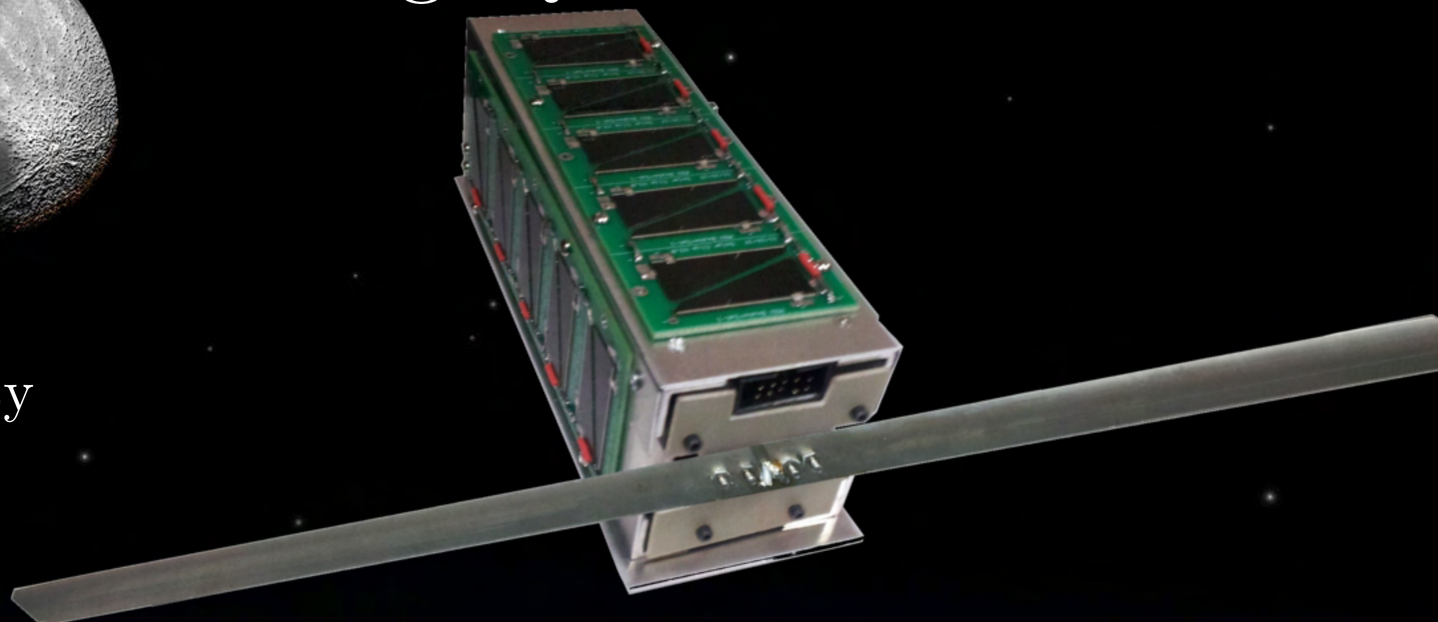
Development and Operation of the PocketQube T-LogoQube

Kevin Zack
Sonoma State University
11^{th} Annual CubeSat Developers' Workshop



T-LogoQube Team

Lead Science Mentor	Dr. Garrett Jernigan (LHR)
Lead Engineering Mentor	Prof. Robert Twiggs (MSU)
Science Mentor	Prof. Lynn Cominsky (SSU)
Science Mentor	Prof. Benamin Malphrus (MSU)
Software Mentor	Brian Silverman (PICO)
Software Mentor	Barry Silverman (DiSUS)
Engineering Mentor	Dr. John Doty (NA)
Engineering Mentor	Jeffrey Kruth (MSU)
Engineering Mentor	Steve Anderson (SSU)

Overall Student Team Leader — Kevin Zack (SSU)

MSU Student Team Leaders — Sean McNeil and Will Roach (MSU)

SSU Student Team

Cunningham, Ben
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Goldsmith, Corbbin (LHR)
Loudermilk, Lauryn
McCowan, Anna
Mills, Hunter
Owen, Aaron
Pacheco, Aaron (SRJC)
Torke, Max

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Fitzpatrick, John
Glaser-Garbrick, Dan
Grindrod, Jennafer
Healea, Jordan
Lawson, Eric
Mabry, Hannah
Mays, David

Institutions

SSU (Sonoma State University)
MSU (Morehead State University)
LHR (Little H-Bar Ranch)
NA (Noqsi Aerospace)
PICO (Playful Invention Company)
DiSUS

Acknowledgements:

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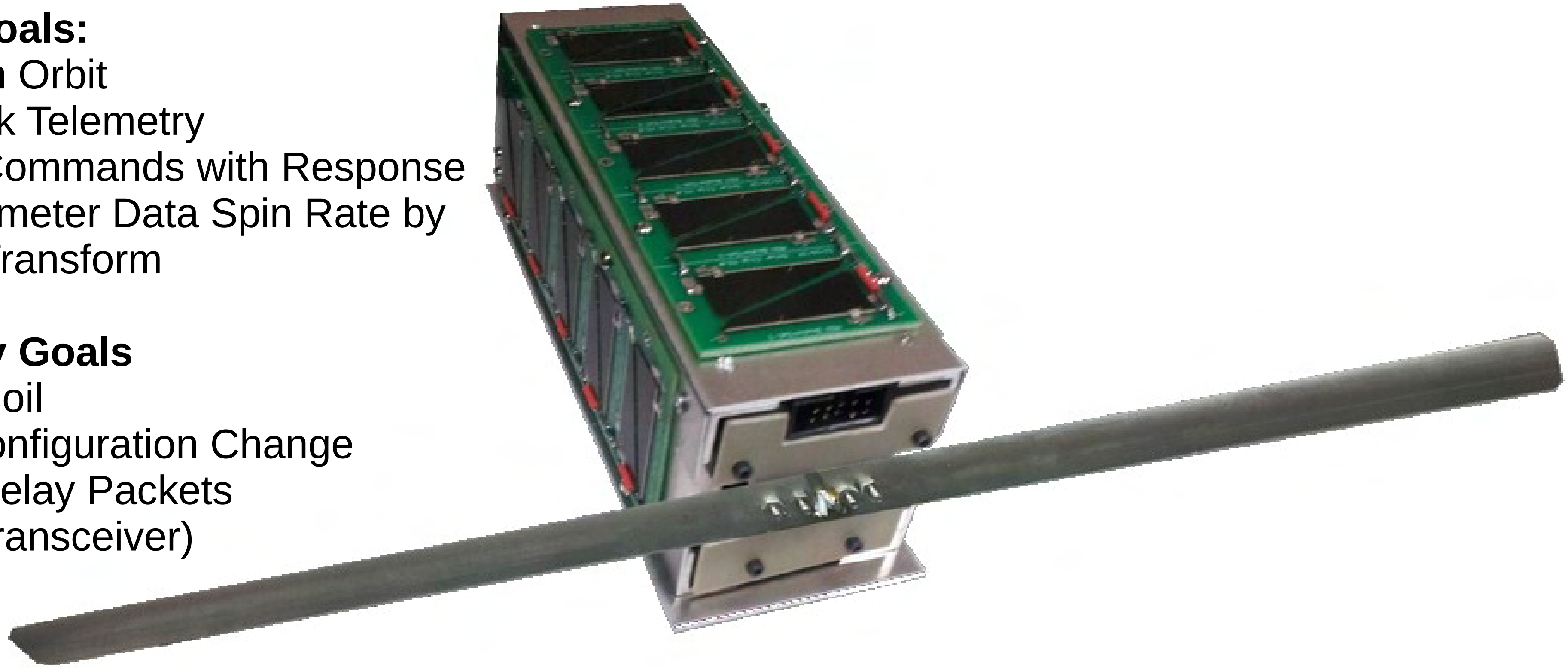
T-LogoQube

Primary Goals:

- uLogo on Orbit
- Down-link Telemetry
- Up-link Commands with Response
- Magnetometer Data Spin Rate by Fourier Transform

Secondary Goals

- Torque Coil
- Radio Configuration Change
- $50sat Relay Packets (Same Transceiver)



- 3P 5 cm x 5 cm x 15 cm
- Launched November 21 2013
- Sun-Synchronous Polar Orbit
- 8 Weeks of Operation
- Uses uLogo for Language
- Re-Programmable Over Transceiver

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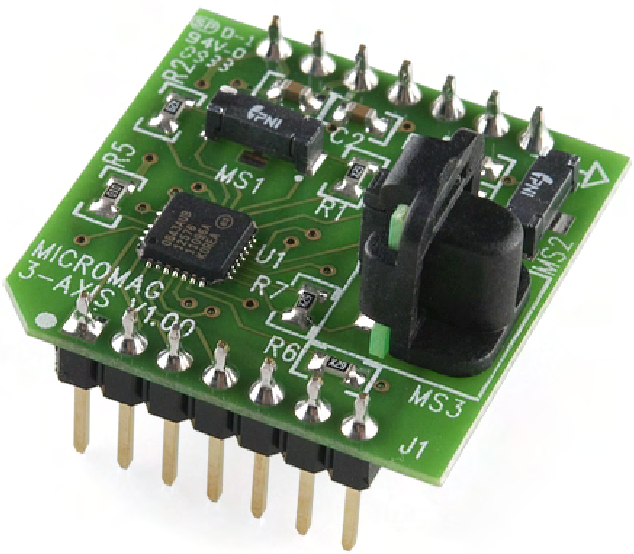
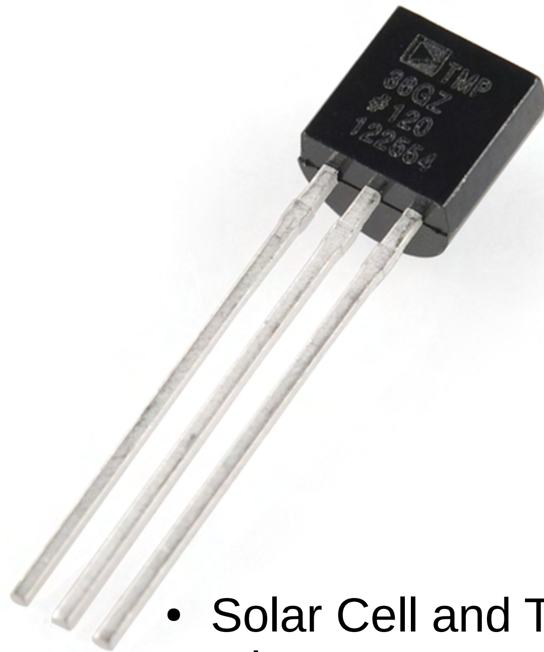
Instrumentation

Magnetometer



- 3-Axis
- Field measurement range +/-1100uT
- Resolution as low as 0.015uT

Temperature Sensor



- Solar Cell and Torque Coil
- Microprocessor
- Battery

Torque Coil

- 150 turns 32guage
- 21 ohm coil
- 157mA
- 29 sq cm Area

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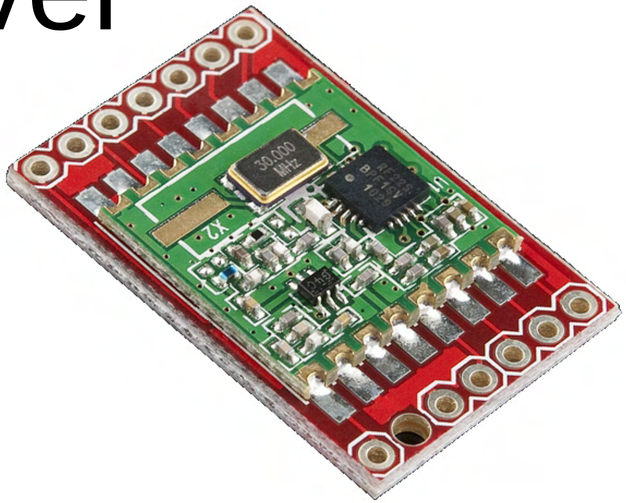
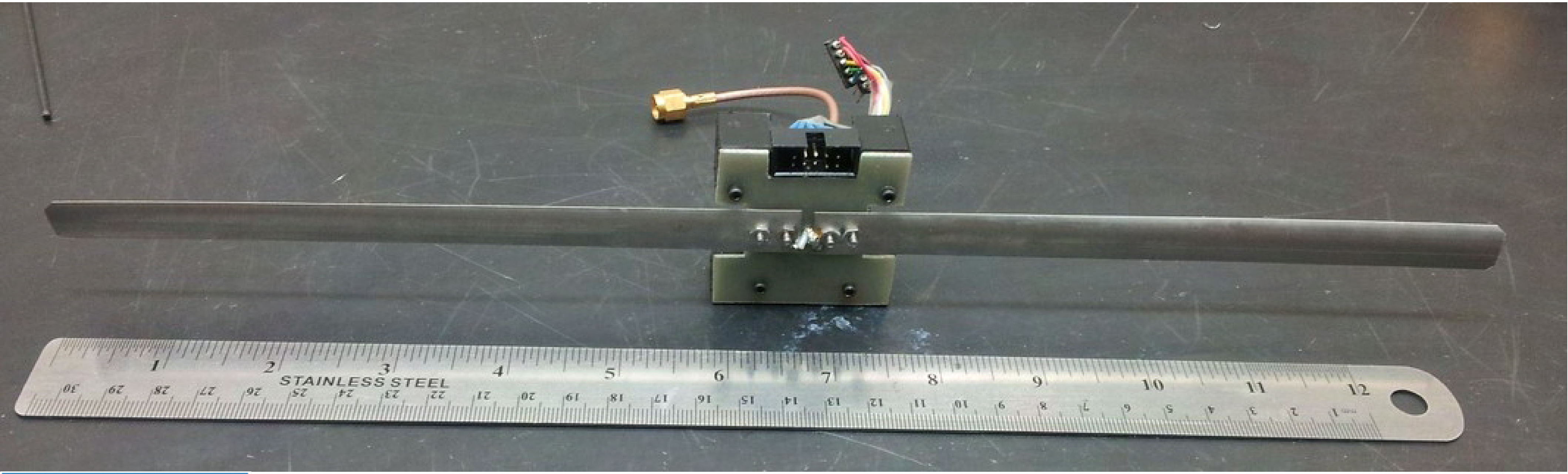
RFM22B Transceiver

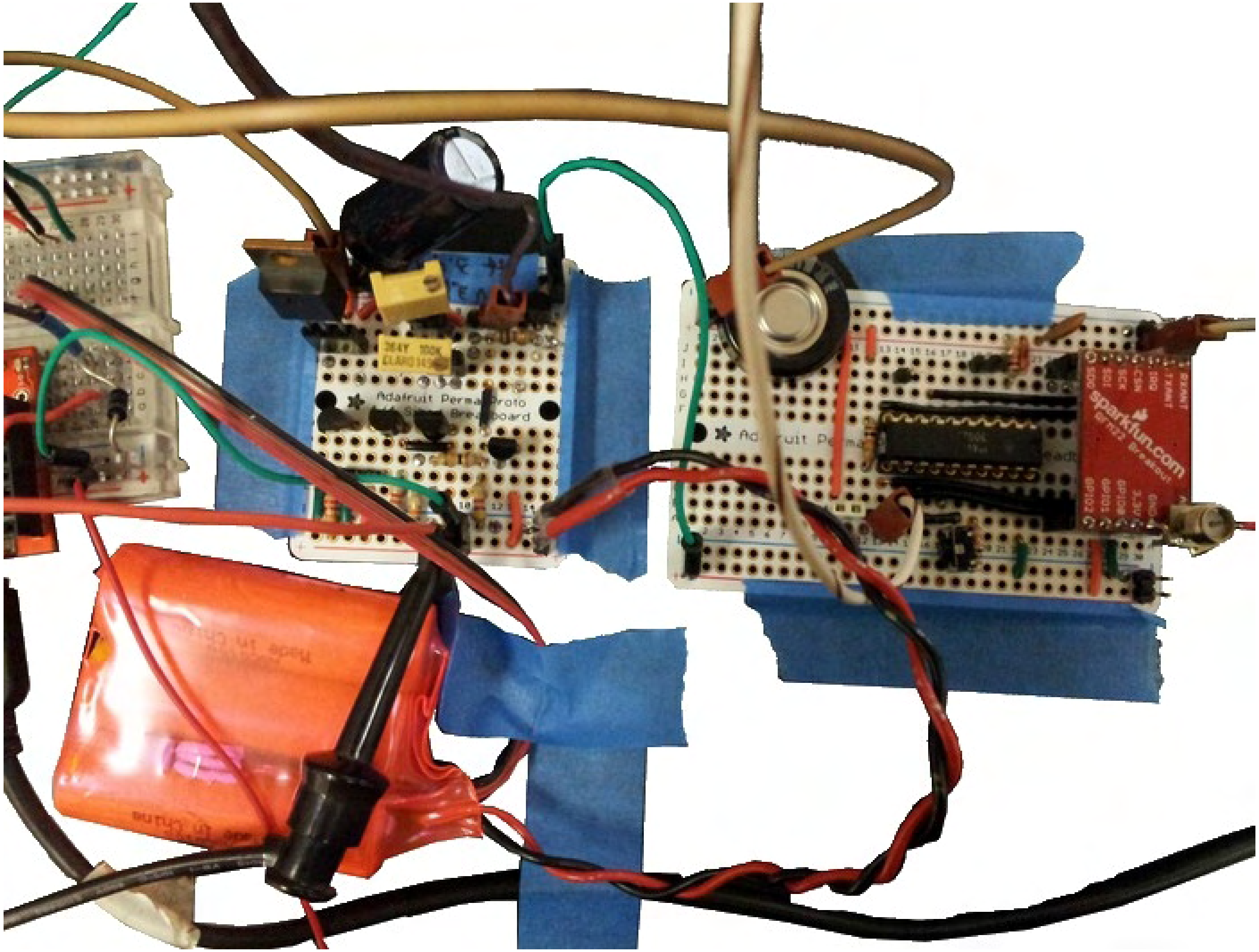
- 437.465 MHz
- 100 mW
- Max Range Receive: 2700 km
- Max Range Transmit: ~1500 km
  w/ 50W transmitter 7element Yagi





2x ~17 cm Foldable Dipole Antenna Elements

Development - FlatSat



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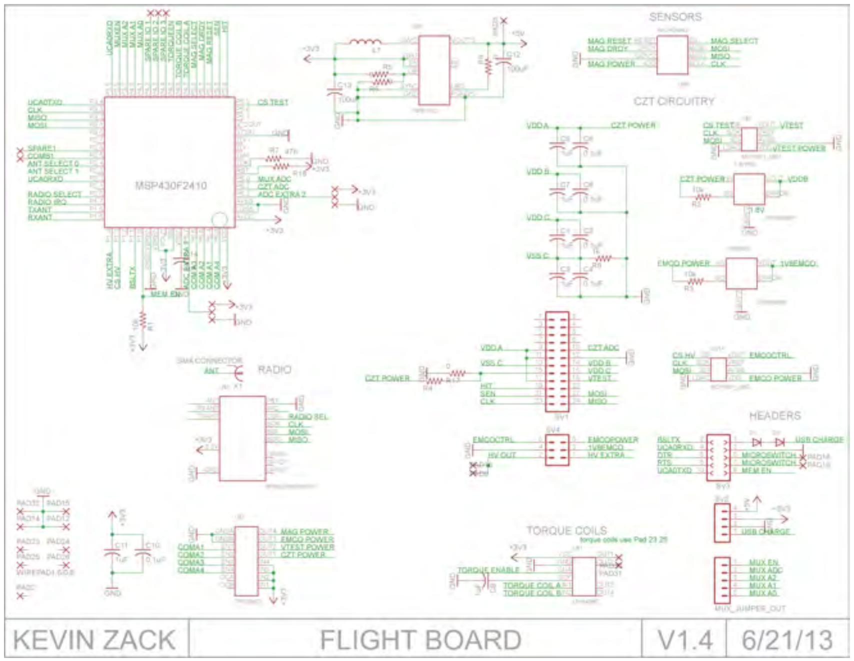
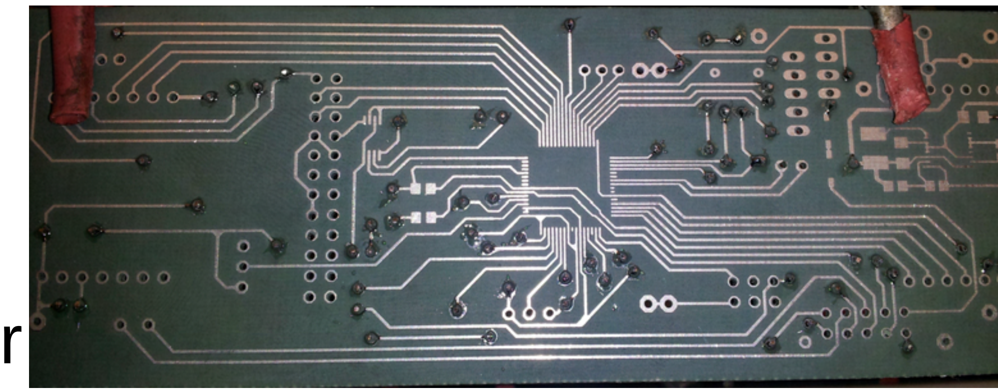
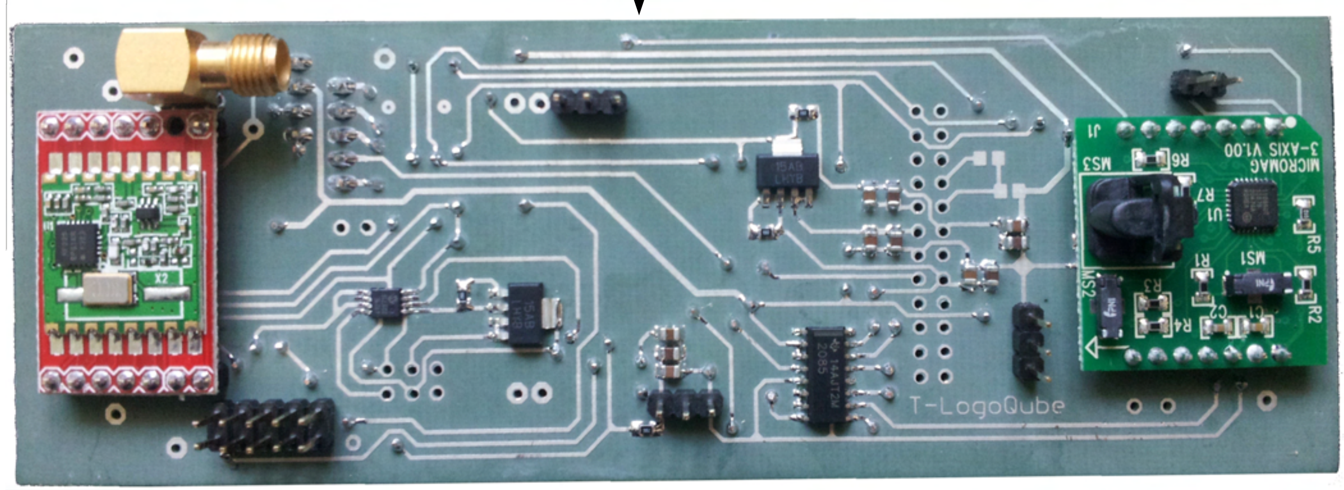
Testing & Rapid (~4 hrs) Prototyping



1 ½ hr



2 ½ hr



Total Time 4 hours
TLQ Revisions ~10

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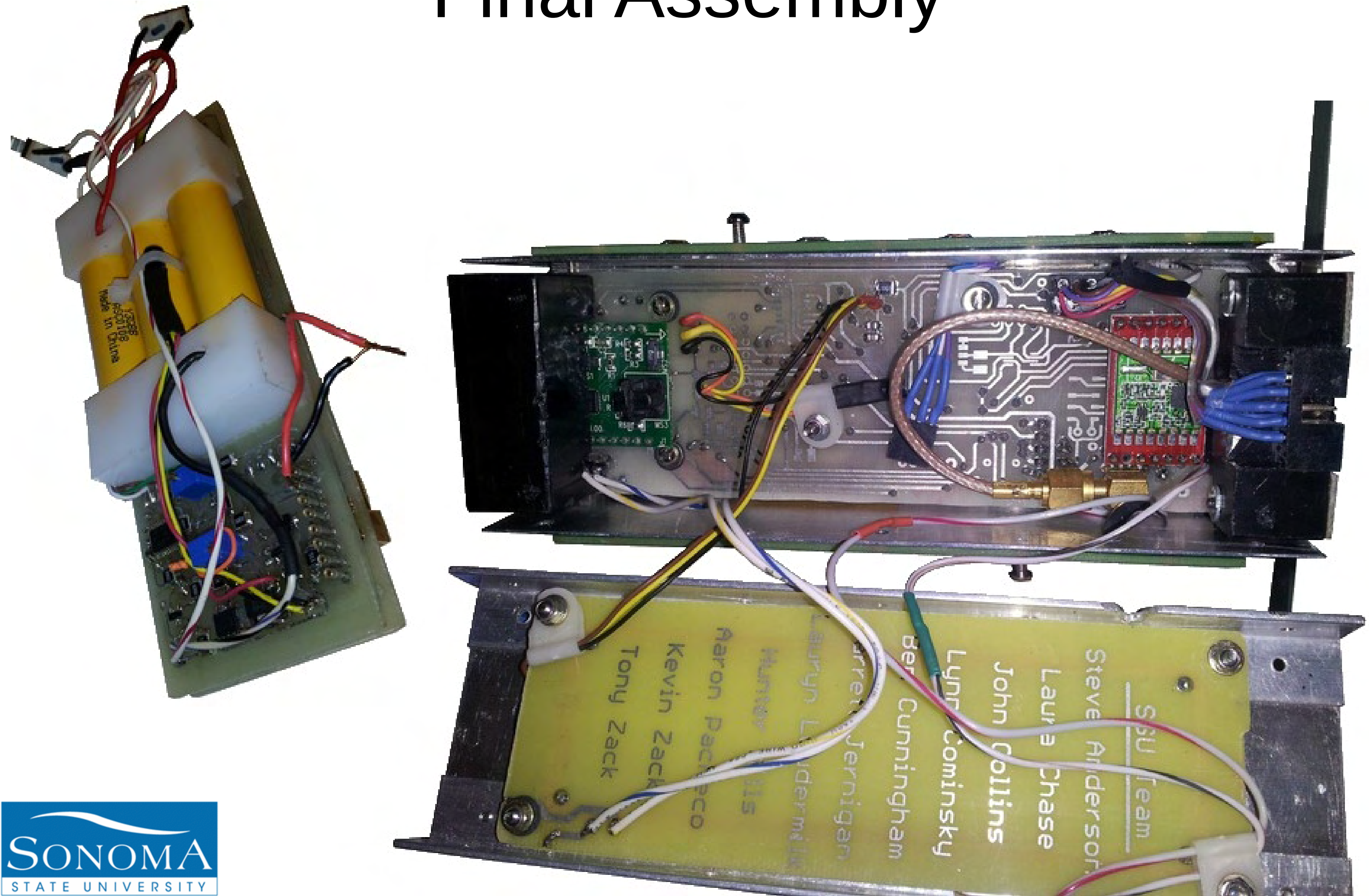
Final Assembly



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Cost

"Doty" Circuit Core				
Part	Description	Quantity	Price Each	Total
LP3855EMP	3.3V LDO Voltage Regulator	1	$4.53	$4.53
NTMS5P05	PNP Transistor	1	$0.72	$0.72
2N3904	NPN Transistor	3	$0.50	$1.50
2N3906	PNP Transistor	1	$0.26	$0.26
LM4041	1.225V Voltage Reference	1	$1.29	$1.29
Trim-pot	50KOhm Trim-pot	2	$3.93	$7.86
ADG608	Mux	1	$5.12	$5.12
22K	Resistor	1	$0.25	$0.25
16K	Resistor	1	$0.25	$0.25
100K	Resistor	3	$0.25	$0.75
10K	Resistor	3	$0.25	$0.75
8K2	Resistor	1	$0.25	$0.25
51K	Resistor	1	$0.25	$0.25
0.1uF	Capacitor	3	$0.14	$0.42
1uF	Capacitor	2	$0.18	$0.36
NiCad	1000mAh AA Battery	3	$5.26	$15.78
NSVR0320MW2T	Schottky Diode	4	$0.55	$2.20
			Grand Total	**$42.54**

Flight Board				
Part	Description	Quantity	Price Each	Total
MSP430F2410	Microcontroller	1	$10.35	$10.35
RFM22B	443MHZ Radio	1	$22.95	$22.95
LB1848	Torque Coil H-Bridge	1	$1.40	$1.40
MicroMag	Magnetometer	1	$49.99	$49.99
TMP36	Linear Temperature Sensor	3	$1.50	$4.50
10K	Resistor	3	$0.25	$0.75
0.1uF	Capacitor	6	$0.14	$0.84
1uF	Capacitor	8	$0.18	$1.44
LP3855EMP	1.8V LDO Regulator	2	$4.53	$9.06
MCP4921	12Bit DAC	2	$2.08	$4.16
Header	Header Pins	1	$1.50	$1.50
TSP2085D	Power Switch High-side quad MOSFET	1	$3.27	$3.27
TSP61032	5V Boost Regulator	1	$3.15	$3.15
6.2uH	Inductor	1	$0.59	$0.59
1M	Resistor	1	$0.25	$0.25
390K		1	$0.25	$0.25
2M2		1	$0.25	$0.25
MBR0540T3G	Schottky Diode 0.5A	2	$0.36	$0.72
SMA	SMA Connector RT-ANGLE	1	$4.56	$4.56
			Grand Total	**$119.98**

Items not purchased
3P PocketQube Frame
4 Solar Panels
Antenna w/ drag cover

Flight Board $119.98
Doty Circuit $42.54

Total Flight Hardware Cost: $162.52

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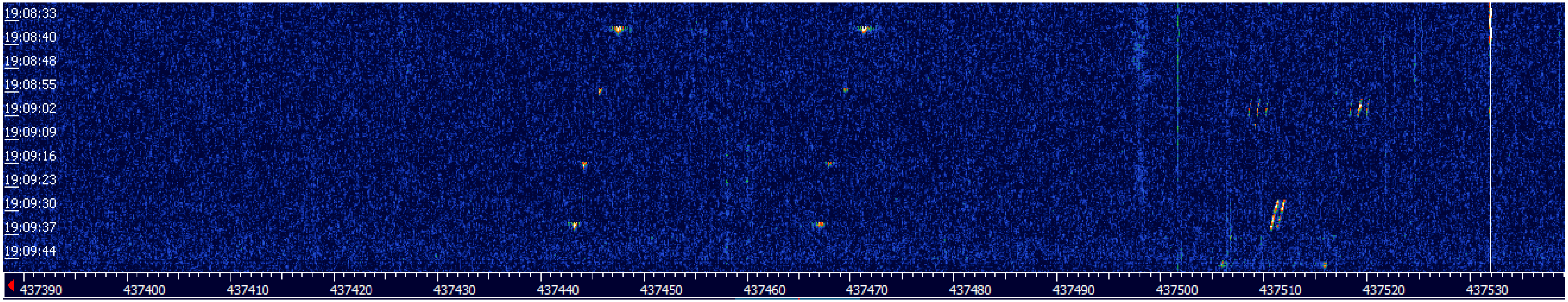
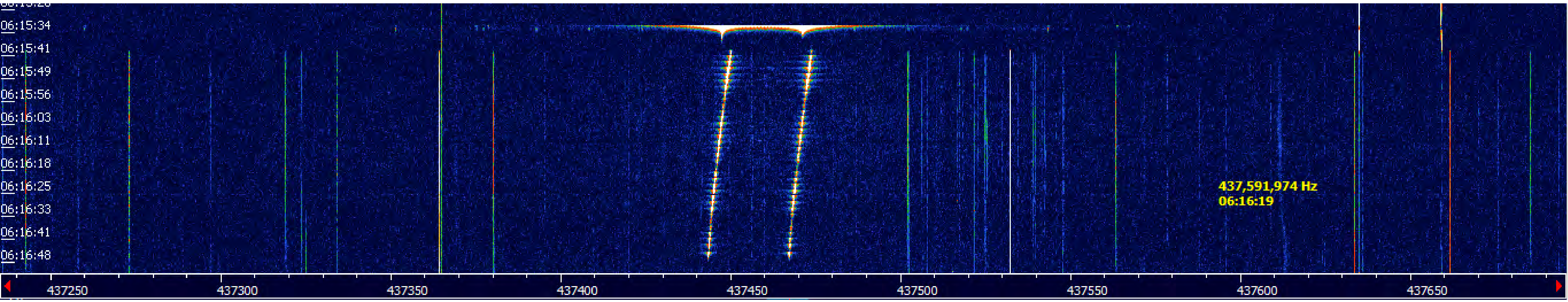
First Packets



38 325 29834 11 34 4612 4835 3251 4401 4789 2726 2684 2793 65533 6 13 3200 569 2 0 1416 65023 65535 0 0
38 325 21110 11 35 4671 4828 4965 4282 3661 2755 2700 2809 0 0 15 2285 425 65533 0 10624 65535 65535 0 0
38 325 21114 11 39 4342 4581 2964 4412 4561 2755 2703 2799 11 9 11 2285 425 65533 0 12154 65535 65535 0 0
38 325 21118 11 35 4552 4726 3551 4419 4735 2755 2703 2809 65534 12 13 2285 425 65533 0 11029 65535 65535 0 0
282 325 21116 12 26997 20790 17485 16320 44306 44306 4290 4290 60594 28 1003 0 0 65535 65535 0 0 65535 65535 0 0

Launch on November 21
First Decoded Packet November 23
First Packets prior to accurate NORAD TLE

First Commands

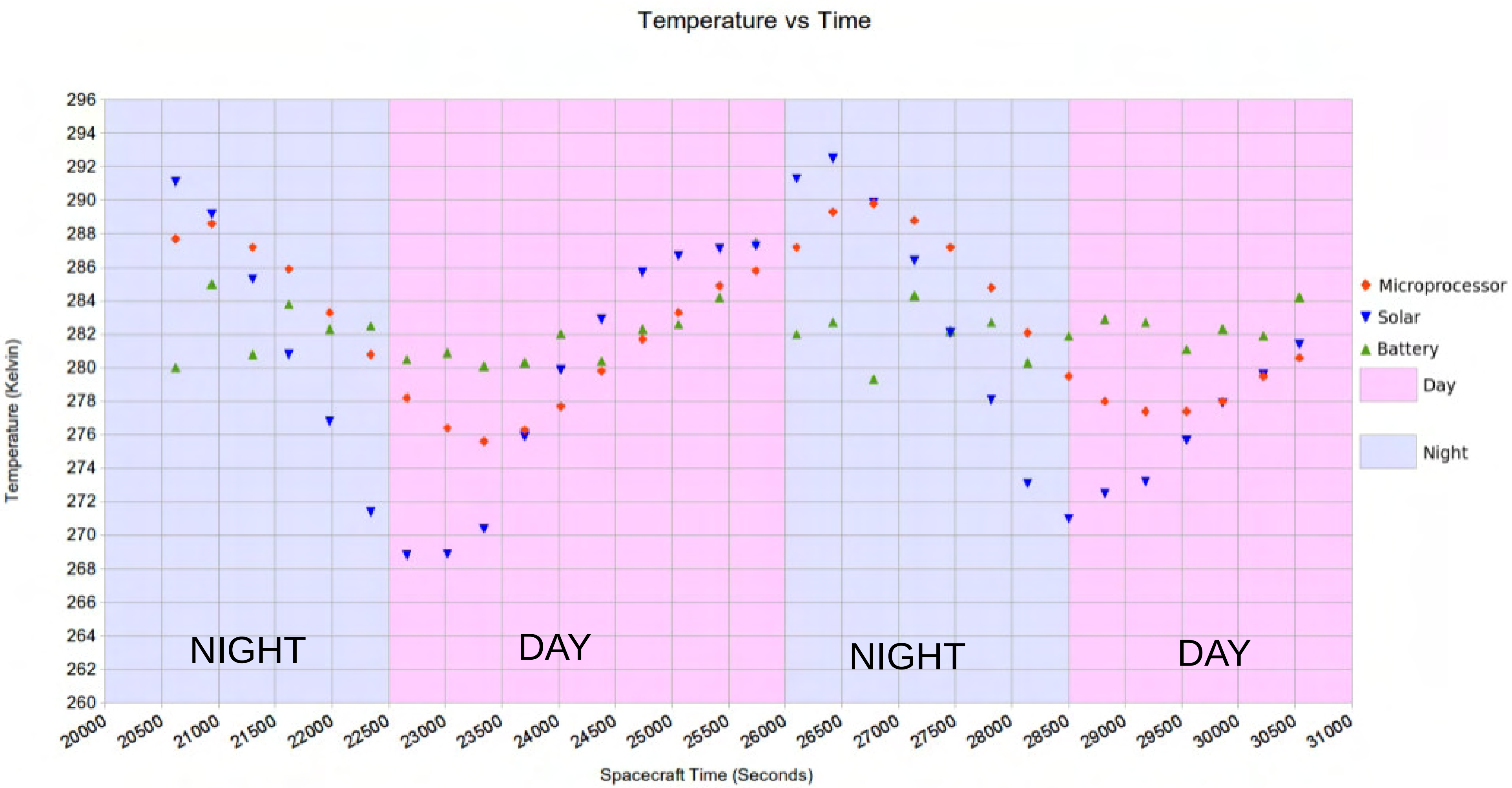


T00 – Beacon Packets
T01 – Checksum Packets
T03 – Magnetometer Packets
T04 – Flag Packets

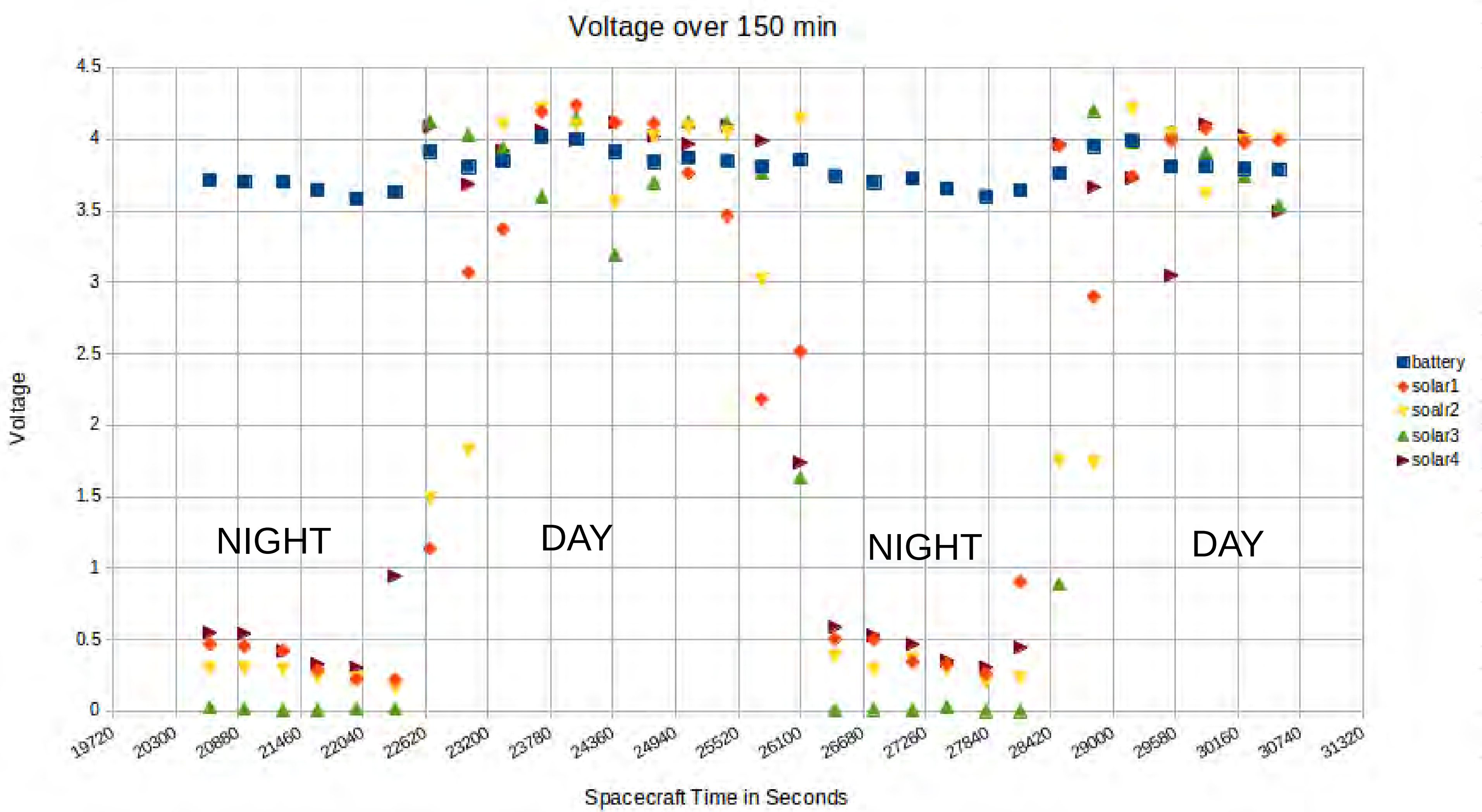
T03 1386881500 00814 00325 13506 08543 00002 00250 00000 00416 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 41680
T03 1386881502 00814 00325 13506 08543 00002 00250 00000 00448 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 41648
T03 1386881504 00814 00325 13506 08543 00002 00250 00000 00480 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 00000 41616
T00 1386881511 00038 00325 13514 00011 00036 04021 03476 04184 04312 04195 02761 02725 02795 65533 65530 65535 57536 00000 57536 00000 39153
T01 1386881529 00282 00325 13516 00012 26997 20790 17485 16320 44306 44306 04290 04290 60594 00028 08603
T00 1386881551 00038 00325 13518 00011 00036 04077 03470 04298 04351 04203 02760 02725 02795 65533 65530 65504 57536 00000 57536 00000 38970
T01 1386881569 00282 00325 13520 00012 26997 20790 17485 16320 44306 44306 04290 04290 60594 00028 08599
T00 1386881591 00038 00325 13522 00011 00035 04148 03469 04331 04363 04220 02761 02727 02797 65533 65531 00000 57536 00000 57536 00000 38797
T04 1386915124 01034 00325 16866 04170 00000 00111 43030

Example Sequence Beacon Packets

Data of Satellite Temp



Data of Satellite – Battery Charge



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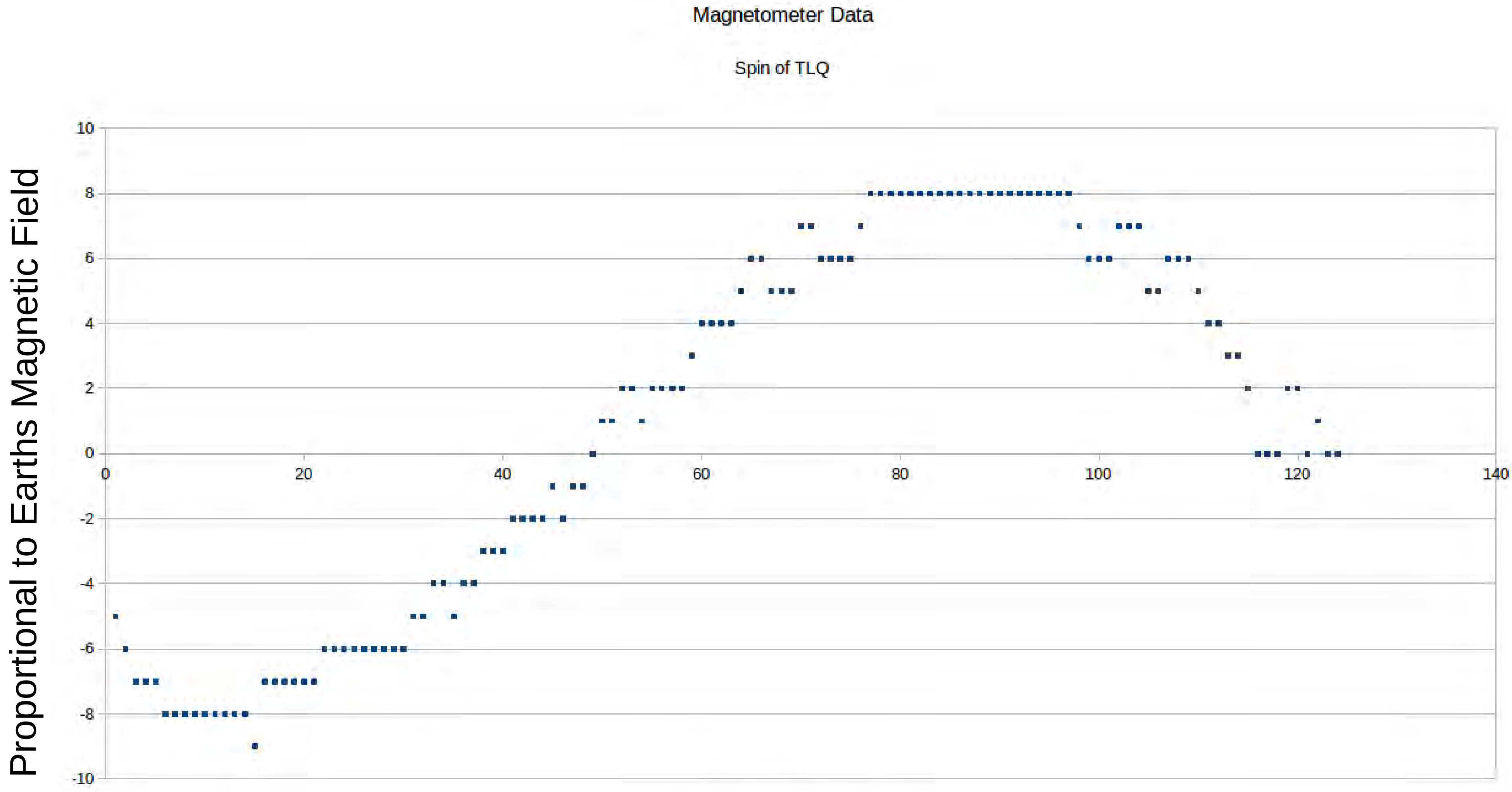
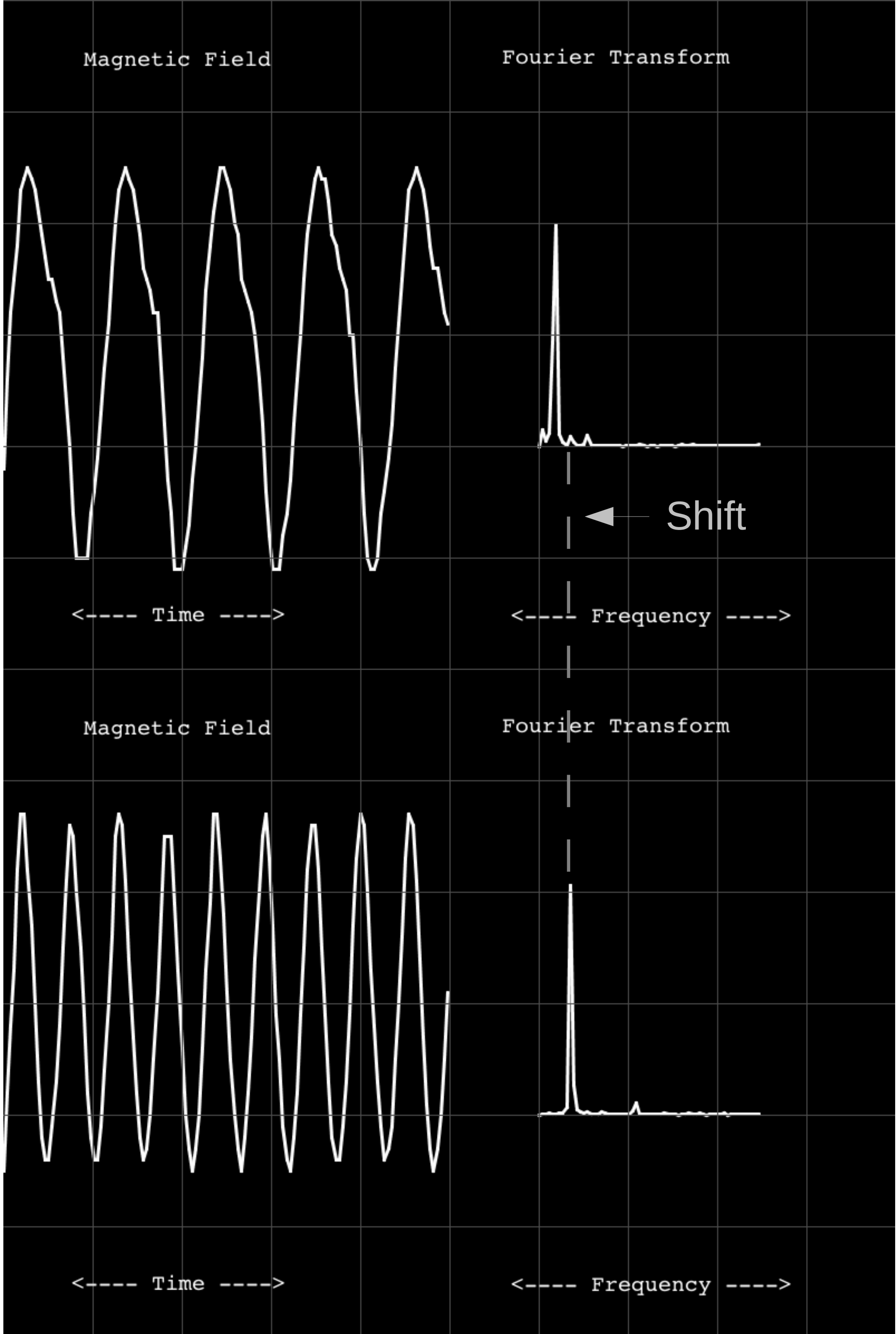
Spin of TLQ from Mag Dump



Time: 128 * ¼ samples = 32 sec

Demonstration of TLQ Fourier Transform with Flight Code

- Change in Spin rate
- 128 ½ Second Samples
- Total Time 64 Seconds
- Comparison Plots Show Frequency Shift



Dr. J. Garrett Jernigan

11th Annual CubeSat
Developer's Workshop
Cal Poly, San Luis Obispo
April 23, 2014

The Application of the Logo Language for the Flight and Ground System of the PocketQube T- LogoQube

T-LogoQube Team

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Engineering Mentor	Steve Anderson (SSU)

Brian Silverman
Inventor of uLogo

Overall Student Team Leader	Kevin Zack (SSU)
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The Logo Language for the Flight and Ground System of the PocketQube: T-LogoQube

The flight and ground software for **T-LogoQube** is based on the **Logo programing language**. This flight software is the first use of the Logo language for the control of any satellite. The Logo language is a member of a class of languages that have **extensible dictionaries of words (similar to Forth).** The process of developing a flight environment is the creation of new "words" that define how to control the functions of the system. Each project becomes an individualized collection of words that are unique to the particular application. The T-LogoQube software is just one example of the application of a Logo environment.

- Each unique Logo environment runs in a **processor with a initial vocabulary called the VM (virtual machine).** The VM has a core set of words common to all Logo environments plus some additional words which form the basic capabilities needed to completely define the T-LogoQube functions. The full complement of the T-LogoQube functions are implemented in the high level Logo language which extends in the form of a **hierarchy of new words which are comprised of the VM words and other added high level Logo words.** The Logo approach to software is similar in some respects to the Forth language and other extensible languages. In the Logo case, unlike for Forth, the compilation of the new words is separate from the run time environment.

- The flight code for T-LogoQube is based on a variation of Logo called microLogo (also designated uLogo) running on an **MSP430** with a **VM based on assembly language as compared to the ground code which is based on Java based Logo VM that runs on any modern OS (OSX, Linux or Windows).** The entire Logo development system fits with a few tens of megabytes. The compiled flight environment for T-LogoQube is less than ten kilobytes. The flexibility and compactness of Logo is well suited for a CubeSat or PocketQube environment.

T-LogoQube's Logo companion flight (uLogo) and ground code (jLogo) form a unique system for the development, implementation and control of a satellite on orbit. The flexibility and simplicity of Logo for the control of an orbiting satellite is ideal for CubeSats or PocketQubes and performs well compared to prior satellites of any size or cost. T-LogoQube is a successful first experiment that could be extended for future science based CubeSats and PocketQubes

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The T-LogoQube uLogo based flight system achieves the following goals:

(1) Transmission **of four types of packet data** with the RFM22B transceiver (beacon, checksum, magnetometer and flag).

(2) C**ontrol T-LogoQube by compiling, sending and receiving the results of a "one line uLogo program"** created "on the fly".

(3) The uLogo VM includes a method for creating a unique time stamp for all data.

(4) Past beacon packets are saved in memory and telemetered to the ground for a history of T-LogoQube status over past time.

(5) Realtime **flight analysis (Fourier Transform) of the Magnetometer samples to determine the spin rate on orbit**

(6) **Ability to upload new uLogo code** to extend the on orbit operation beyond the level implemented prior to launch

(7) Ability to use a **single torque coil to point the T-LogoQube spin axis in any direction**

(8) Detection and ability to correct SEUs

The T-LogoQube Logo based companion ground system achieves the following goals:

(1) Formation and testing of **new uLogo code for upload** to the flight system

(2**) Automated procedures for initially finding T-LogoQube** prior to any accurate TLEs (jLogo code)

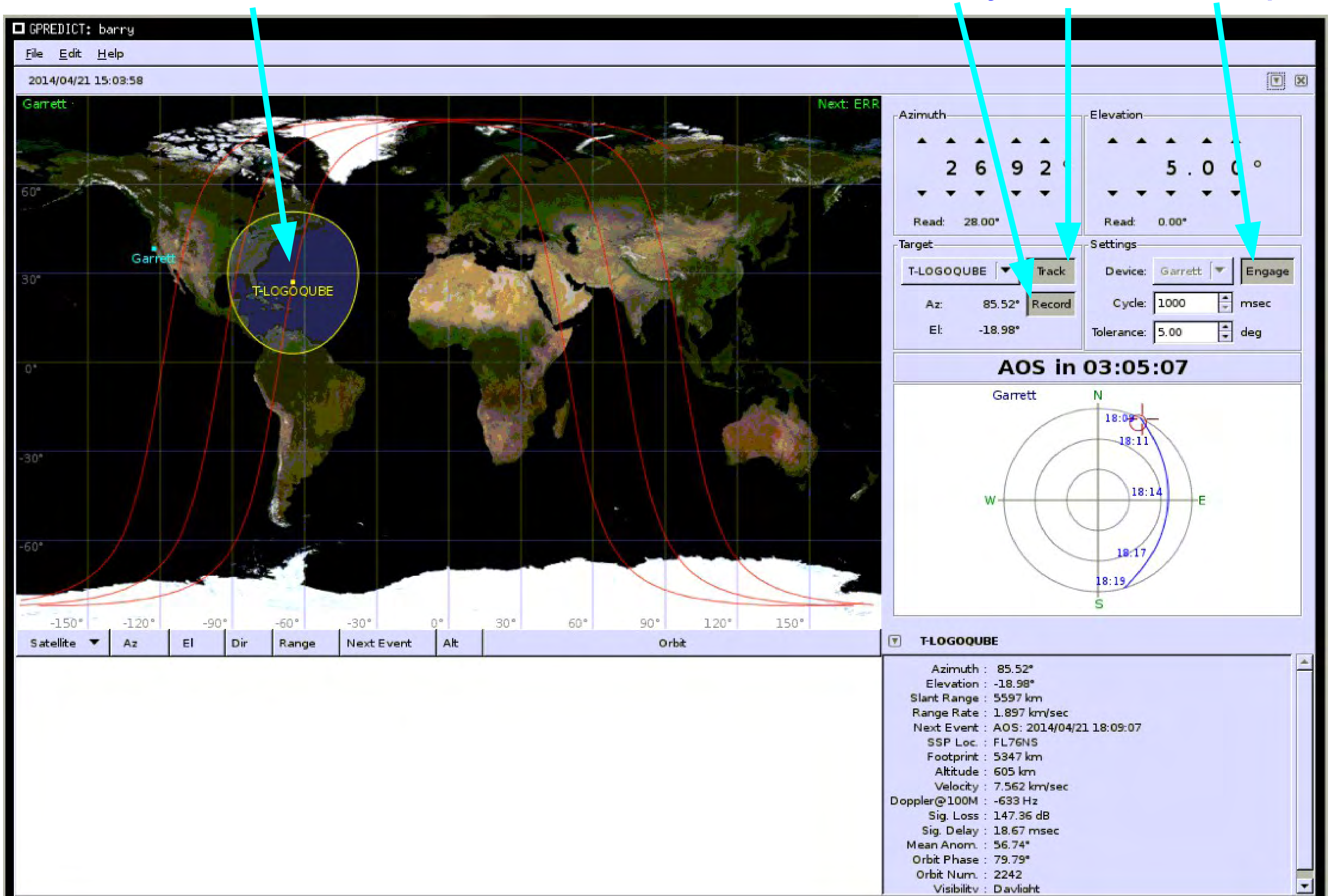
(3) New **software for an Ettus B100 GnuRadio to decode RFM22B packet data** and measure doppler shifts of transceiver frequencies. Also includes waterfall movies and decoding of AX25 Ham standard packets.

(4) **Automation of the receipt of T-LogoQube data** with modifications of Gpredict (an open source satellite tracking tool).

Modified Version of Gpredict (Open Software) for Automated Antenna Pointing and Data Recording

Satellite Name and TLE Already Selected At Start Up

Record, Track and Engage Already Selected at Start Up



Content of Beacon Packet

T00 1386053015 00038 00325 30038 00011 00034 04109 00452 00328 00013 00449 02886 02851 02836 65532 65532 00003 57536 00000 57536 00000 37171

AA BBBBBBBBBB CCCCC DDDDD EEEEE FFFFF GGGGG HHHHH IIIII JJJJJ KKKKK LLLLL MMMMM NNNNN OOOOO PPPPP QQQQQ RRRRR SSSSS TTTTT UUUUU VVVVV WWWWW

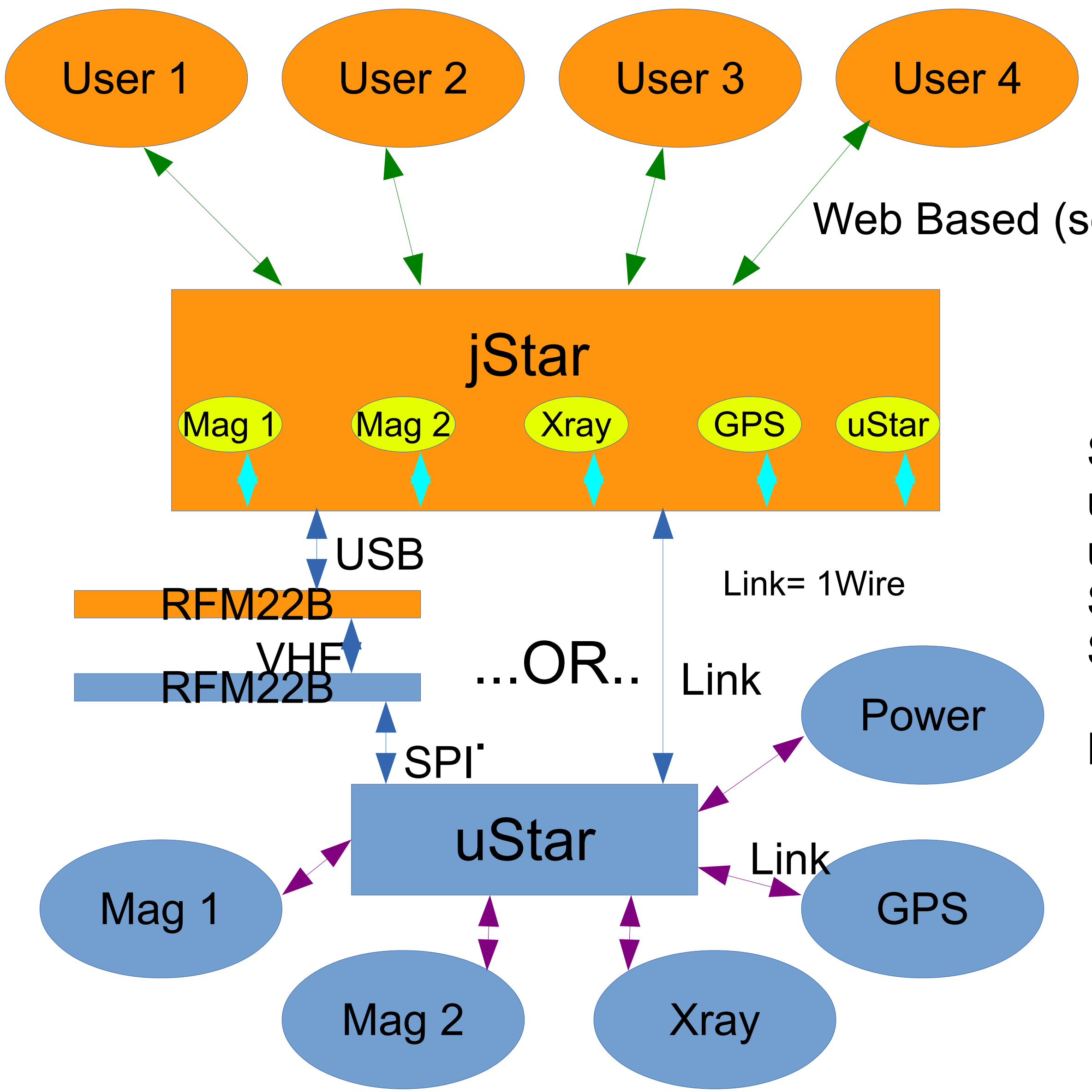
A - Packet Type i.e T0 for beacon, T1 for check-sum, T3 for Magnetometer, T4 for Flag
B - Unix Time
C - Packet Type
D - Bump-Count
E - Time-stamp High (its in 10's of seconds) ie. if 84 then it is 840 seconds
F - Time-stamp Low its in microseconds
G - RSSI (its a signal strength measurement)
H - Battery Voltage
I - Solar 1 Voltage
J - Solar 2 Voltage
K - Solar 3 Voltage
L - Solar 4 Voltage
M - Temperature 1 in Kelvin ie. 02851 is 285.1 K
N - Temperature 2 in Kelvin
O - Temperature of the battery in Kelvin
P - Magnetometer X axis
Q - Magnetometer Y axis
R - Magnetometer Z axis
S - Period of Peak 1 for last FFT
T - PD of Peak 1 for last FFT
U - Period of Peak 2 for last FFT
V - PD of Peak 2 for last FFT
W - Check sum

ulogo Flight Code to Send Beacon Packet

```
to send-beacon-packet                  ;(code at this level is almost self-documenting)

   let [bvolt 0]                       ; define local variable bvolt

   clear-res                           ; clear packet buffer

   writeb rpacket + 1 type_beacon      ; length and type of packet
1  fprint read bumpcount               ; S/C Power Reset Count
2  fprint timestamph                   ; High Order Clock since last reset   (every 10 seconds)
3  fprint timestampl                   ; Low Order Clock since last reset   ( milliseconds  0-10000)

4  fprint rssi                         ; RFM22B rssi value

   make "bvolt read-bat-ave            ; read battery voltage
5  fprint :bvolt                       ; Battery Voltage
6  fprint read-solar1-ave              ; Top Solar Panel Voltage

7  fprint read-solar2-ave              ; Side Solar Panel Voltage
8  fprint read-solar3-ave              ; Bottom Solar Panel Voltage
9  fprint read-solar4-ave              ; Side Solar Panel Voltage

10 fprint read-temp1-ave               ; Solar Panel Temerature
11 fprint read-temp2-ave               ; Processor + RFM22B Temperature
12 fprint read-bat-temp-ave            ; Battery temperature

   repeat 3 [ignore readMag 1 mwait 100]   ;settle readings for 1
13 fprint readMag 1                    ; X component of Magnetic Field
   repeat 3 [ignore readMag 2 mwait 100]   ; settle readings for 2
14 fprint readMag 2                    ; Y component of Magnetic Field
   repeat 3 [ignore readMag 3 mwait 100]   ; settle readings for 3
15 fprint readMag 3                    ; Z component of Magnetic Field

16 fprint period peak1                 ; spin period of peak1 in multiple of 10 millseconds
17 fprint peak1_pd                     ; power density of peak1 of Fourier transform

18 fprint period peak2                 ; spin period period of peak2 in multiple of 10 millseconds
19 fprint peak2_pd                     ; power density of peak2 of Fourier transform

   if batOK [ mwait bwait :bvolt       ; batOk blocks sending packet if battery voltage too low
          Send-packet ]                ; Delay of Beacon indicates Battery Voltage (no decode necessary)

end
```

Note: fprint puts 2 bytes In a packet. Beacon packets require 18 fprints or 36 bytes of data. Length of beacon packet is 38 bytes with a 2 byte checksum added by the send-packet word.

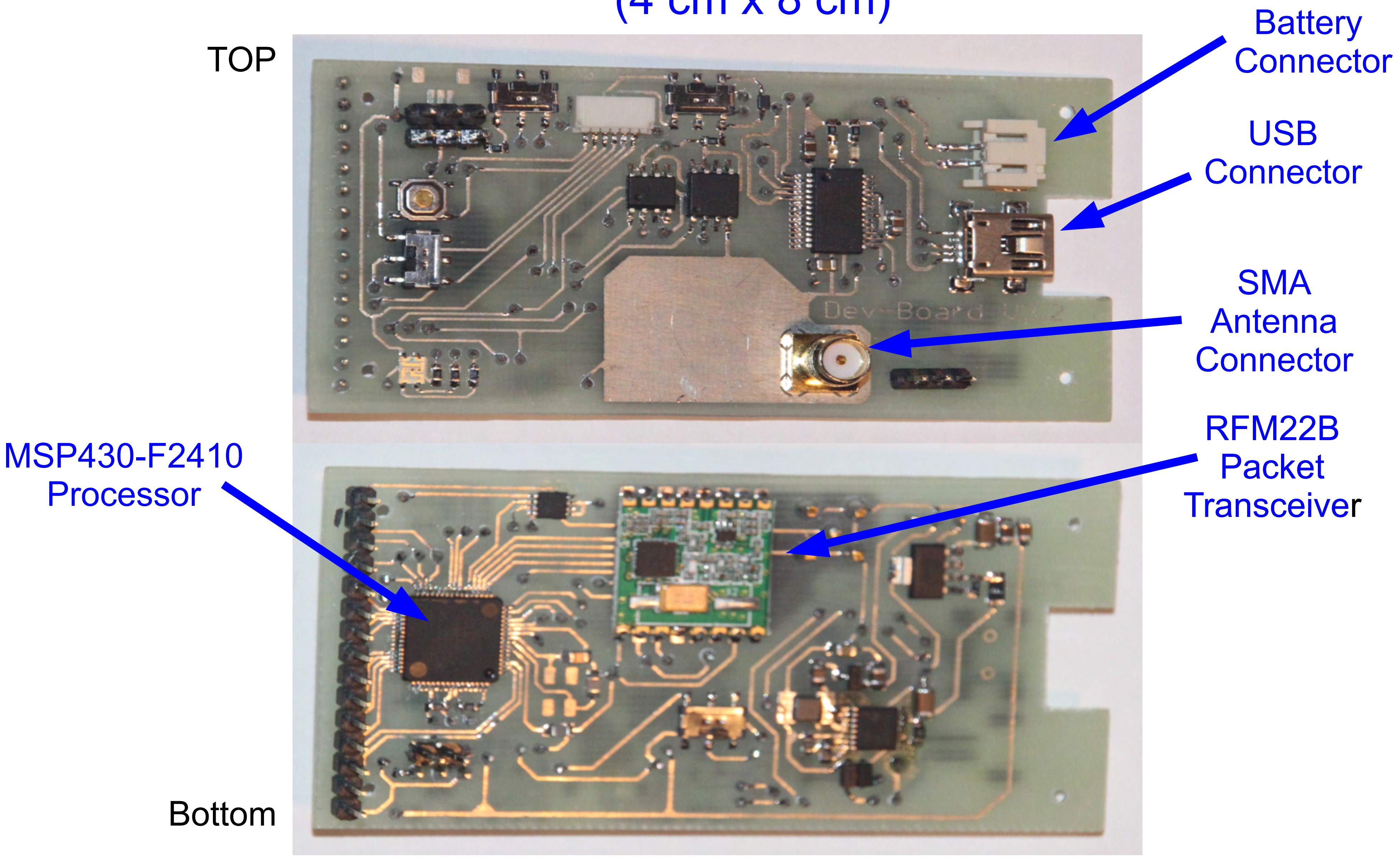
Future uLogo Beyond T-LogoQube



1 Wire Network:

Single Bussed Data Line
uStar Boots all nodes
uStar syncs all timestamps
Shared Variable Between Nodes
Shared Telemetry From All Nodes
(Control by Packet Priority)
Parallel Debugging for Each Node

ulogo Flight Development Board
Sized for 2P PocketQubes or CubeSats
(4 cm x 8 cm)



T-LogoQube Ground System

jLogo code interfaces to both
Ettus B100 and RFM22B Transceivers
via USB cables (runs on any OS)
(Planned Open Hardware
and Software release >Fall 2014)

RFM22B
Packet
Transceiver

8 Element Wide Field
Yagi Antenna

18 Element Crossed
Narrow Field Yagi Antennas

7 Element Transmit
Yagi Antenna

Summary of Logo Open Hardware and Software

Flight System:
Initial Public Release > Fall 2014
No Cost for License for hardware or software
Flexible Development Board for Interface to New Sensors
All Flight Boards connected to 1-wire Network
Simple Hardware and Software Compared to Alternatives
Easy to add new flight uLogo code (hot running flight)
Demo: Prototype of hot code additions part of T-LogoQube
Easy to boot an entirely new flight code for each uLogo board

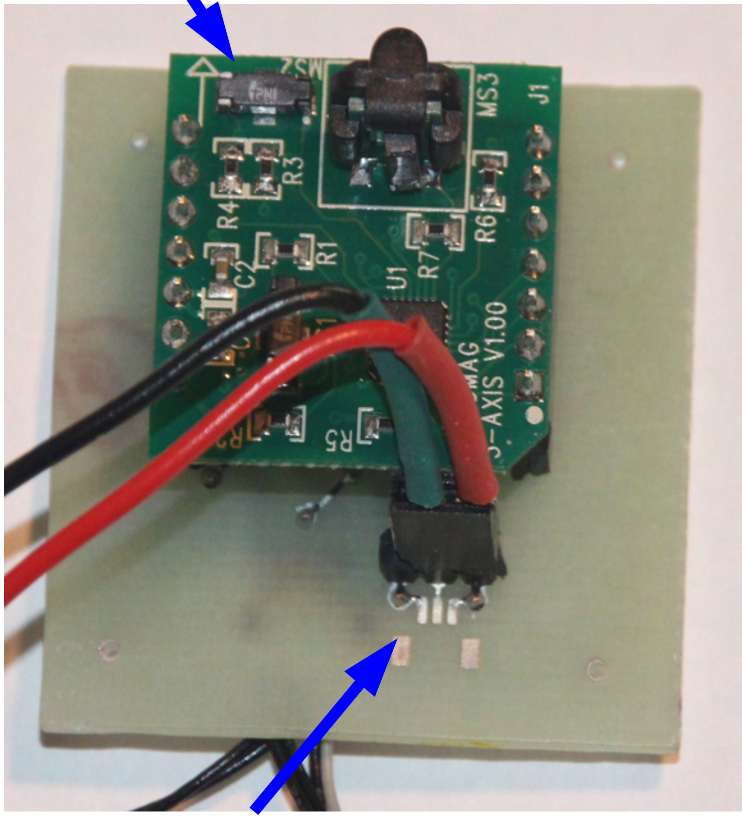
Ground System:
jlogo Code for Ground System (open software license)
Decodes RFM22B packets
Decodes AX25 Ham Standard

Notes:
Every uLogo Board has One Processor and One Job (no need for OS)
Extra Computation Capacity can also be on the Network (microLinux)
Ideally two uStar Boards each with a Radio (only one on at any time)
Each Sensor is part of a single uLogo Board
Redundant Sensors does not increase software complexity
Easy development of multiple boards/sensors by independent groups
No Need to Merge Software into a common processor

ulogo Flight Magnetometer Board
(4 cm x 4 cm)

3-Axis
Magnetometer

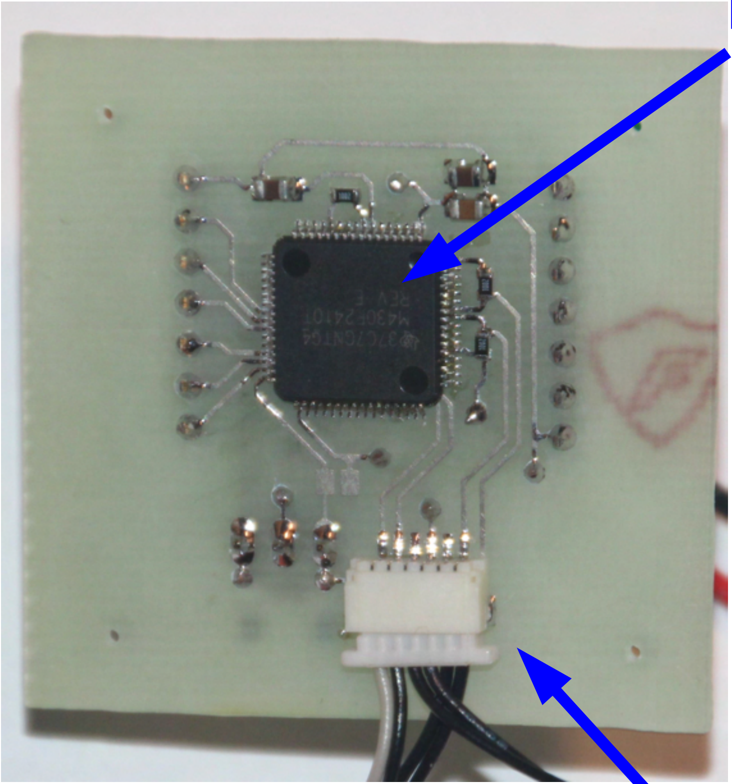
TOP



One Wire
for Data

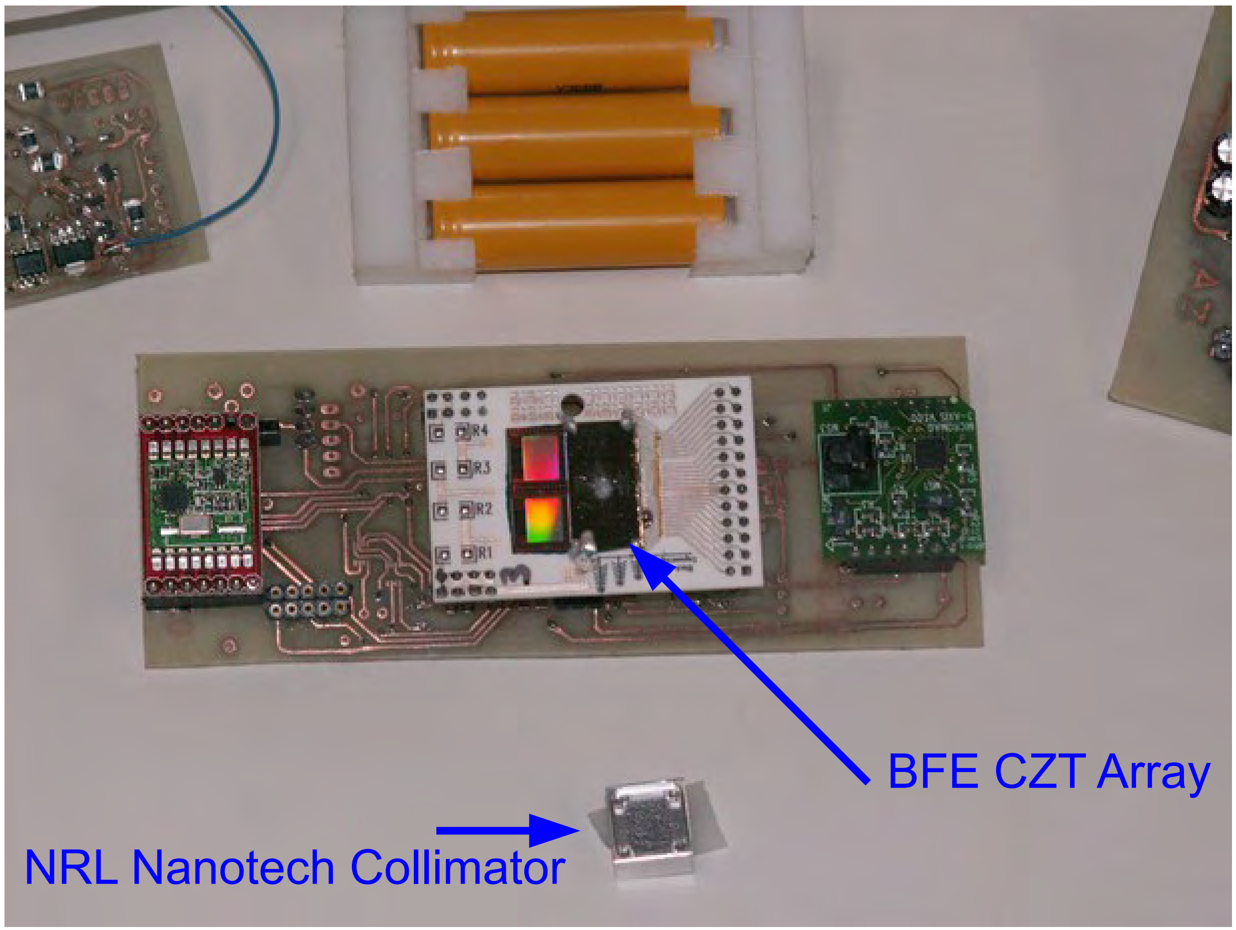
Bottom

MSP430-F2410
Processor



ulogo Software
Installer Connector
(Not Used in Flight)

X-ray Sensor CZT Array Nanotech Collimator



Fact sheet: Cubesat Danjon for Monitoring the Albedo of the Planet Earth

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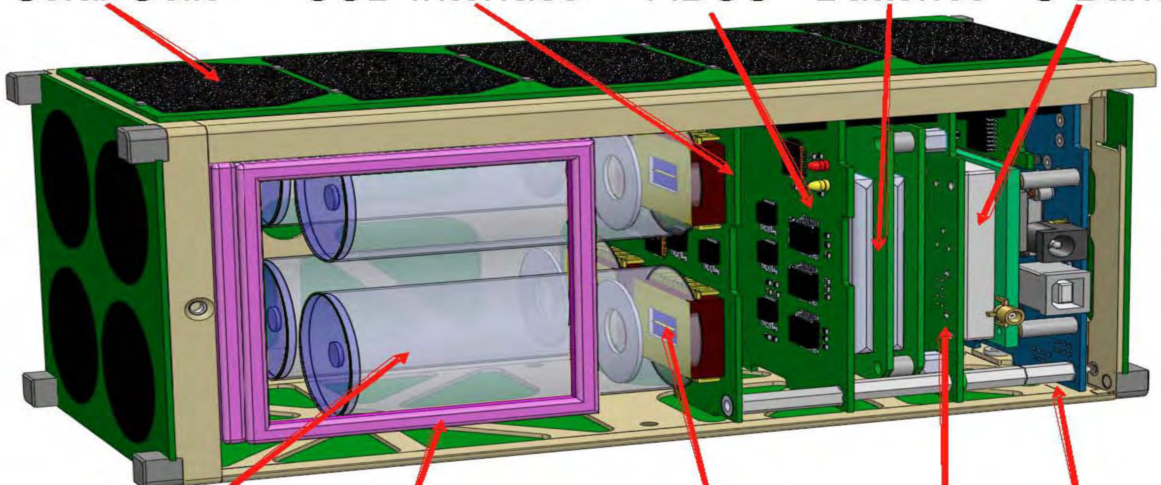


Project Objectives
- Monitor Earth's Albedo in three wavebands
- Joint calibration of the method with the ground based BBSO earthshine project
- Comparison with results from other systems

Project Characteristics
- 2U CubeSat (10 cm x 10 cm x 20 cm)
- Equatorial Orbit (635 km)
- Student Built and Operated (Supervised by Experienced Engineers)

Science Instruments
- Four telescopes (3 cm primary mirrors): Two @ 400-700 nm (primary science)
- One @ 700-900 nm, One @ 200-400 nm

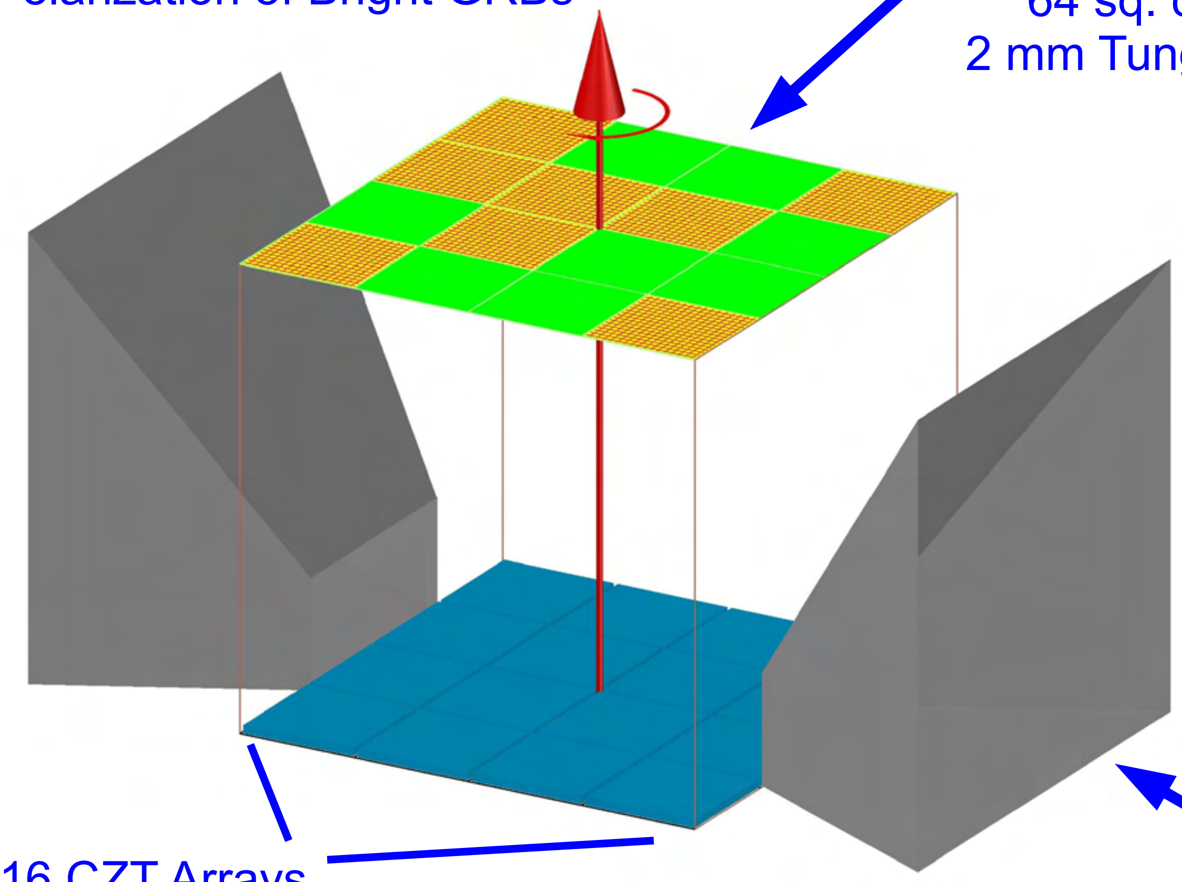
Spacecraft Characteristics
- Total mass: 1.8 kg
- Avg. power: 1.54 W (BOL)
- Spin stabilized (20 seconds) aligned with Lunar orbit
- 1° pointing control (1' knowledge)
- 3-axis magnetic ACS and spin-up (based on HETE-2)
- Fourteen rigid, body mounted, ITJ solar cells
- 2048 Mbits Storage
- 9.6 Kbps COTS S-band communications (UHF beacon w/telemetry)

3P PocketQube or 1U CubeSat As A Testbed for PolOCube (3U)

Science Objective: Study Gamma Ray Bursts (GRBs)

Detect and Localize GRBs

Measure Polarization of Bright GRBs



THE END