Recent Cornell work on RF tags

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Plan of our talk today

Intro (Wink)

Geolocation transceiver tag and receiver (Rob)

Geolocation logger (Rob)

Spread-spectrum tag and receiver (Rob)

Projects we are interested in pursuing (Wink)

How can tags help us understand migration?

They can help us learn about a bird’s:

- *Location* and its
- *State*

Localization

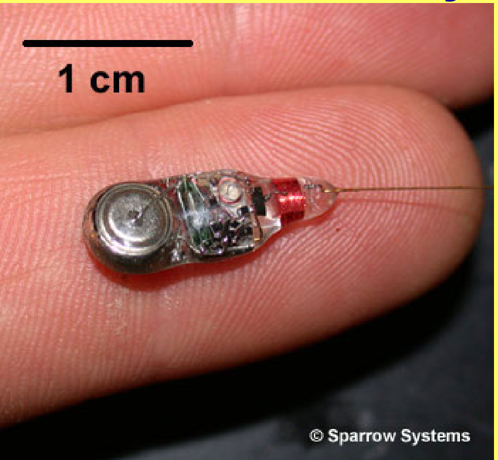
- Classically requires a large number of field workers;
- Or a single observer moving around a less-rapidly moving subject.
- Recently, more and more animals are being localized by satellite tags;
- And solar geolocation is proving serviceable for many systems.

State variables of interest

- Location can include altitude and temperature
- Heart-rate, body temperature or wing-beat frequency
- We would like to know much more about mass, energy consumption, behavior during migration, etc.

40 years of analog wildlife telemetry has been very productive

- Creative packaging and attachments to birds and other wildlife have been developed.
- Amazing reductions in size and creative ways of getting state information (heart and wing-beat rate) from an analog signal.
- However, there are many other sensors that cannot be so adapted, and all these tags have relatively short endurance.



The cell phone industry has produced a revolution in tiny sensors, processors and memory.

- Microprocessors provide the possibility of highly flexible and programmable schedules of transmitting and receiving.
- They also provide the possibility of on-board data analysis from a wide array of sensors.
- On-board memory provides the potential to store data for later retrieval directly or via an RF transmission.

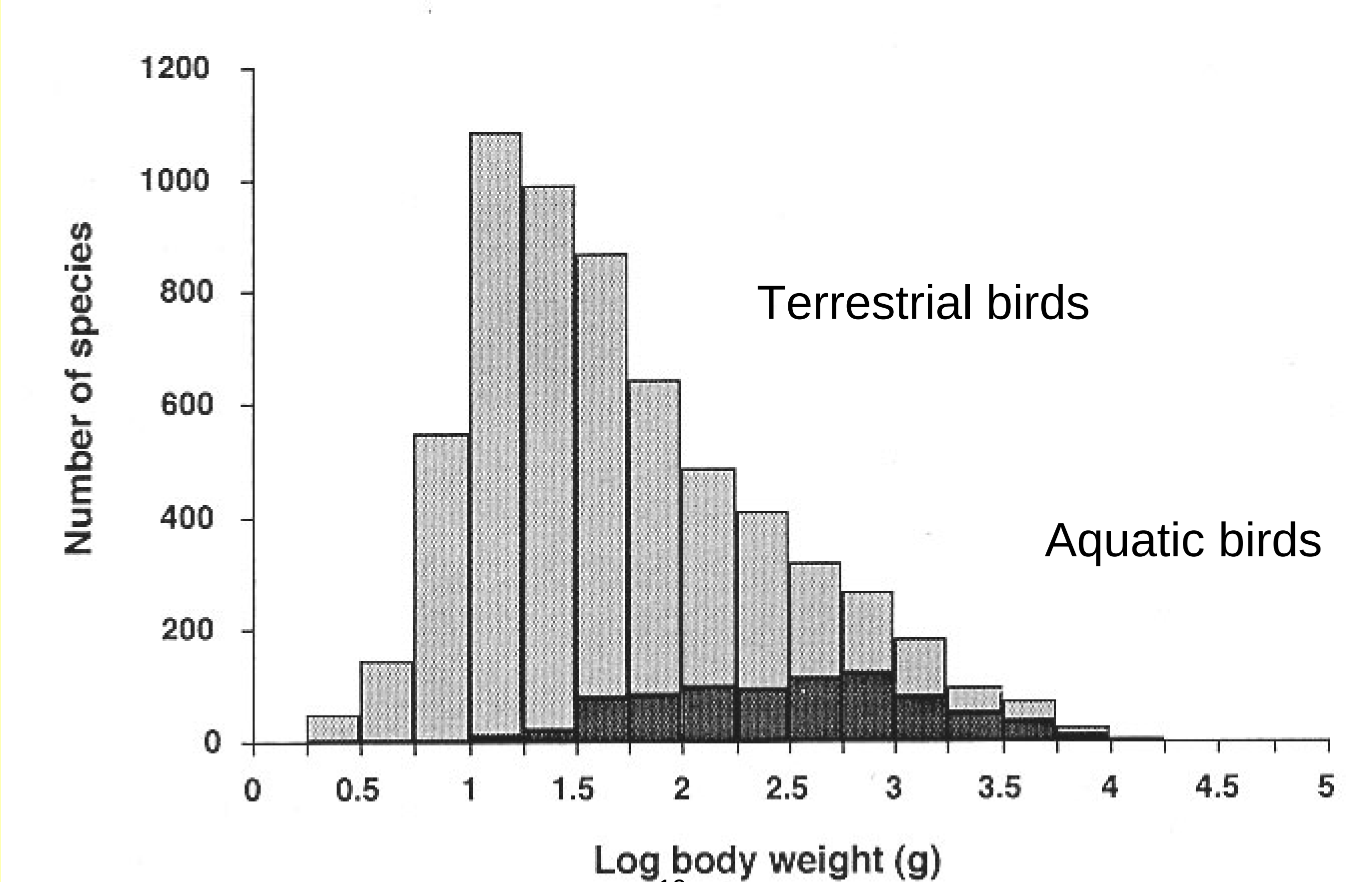
Once you have digital data on a tag, there are two ways to get it back:

- Catch the animal again and download the logged data directly from the tag: loggers.
- Use RF signals to get the information back, just getting close to the animal, not having to catch it again: transmitters.

So, why aren’t we all using these new tags?

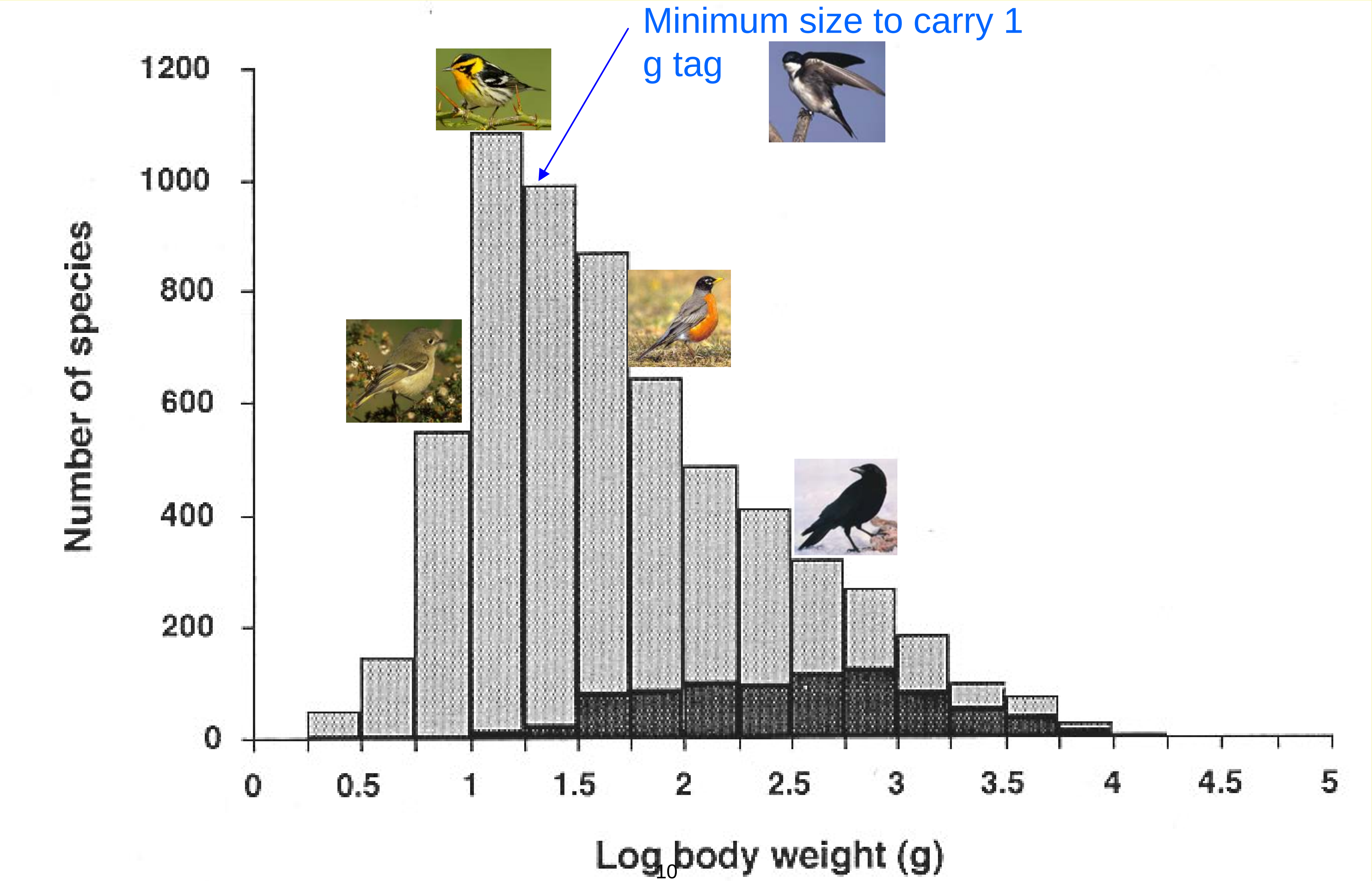
- Biggest problem is mass
- Batteries are still over half the mass of most tags
- And just about everything we want to do requires energy, which translates into more battery (unless, of course we harness some other sort of energy!)

The problem is that birds are small organisms (relative to many other vertebrates), and they can be asked to carry no more than 5% of their lean body weight.



From Gaston, K.J. and T.M. Blackburn. 1995. The frequency distribution of bird body weights: aquatic and terrestrial species. Ibis 137:237-240.

Despite constant pressure for reduction in mass, we have settled on trying to achieve a 1 g package.



Tag Development at CLO/BRP

MIGRATE Conference
4/4/08

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Current Tag Developments

- 3 Tag Lines:
  - Programmable telemetry tag
  - Non-RF geolocating logger
  - Automatic localization tag

Microcontrollers increase tag functionality

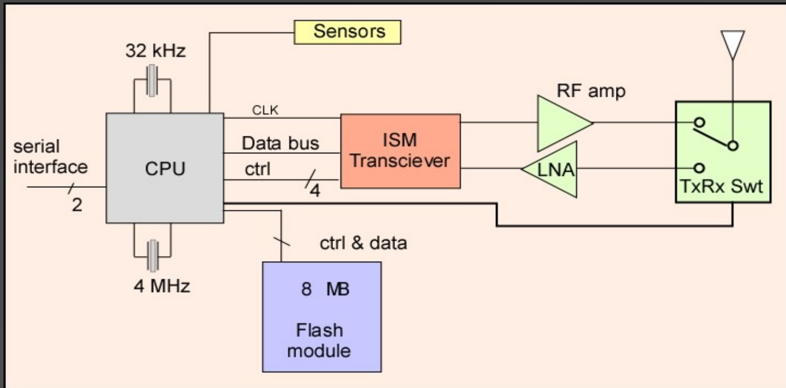
CLO is building small, power-efficient uC based tags

uC's Enable:

- Flexibility, optimized power usage, data telemetry, data processing, data storage

I. Telemetry Tag

- Onboard data processing/aggregation/storage
- On-demand or pre-programmed transmission of data
- Provides core technology (node) for sensor network

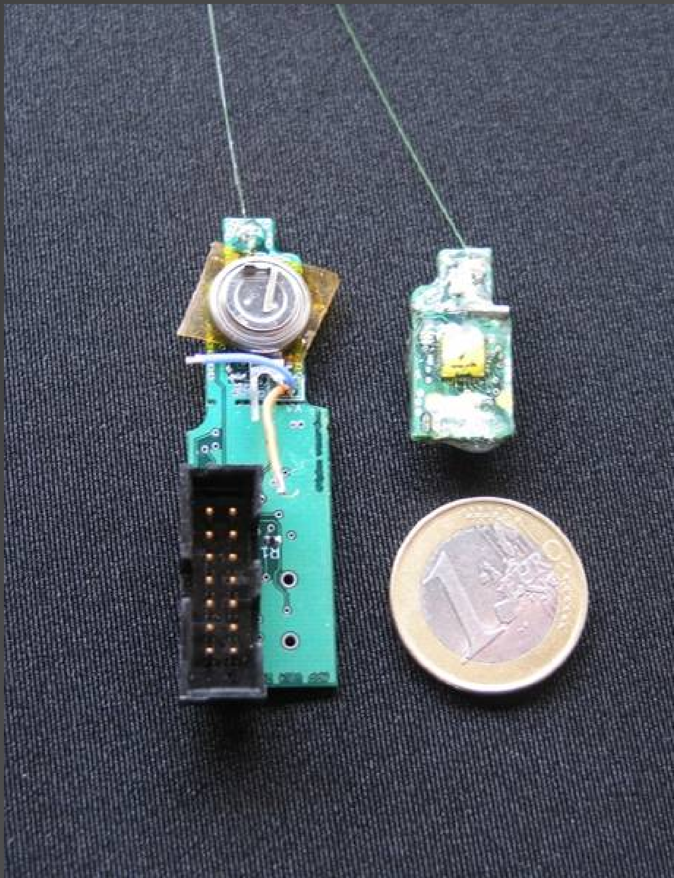


Why another telemetry system?

- Numerous commercial solutions exist, but…
- There is currently no way to efficiently track a small, long range migrant – weight is the issue
- Efficiently processing, storing light data and retrieving information at a single point via low-power protocol makes this a possibility

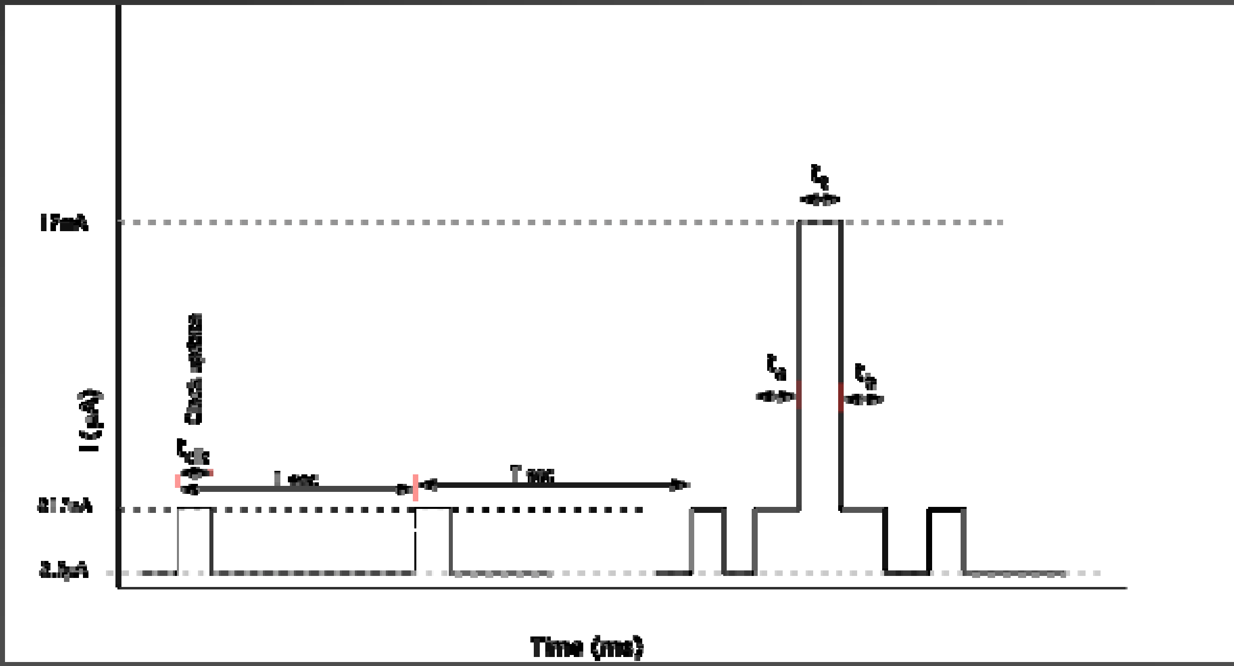
A small bird tag

- 1.2 g total weight without potting
- 315 MHz operation
- 5 kB of available storage
- 600 nm peak sensitivity light sensor



Duty-cycling is key to low-energy usage

- Tag spends most of time in sleep mode, just keeping time with Real Time Clock (RTC)
- Scheduled events wake processor up



Energy budget for a 6-month mission

Subsys	I (uA)	T(sec)	E (Joules)	mAh @3V
Stand-by	2.8	$16.1e^6$	135	12.5
Sense Light	150	1473	0.663	0.061
Data Transmission	17000	19.2	0.979	0.091
Sync Acquisition	17000	806	41.1	3.80
Totals			177	16.5

Battery specs

Part number	Company	Chem.	V	Standard I (mA)	Capacity (mAh)	E (Joules)	mass (mg)	Ed J/mg
TL4902	Tadiran	Li	3.6	20	1200	15552	9600	1.620
192	Energizer	MnO_2	1.5	0.083	45	243	500	0.486
BR425	Panasonic	Li	3	0.5	25	270	521	0.519
CR1216	Renata	Li	3	0.05	25	270	659	0.410
CR1025	Renata	Li	3	0.05	30	324	600	0.540
CR1025FFV-LF	Renata	Li	3	0.05	30	324	800	0.405
317	Energizer	Ag_2O	1.55	0.023	12.5	70	180	0.387
PGEB201515	Full River	LiPo	3.6	10	10	130	420	0.309
ML621	Panasonic	LiMn	3	0.01	5	54	300	0.180
CR2032	Sanyo	Li	3	?	230	2484	3000	
ML414	Panasonic	LiMn	3	0.005	1.2	13	80	0.162

The base receiver unit

- Same RF chip as used in tag
- Waterproof housing and keypad
- LCD display
- 32 MB of flash
- Serial interface
- Built in GPS
- Fully automated
- Low cost ($500)

Overview – the first implementation: Knot migration

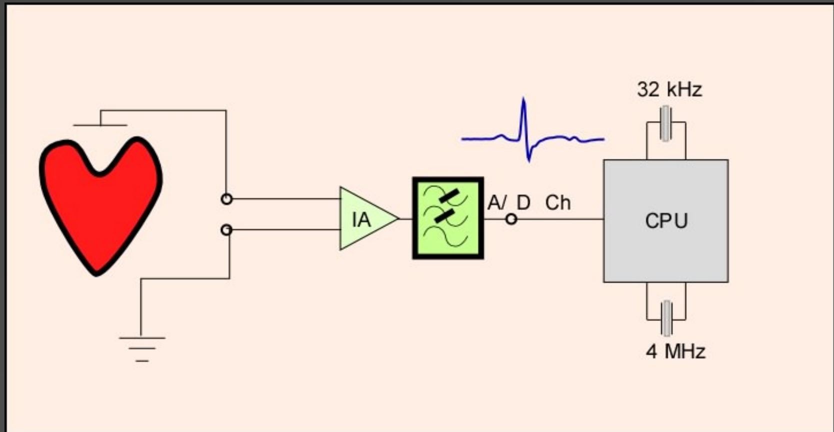
- Tags record light data for geolocation during a season
- Inexpensive receiver awaits for the return of the animals and captures the data during a single event transmission

On the knot

- First attempt was not successful
- Insufficient strain relief, weak antenna
- Next attempt this season

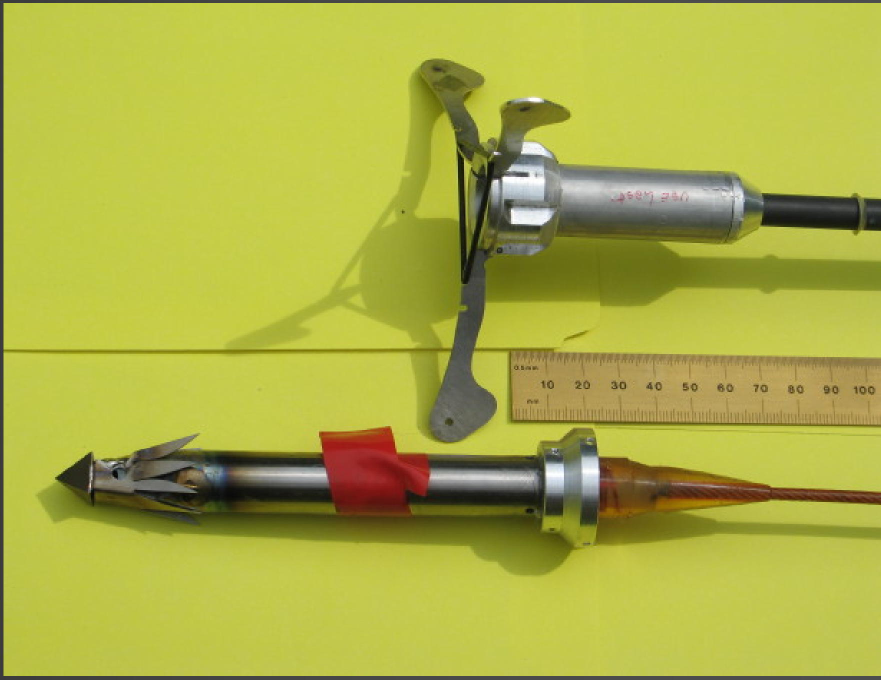
Other possibilities for a smart tag: Heart rate monitor

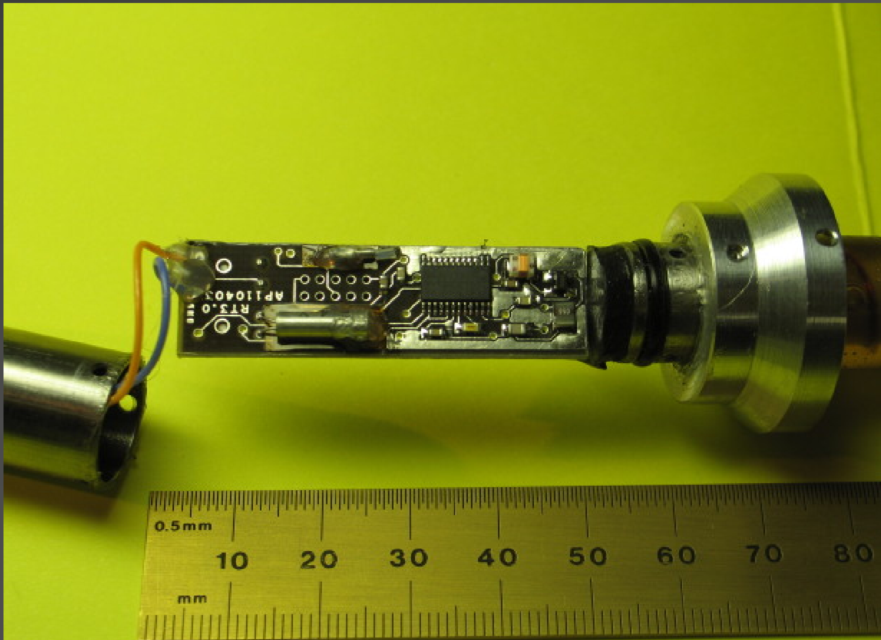
- HR requires relatively large sample rate for ultra-low power system
- Data reduction via onboard processing enables dramatic reductions in power consumption because writing to memory is energetically expensive



Whale tag

- Low mass is important for whales too!
- Ballistic design can be deployed using a crossbow - should be small as possible to aid implantation, minimize impact
- Tag gathers data, burst TX to receiver when at surface
- Titanium construction for low tissue rejection, strength, weight



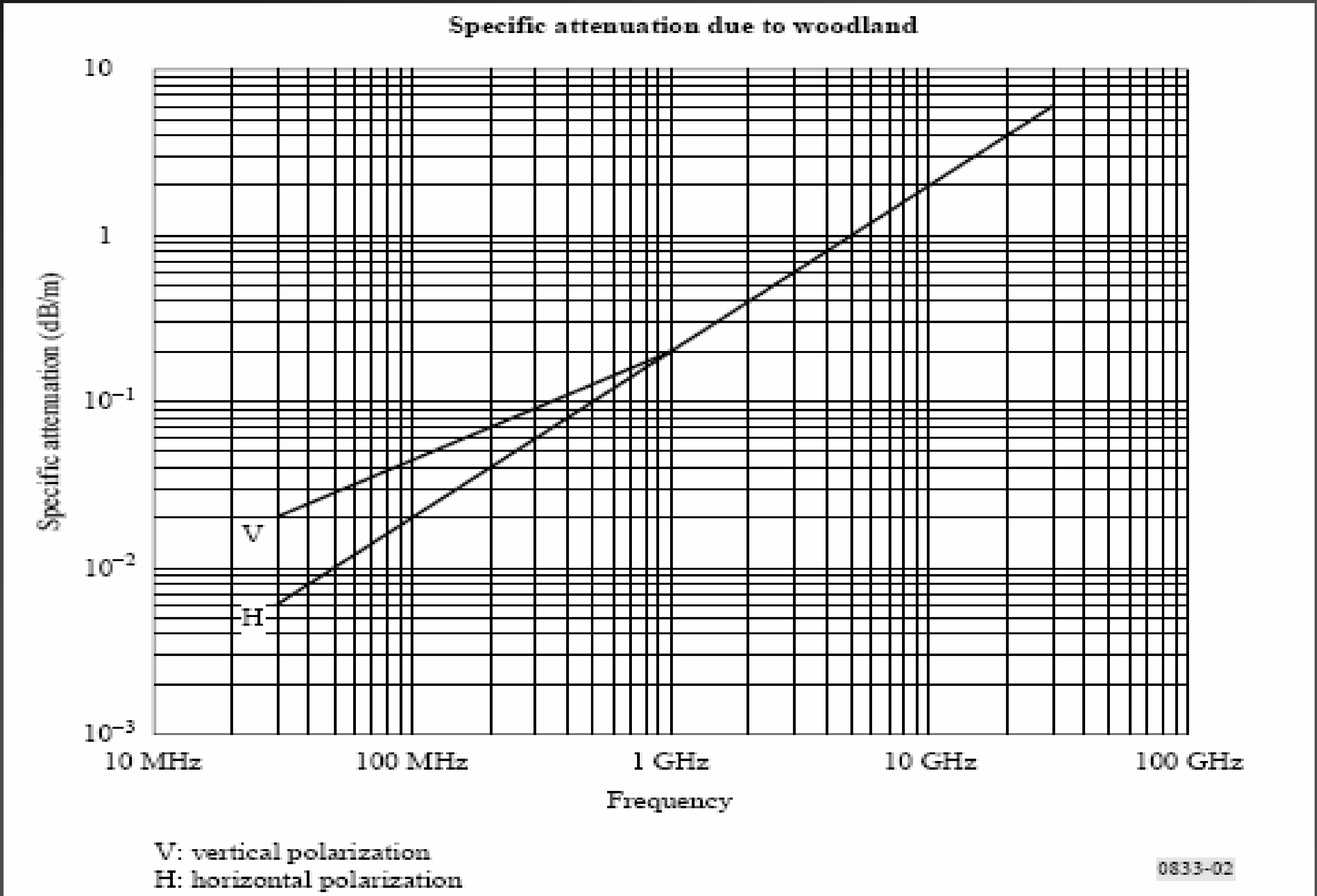


2 Key RF Design Considerations:

- Operating Frequency band
  - Availability
  - Antenna size and material vs attenuation
- Data rate
  - Slower = better range, but more energy for same output

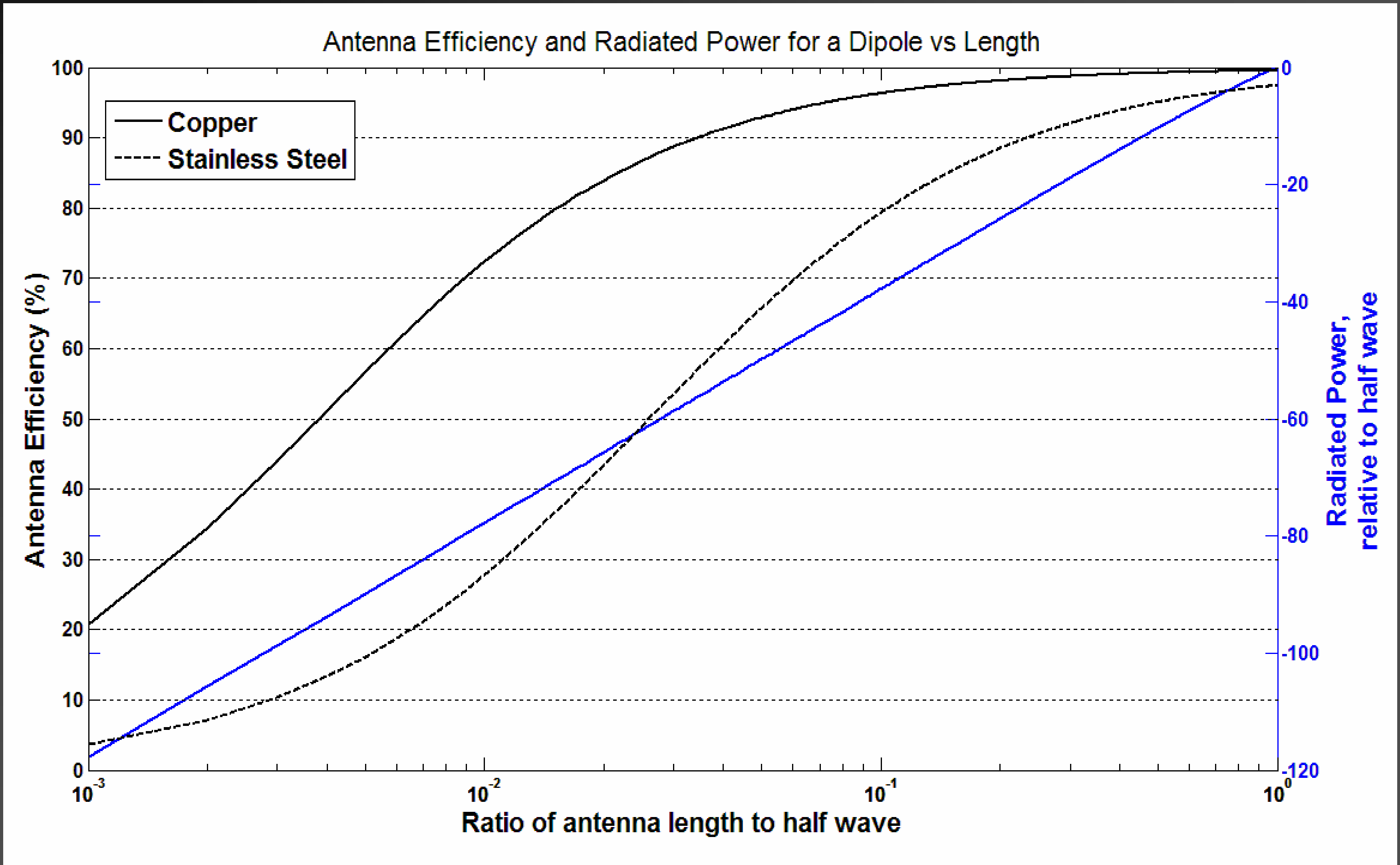
Foliage attenuation vs Freq:

Lower frequency = less attenuation



However, lower frequency comes with a price:

Larger antenna size, or reduced power output for same size



So, a tradeoff in frequency is required. Where is our optimum?

Tradeoff exists in selection of data rate as well:

Lower rate requires more energy per bit, but yields longer range

Specs for CC1101:

Data Rate (kbps)	Sensitivity (dbm)	RX,TX (0dbm) Current (mA)	Time to send 1KB (msec)	Energy to send 1KB (mJ)
1.2	-111	15.4,15	6600	326
38.4	-103	15.2,15	208	10.3
250	-94	16.5,15	32	1.58
500	-87	na	16	0.792

- Spherical spreading implies 6db loss for each doubling in range
- Slowest rate -> 24db more sensitive than fastest rate
- Slowest rate -> 16x larger range than fastest rate, but at energy cost

Conclusion: Telemetry Tag system

- Onboard processor allows data processing, scheduling
- Energy demands minimized via scheduling
- Inexpensive base stations allow for affordable high spatial density arrays
- Flash memory storage allows recovery months or even years after original deployment
- RF data download obviates need for recapture

II. Geolocation Logger

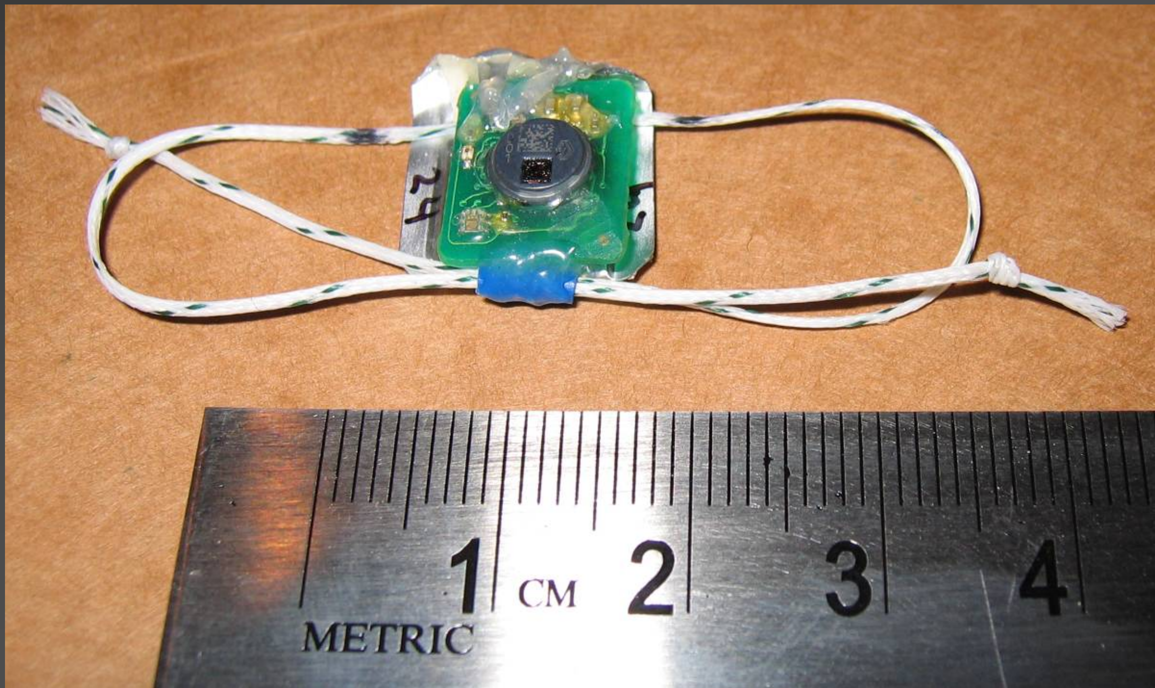
- RF sections of tags add complexity, weight
- The smallest tag possible will not transmit data – it logs it and must be recaptured

Geolocation Fundamentals

- Length of day depends on season and latitude
- Absolute time of midday defines longitude
- This requires an accurate Real Time Clock on board

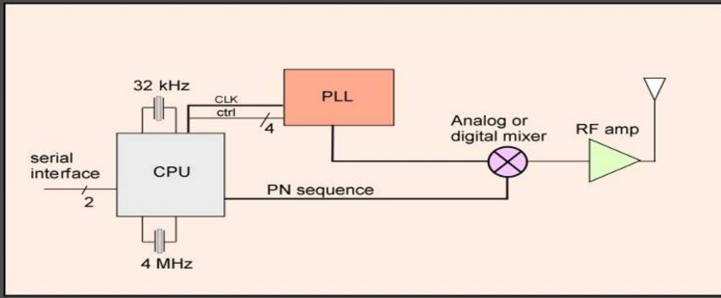
Geolocation Logger

- Present tag deployed weight is 0.9g
- Includes light, pressure & temperature logging
- 8kB memory
- 6 mo lifetime (solar cell for much longer life)
- Being deployed on swallows
- Now improving design for better data acquisition and off-loading



III. Automatic Localization Tag

- Optimized for long-distance detection
- Low power consumption = long life & small size
- Large number of individuals can be tracked simultaneously.
- Must be used in system



What is wrong with existing receivers?

- Labor intensive – leads to incomplete data & high costs
- Limitations on number of simultaneous tags
- Only real-time if people can be out gathering data all the time
- Short transmitter life
- Short range
- Require power-hungry tags

Automatic Radio-location Project

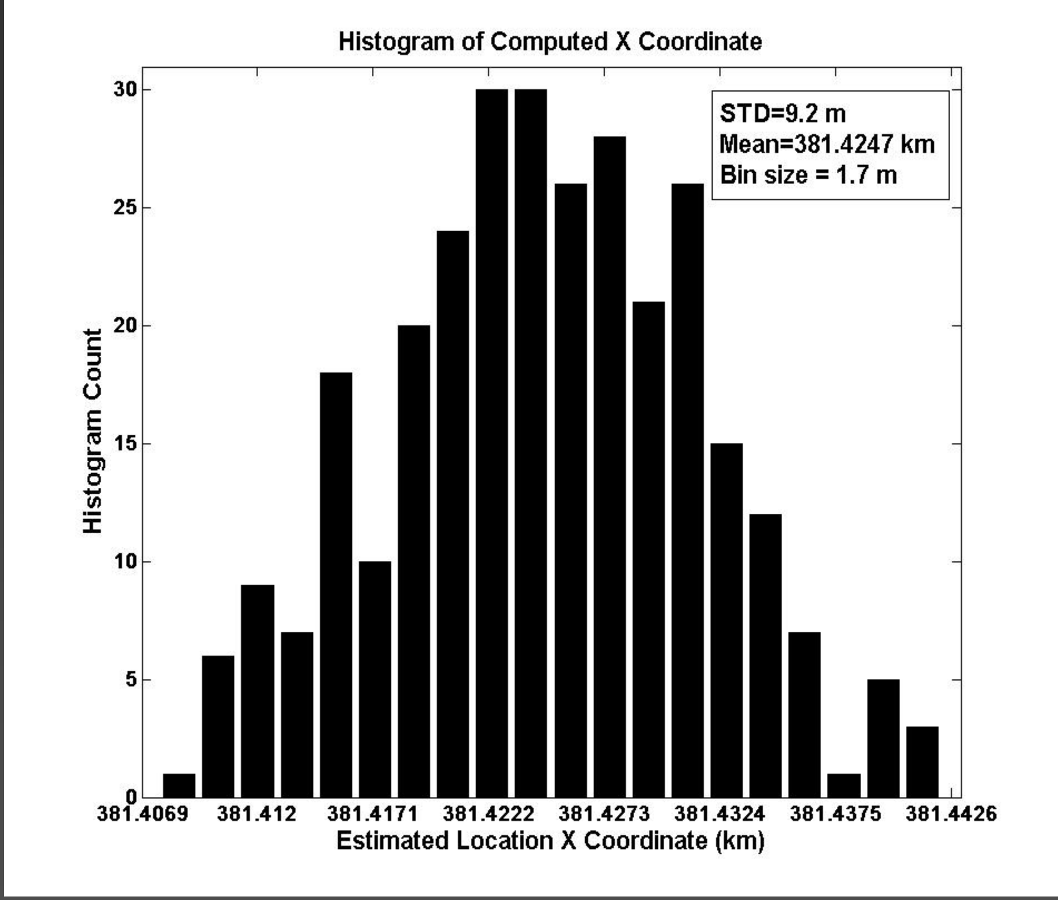
- What are we building?
  - System allows researchers to monitor the position of animals in real time
  - Completely automated: After system is installed, no human intervention is required
  - Thousands of animals can be monitored simultaneously
  - Uses much lower power tags than conventional tracking tags – allows longer lifetimes for comparable weights

How does it work?

- System is GPS in reverse
- Transmitter on animal sends Gold Code pseudo-noise sequence
- Receivers at fixed locations run matched-filter detectors (correlation) and time receipt of Tx event
- Position is computed via Time of Arrival algorithm

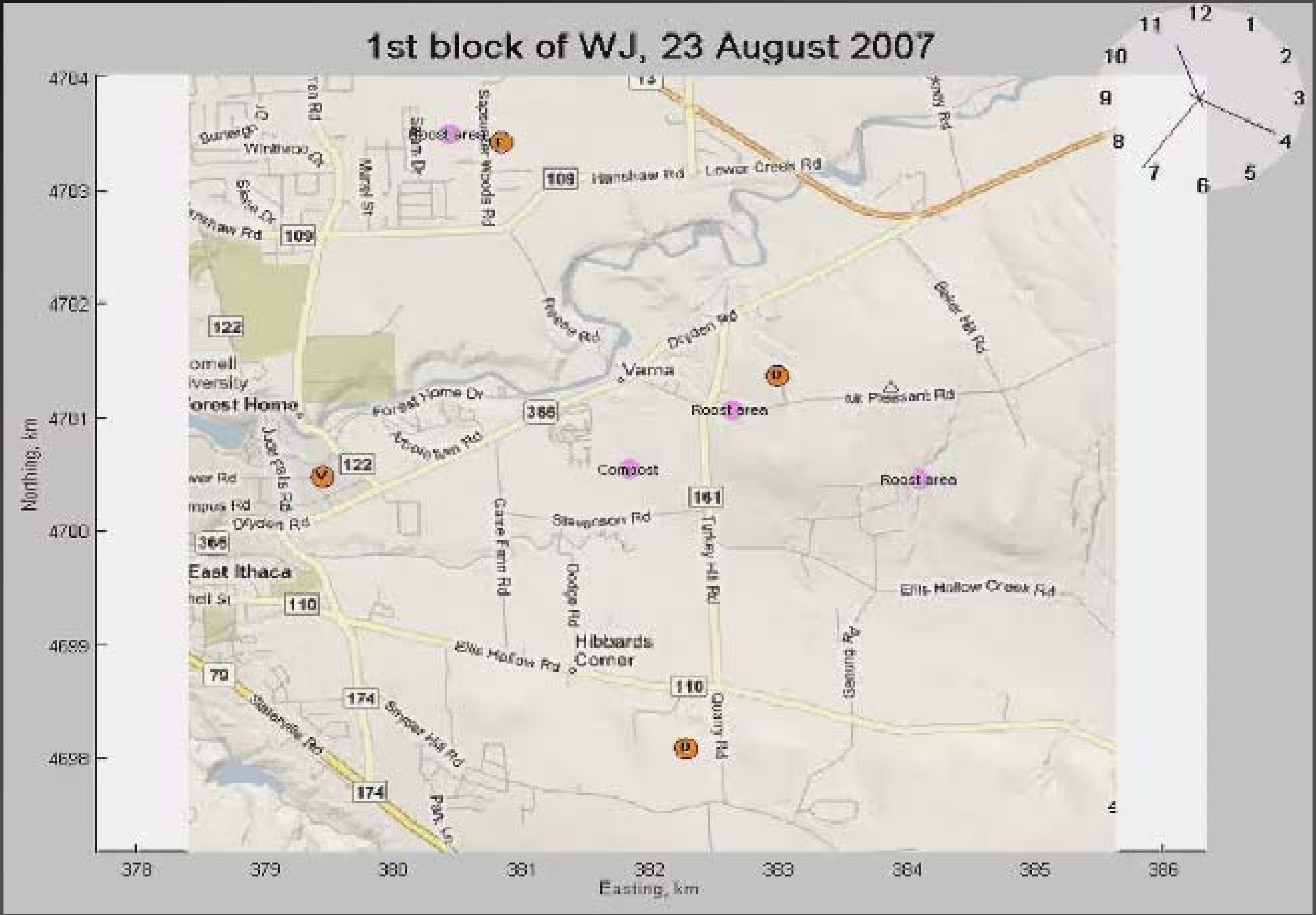
Current Performance

- Verified ~26db processing gain (some reduction from theory due to roundoff error
- 2.8125Msps samp rate yields +/- 27 nsec accuracy -> +/-10m
- With present transmitter get ~7+ km, ground to ground range



System performance

Local tests are under way to evaluate system performance:



What is the project status?

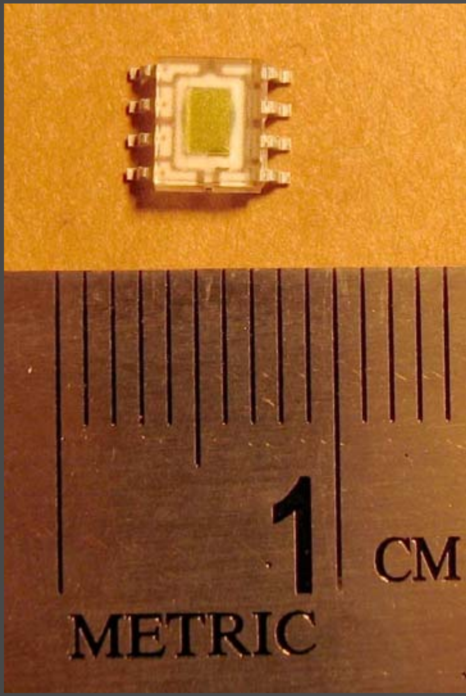
- Prototype transmitters and receivers built
- Local tests performed to evaluate system performance:
  - Current range is 7 km (covering an area of 25 km^2 with 4 receivers)
  - Position accuracy is <20m
- Network of 4 receivers in Ithaca tracked crows successfully
- Seeking follow-up funding for development

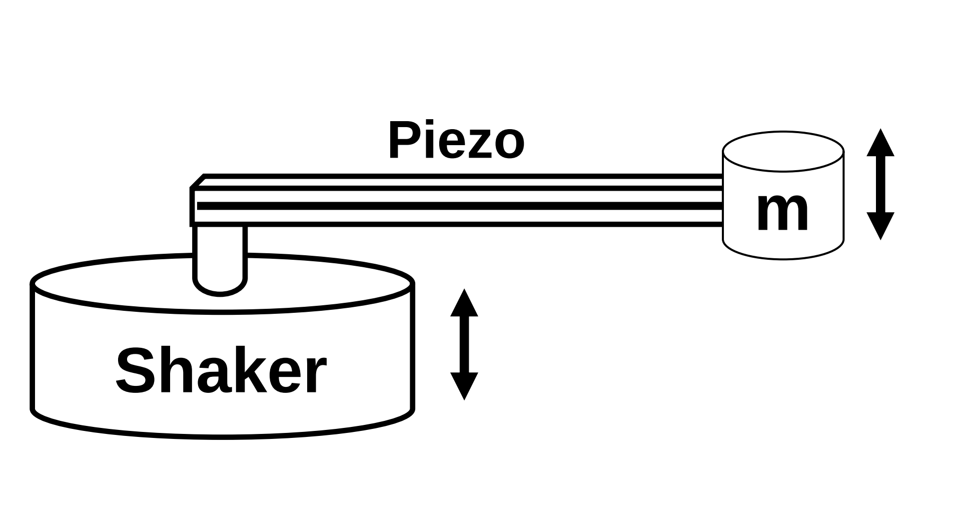
IV. Future engineering work

- Different frequency choices
- Antenna materials & Design
- Tag & Base communication protocol improvements
- Energy harvesting

Energy harvesting can extend runtime

- Small solar cells are appealing option
- CPC1822: 62mg, 4v, 50uA
- Occlusion by feathers is an Issue
- Small piezo bimorph delivers hundreds of microwatts with a reasonable excitation
- Integration, control, conditioning remain challenges





Credits

- Collaborators
  - Chris Clark
  - Eric Spaulding
  - Kathy Cortopassi
  - Kevin McGowan
  - Anne Clark
  - Ephraim Garcia
  - Tim Reissman
  - Jimmy Chang
- Funding sources:
  - The Gordon & Betty Moore Foundation
  - NSF

We are working with Theunis et al. to develop a real-time localization system for shorebirds in the Wadden Sea.


http://www.dcwild.com/images/Red-Knot.jpg

Imagine what this could do for studies of stop-over and refueling ecology in other stop-over areas…

Another long-term goal is a radio turnstile project.

- Every year, billions of migrants fly across southern North America on their way to and from wintering areas in Central and South America.

If these migrants were smart-tagged:

Receivers in their path could down-load a great deal of data in the time it takes to fly into and out of range.

Here, the challenge is not to localize but to maximize distance of detection and data transfer.

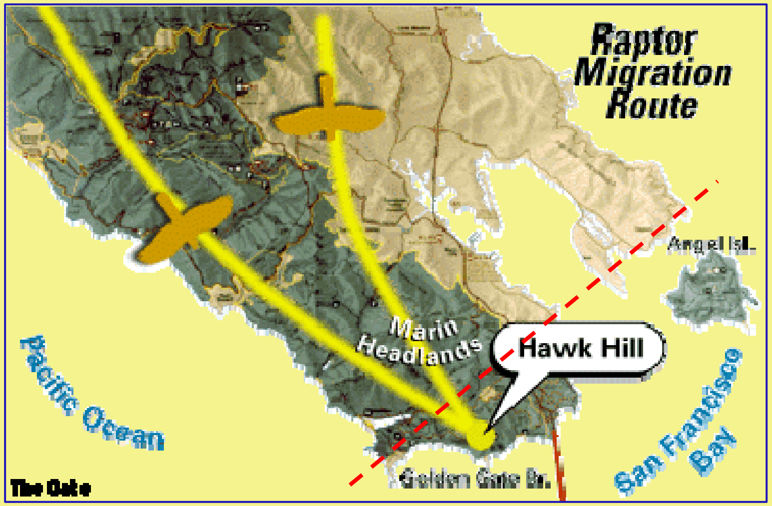
With the solar geo-location tag:

We could know the breeding and wintering localities and the migration timing of very large numbers of birds.

Knowing when, and if, birds checked in would give us unprecedented detail on patterns of mortality.

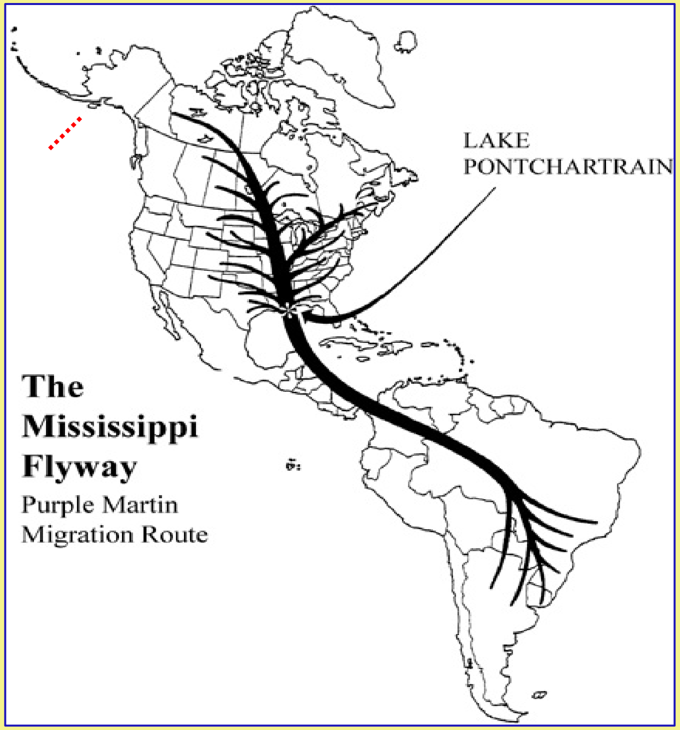
This would target conservation efforts as never before.

A line of receivers across Marin County, CA, or Cape May, NJ, could intercept very large numbers of coastal migrants.



A line of receivers across Panama could intercept a large number of species crossing to South America.

We are likely to start in Veracruz, in an area where diurnal raptor migration is very strong.



We believe these systems could produce data of unprecedented quality on the movements and mortality of individual birds.

And such data could revolutionize our understanding of avian movements, both from basic and conservation perspectives.