times 10^{-23}$ Watt/K/Hz.

After the appropriate computation these assumptions result in a required generated pulse power of 1.0 milliwatt. It is realistic to expect a one-gram transmitter to produce this power input to the antenna under the assumed conditions.

SPACECRAFT ANTENNA CONSIDERATIONS

An antenna having 15 dBi of gain at 150 MHz has an effective area of 10 M^2 and a half-power beamwidth of approximately 19 degrees. Its half-power footprint on the ground from a height of 400 Km is approximately 125 Km. This might be adequate for some migration studies, but it would certainly be desirable to have much better precision of position location. (It is confidently assumed that the satellite's position is precisely known.) Further, at the equator. The sub-satellite point advances approximately 1800 Km in the orbital period, so the geographic coverage from a single such antenna would be very poor. One alternative would be an array of similar antennas pointing at various angles in a plane normal to the orbital plane, each with its own receiver. Another option would be an array of antennas with hemispherical patterns, to be employed in an interferometric imaging array with a separate, phase locked receiver for each antenna. The latter arrangement allows for a variety of signal processing techniques. The best choice of antenna/receiver arrangement will depend on many considerations involving the spacecraft configuration, orbital parameters, stowage and erection methods, acceptable geographical coverage, and space allocation on the spacecraft. The antenna configuration is fundamental to the whole system concept and will require much study and experiment. Signal processing methods are also of great importance and will depend on the antenna system chosen.

AREAS OF CONCERN

There are several major design decisions to be made involving subsystems which are critical to the success of the proposed system.

1. The orbit. In a 90 minute polar orbit the distance between successive apparitions is 1800 Km, probably not acceptable. A lower inclination orbit reduces the longitude distance

between apparitions for a stationary target. A compromise probably is to be made regarding complete global coverage versus complete coverage within a more restricted latitude band. The geographical coverage would benefit if there were a constellation of satellites, even as few as two. This deserves study.

2. An antenna system large enough to map a number of targets with usable accuracy will require considerable real estate on a satellite. How much and how will it be packaged for launching and how will it be erected in orbit. The antenna design and the orbit design are inextricably interdependent.. The signal strength budget outlined above assumes that the black body temperature of the earth dominates the system noise. The Sun has a black body temperature of thousands of degrees at our wavelength; Either the antenna system must discriminate strongly against energy coming from the Sun's direction or operation of the system will be restricted to the part of the orbit on the nighttime side of the earth. Local noise. Spacecraft are notoriously noisy. Our system requires a quiet environment. Every effort must be made to preserve radio quiet.

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