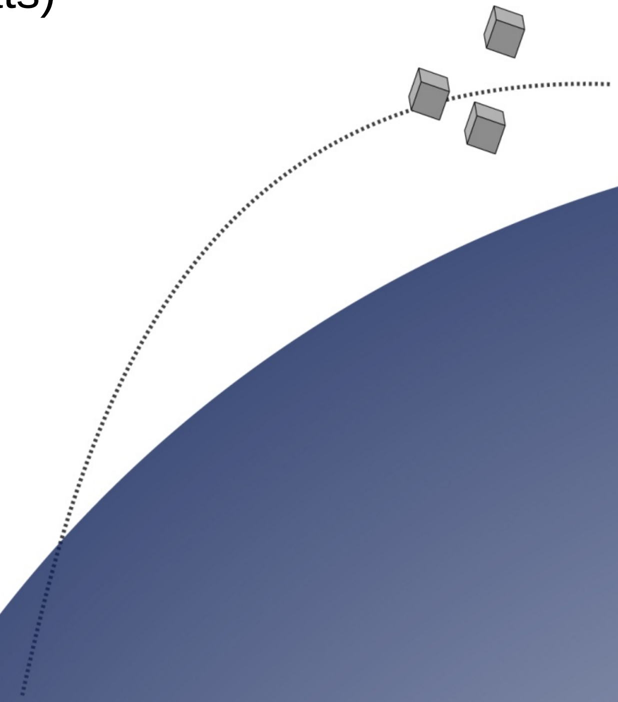
# Progress in Development and Implementation of a Spacecraft Radio Identification Tag System

(The SRI-Tag Transponder for CubeSats)



More about CubeSat RFID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# CubeSat RFID – Introduction

- Previously (2008) described the mis-identification or crosstagging issue and the potential for a low-power RFID solution
- The problem persists and the solution described in concept remains applicable
- The path to use of custom CMOS RF circuits is difficult, an impediment to the rapid demonstration of the concept
- Alternative means exist to achieve low-power operation with an appropriate choice of commercial off-the-shelf parts
- Here will review the basics of problem and concept, describe the design of the spacecraft radio identification tag (SRI-Tag) system as developed to this time
- A discussion of engineering issues arising in this design may resonate with small spacecraft developers in a general sense
- Development of the SRI-Tag has been IR&D funded so far
- Wish to encourage interested parties to adopt the technology when fully developed and attract the attention of possible sponsors

# CubeSat RFID – Outline of General Points

- Review of the crosstagging problem
- The proposed solution – transponder with interrogating fence: SRI-Tag system
- Concept of Operations
- System blocks and functions
- Space segment requirements / interfaces
- Ground segment requirements
- Antennas – choices, characteristics, tradeoffs
- Receiver, Transmitter and Microcontroller
- Power system issues
- Development status
- Other functions beyond identification
- Demonstration, test and implementation thoughts

# CubeSat RFID – The Problem Illustrated
# Crosstagging on Launch 2008-021

## Launch from India on Day 119 of 2008

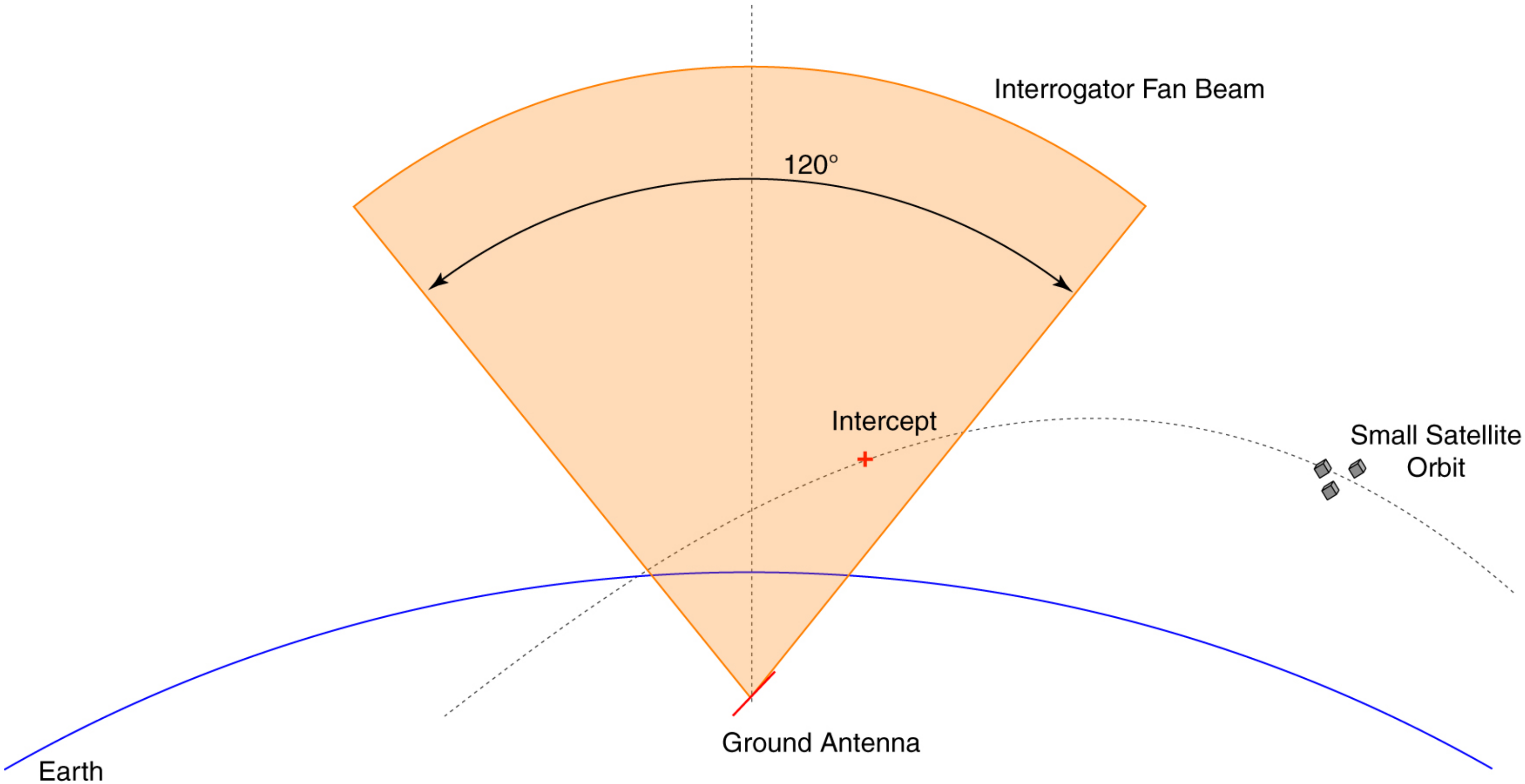
| | Time | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Object | 120.2 | 120.8 | 121.2 | 121.8 | 122 | 126.1 | 127.1 | 128.1 | 129.1 | 130.1 | 131.1 | 132.1 | 142.2 | 146.2 | 148.2 |
| 8021 | | | | | | | | | | | | | | | |
| A | U | U | CARTO | CARTO | CARTO | CARTO | CARTO | CARTO | CARTO | CARTO | CARTO | CARTO | CARTO | CARTO | CARTO |
| B | U | U | U | CANX6 | CANX6 | CANX6 | CANX6 | CANX6 | CANX6 | CANX6 | CANX6 | CANX6 | CANX6 | CANX6 | CANX6 |
| C | U | U | U | CUTE | CUTE | CUTE | CUTE | CANX2 | CANX2 | CANX2 | CANX2 | CANX2 | CANX2 | CUTE | CUTE |
| D | U | U | U | IMS1 | IMS1 | IMS1 | IMS1 | IMS1 | IMS1 | IMS1 | IMS1 | IMS1 | IMS1 | IMS1 | IMS1 |
| E | U | U | DELFI | CANX2 | CANX2 | CANX2 | CANX2 | COMPA | COMPA | COMPA | COMPA | COMPA | COMPA | COMPA | COMPA |
| F | U | U | AAUSA | U | AAUSA | AAUSA | AAUSA | AAUSA | AAUSA | AAUSA | AAUSA | AAUSA | AAUSA | AAUSA | AAUSA |
| G | U | U | U | SEEDS | SEEDS | SEEDS | SEEDS | DELFI | DELFI | DELFI | DELFI | DELFI | DELFI | DELFI | DELFI |
| H | U | U | U | U | U | DELFI | DELFI | CUTE | CUTE | U | U | U | U | U | CANX2 |
| J | U | U | COMPA | COMPA | COMPA | COMPA | COMPA | SEEDS | SEEDS | SEEDS | SEEDS | SEEDS | SEEDS | SEEDS | SEEDS |
| K | M | U | RUBIN | RUBIN | RUBIN | RUBIN | RUBIN | RUBIN | RUBIN | RUBIN | RUBIN | RUBIN | RUBIN | RUBIN | RUBIN |
| L | M | | | | | | | | | CUTE | CUTE | CUTE | CUTE | CANX2 | DEB |

**Note the shuffling of Object Identifiers vs Names (color coded) over time**

**Confusion about identity yields increased mission RISK**

**A future proliferation of CubeSats will multiply crosstagging problems & risks**

# CubeSat RFID – Solution: Transponder system with interrogating fence

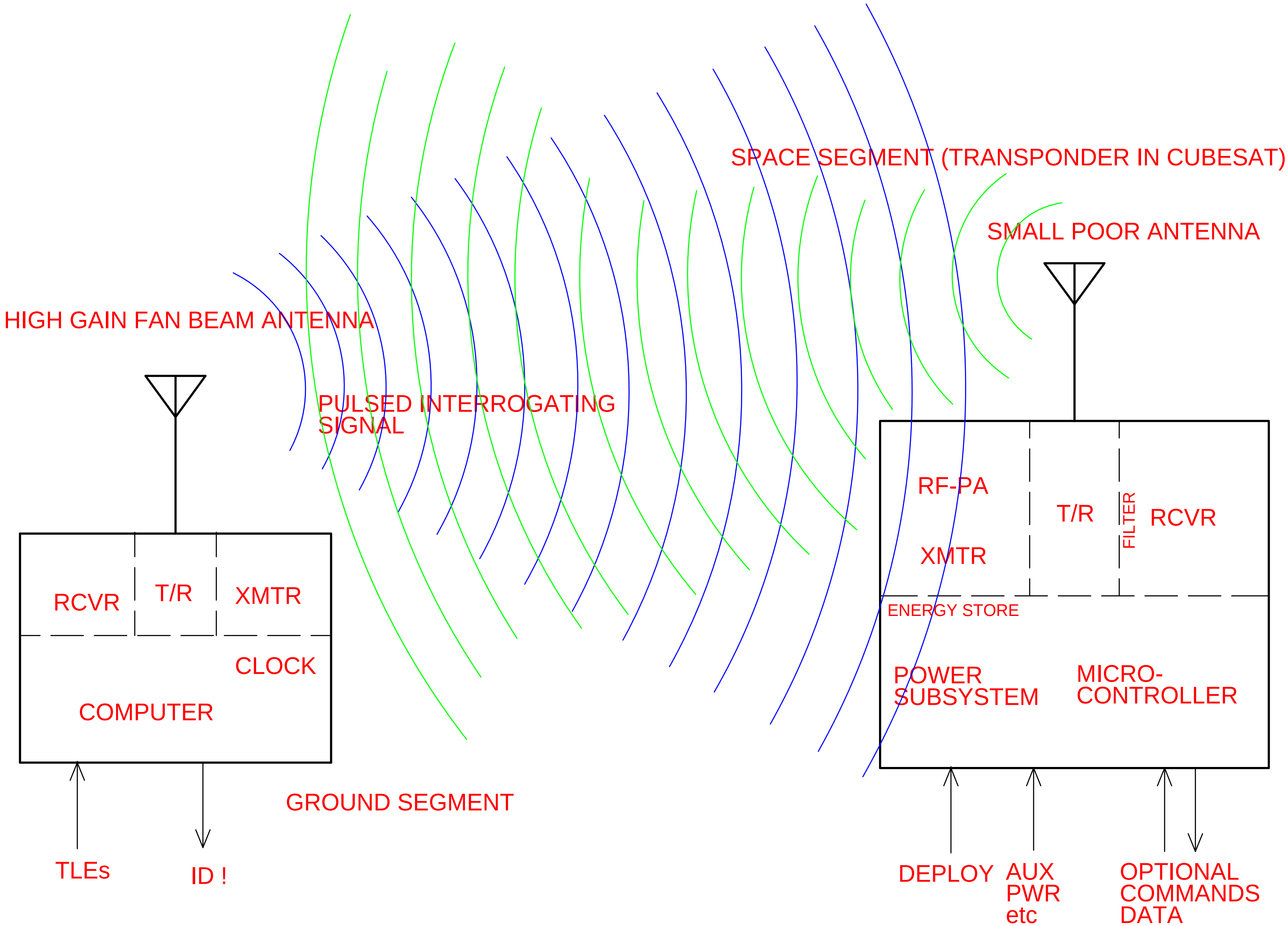



**Azimuth orientation and geographic siting optimized for specific satellite orbits**

# CubeSat RFID – Concept of Operations

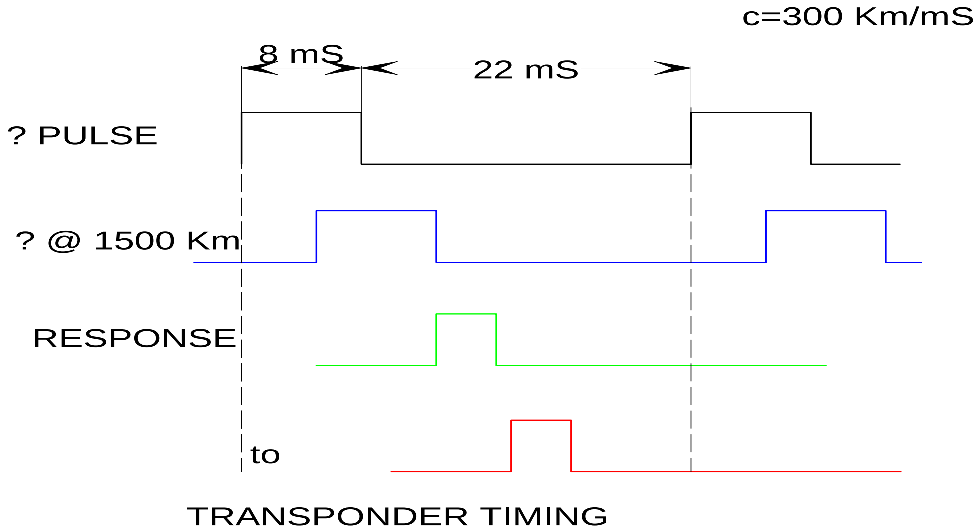
- Send pulsed ? messages to an expected spacecraft as it transits a zone defined by a thin fan beam, very strong signal not easily confused with noise
- Transponder on spacecraft responds when addressed by ? message and thus identifies the time of passage
- Comparison with ephemeris predicted times of passage for expected objects establishes the identity
- Early ephemeris could be poor but possibly refined with transit time data
- Subsequent passes thru beam confirm identity with tracked object ephemeris

# CubeSat RFID – System Blocks & Functions



# CubeSat RFID – System design specifics

- Pulsed transponder system – 900 MHz ISM band
- ? Message is FSK modulated pulse
- Transponder detects ? pulse, receives message, decodes & responds
  - Sampled receiver operation to save power
- ? Signal is 8 msec pulse, 22 msec IPP, followed by 4 msec response
  - >2400 Km maximum unambiguous range



# CubeSat RFID – Transponder design objectives

- Easily fit in Cubesat structure
- Operate autonomously with small self-contained primary battery
- Use spacecraft power (sparingly) if available
- Receive and recognize ? pulses, reject others, decode while minimizing power
- Send powerful response signal back to ground system, ½-watt, 4 msec
- Operate for at least 30-days even on a dead spacecraft
- Provide means for auxiliary commanding, messages and beaconing
- Use a simple antenna requiring minimal space

# CubeSat RFID – Ground Segment

- Xmit/Rcv circular polarization due to unknowable spacecraft orientation
- Generate fan-beam of pulsed transmissions, approx ½-deg x 120-deg pattern
  - Linear broadside array, distributed transmitter
- Coincident received beam, low-noise figure, high sensitivity
  - LNA per element for maximum sensitivity, a la incoherent scatter radar
- Link calculations with linear array antenna, gain of 26.2 dB suggest
  - Uplink can have power of order 1Kw total
  - Downlink is limiting factor
  - Doppler + Oscillator uncertainties + modulation < sensible bandwidth
  - May need to segment receive array to have greater gain in 2-4 parts
- Design details TBD when transponder complete and funding available
- Experimental license application in process to demonstrate system

# CubeSat RFID – Antennas choices, characteristics, tradeoffs

- SRI-Tag an auxiliary instrument, antenna must be minimal but external and meet CubeSat launcher standards
- λ/4 whip, patch and commercial dielectrically loaded stub antennas investigated
- Practical choice is whip due to space required, performance and mounting simplicity, patch antennas large for 900 MHz band
- Antenna range tests whip vs stub show effects of spacecraft body as expected
- Whip much longer than stub, broader VSWR minimum, more gain
- Design feasible with whip, may be separate from electronics part to facilitate mounting choices
  - MMCX connector on cable
- Details TBD, springs, popup, no loose parts

CubeSat mockup testing with whip antenna

# CubeSat RFID – Receiver, Transmitter & Microcontroller

- Receiver IC chosen from available ISM band parts providing high sensitivity, lowest possible power, rapid start-up, FSK de-modulation capability, RSSI function, SPI bus communication
  - Since the receiver must be used to detect the presence of ? pulses the reduction of steady power drain is important
- Transmitter IC chosen for compatible operation with receiver and microcontroller, FSK modulation, minimum standby power, good efficiency
  - 1/2w output requirement needs added power amplifier using standard IC amplifiers
  - Operation is infrequent and short, requires energy storage to supply load
- Microcontroller chosen for low power and small size with minimal pinout configuration giving just enough functionality for the job
  - Low speed to save power (80 KHz, 13µA)
  - Easy programming in-circuit, on-board EEPROM

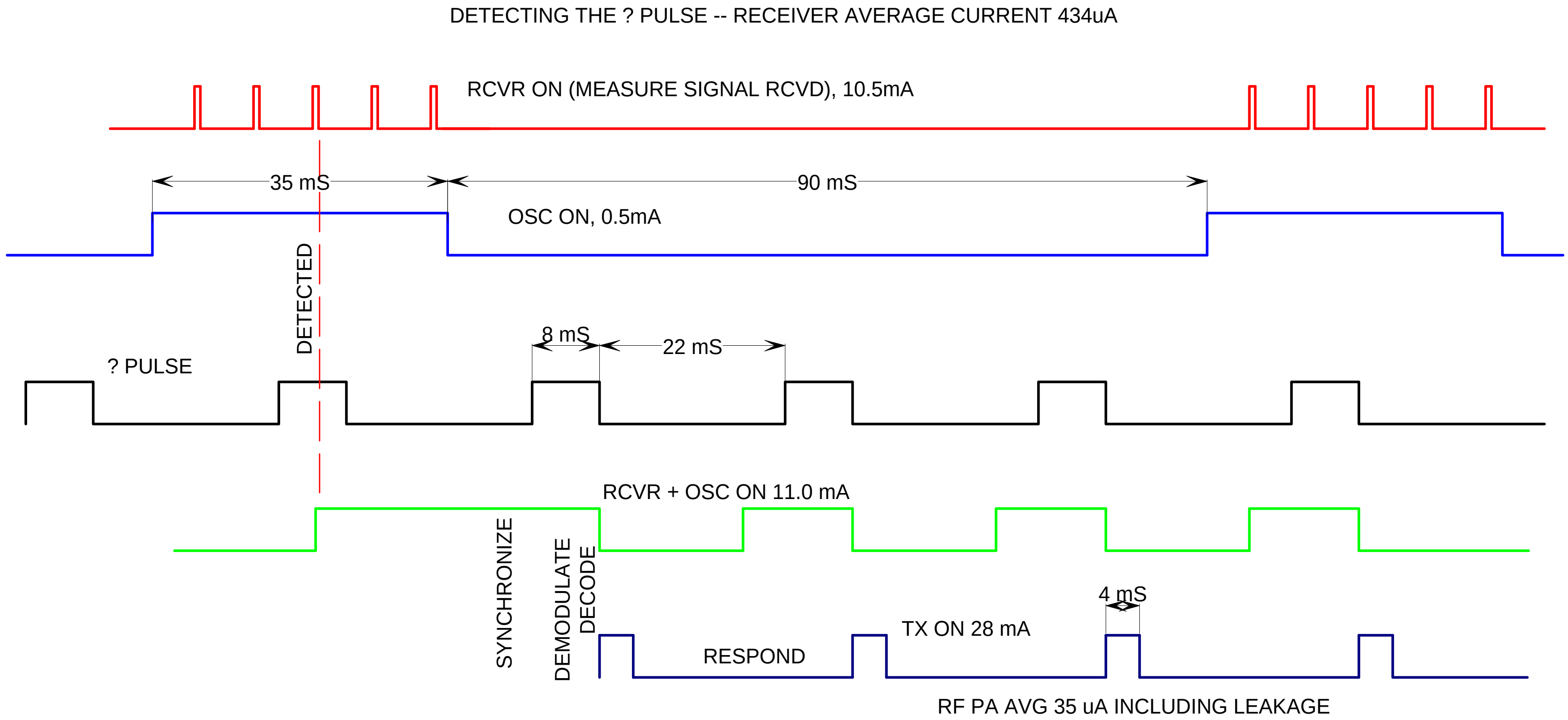
*Parts are: Silicon Laboratories SI4222, SI4322, C8051F332*

# CubeSat RFID – Power System Issues

- Minimization of steady loads, no large peak loads,
  - N-size Li-ion battery, Tadiran TL-5902 3.6v 1200 ma-Hr, 0.57” dia x 0.99”, 9.2gm
- Reduction of receiver load by sampled signal measurement to detect ? pulses
- RF ½-w PA requires 5v pulsed power hence
  - DC-DC converter to charge 5v ultracapacitor for transmitter responses
- Accumulated effect of leakage and quiescent currents
- Overall dominated by receiver because of continuous operation

- Power budget (after deployment):
  - Receiver loads, avg 434 µA [85.4%]
  - Transmitter quiescent and active loads, avg 36 µA [7.1%]
  - Microcontroller, avg 30 µA [5.9%]
  - T/R switch 8 µA [1.6%]
- Expected battery life @ 60% utilization: 59 days

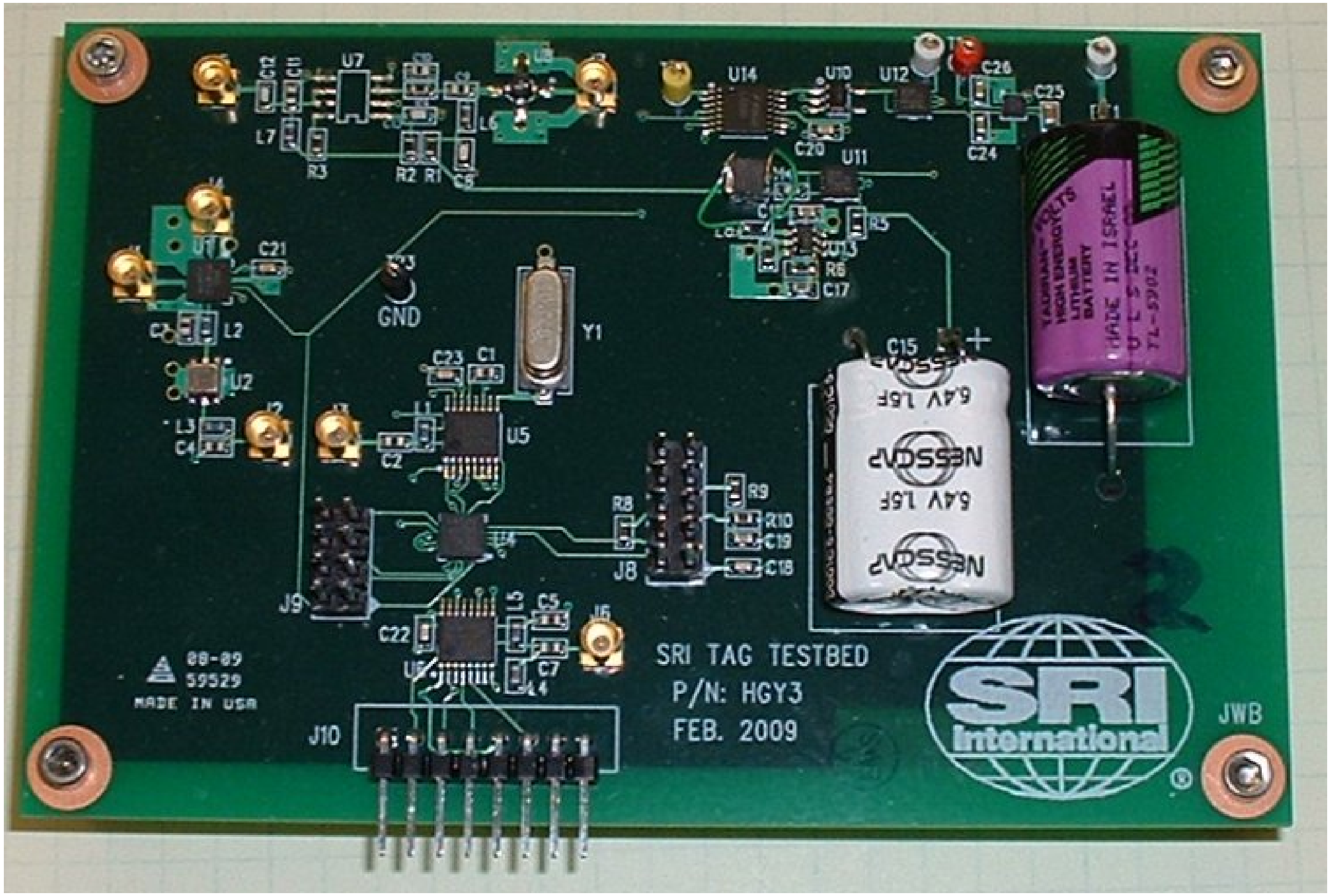
# CubeSat RFID – Timing of Loads for Detection & Response



# CubeSat RFID – Development, the SRI-Tag test bed

- Transponder block diagram circuits fabricated in more accessible form
  - A test bed or breadboard
- Breakouts for most signals from microcontroller to other parts provided
- Programming connections identical to evaluation boards
- Xmtr and microcontroller evaluation boards assemble test ground segment
- Microcontroller programming underway
  - First establish pinout significance of µC
  - Provide SPI bus communication code
  - Receiver and Transmitter initialization
  - Interrogation pulse recognition code via DRRSI read against threshold
  - Data handling through FIFO buffer in receiver, process
- Expect to test individual parts of code using test bed, then assemble fully
- So far a few changes needed in design have been identified
- Shortcomings in documentation an issue

# CubeSat RFID – SRI-Tag testbed 2




Test circuitboard 3.0” x 4.5”, reported largest available underutilized volume in Pumpkin kit is 2.83” x 0.59” x 0.9”

# CubeSat RFID – Other Functions beyond Identification

- SRI-Tag design envisions ancillary uses when ID function achieved
  - With s/c bus power available may operate as a beacon or minimal data link
- Back door command receiver, useful for Reset of hardware
- Some already planning supplemental tracking use of beacon
  - Use external 10 MHz high stability standard to implement accurate doppler tracking
- Uncertainty about on-orbit radio noise in ISM band could use Tag to log signal level measurements while searching
  - dump data via beacon to SRI ground station

# CubeSat RFID – Demonstration, Test and Implementation

- Bench testing of Tag test bed, completion of design modifications
- Fabrication of prototype flight instrument
- Bench testing with mockup of ground equipment
- Vibration, thermal and thermal-vacuum testing of module
- Fabrication of partial ground segment
- High altitude balloon flight test(s) SRI-Tag
- Initial application on CubeSat TBD

# CubeSat RFID – Summary / Conclusions

- Crosstagging of CubeSat spacecraft a continuing problem that will grow with the number of objects deployed and launch opportunities
- The SRI-Tag system described can help with this and other matters of concern to small satellite developers
- An alternative to custom CMOS circuits for an ultra-low power spacecraft radio identification transponder is nearing completion of prototype development
- Several further steps required before demonstration beyond bench testing
  - Revision of test bed, design changes to accommodate size issues
  - PCB layout and mechanical design, flight prototype fabrication
- Method available for realistic system testing before actual spacecraft flight
- Interest present for application both for the prime RFID mission as well as ancillary uses