Passive Microwave Energy Harvesting for Space Applications

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IEEE WiSEE 2019 PWST Workshop

About Us…

Prof Durgin is

- Professor of ECE at GT
- Director of Propagation Group
- Director of Opportunity Research Scholars
- Active in IEEE Council on RFID

Orlando, FL, April 28-30

Co-located with RFID Journal LIVE!

North American Tradeshow

Talk Overview

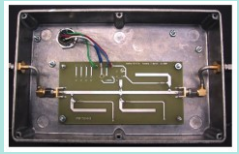
- Overview of RF Power-Harvesting Digital Sensor Effort at GT
- State-of-the-Art Review
- Technology for Extending Range
- Applications for Passive and Semi-Passive Backscatter Sensing

I. About Our Work

Summary of the GT Microwave Backscatter Research Program

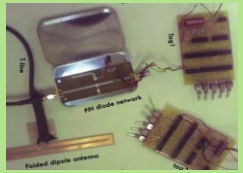
16 Years of GTPG Microwave Backscatter Research

Radio Assay



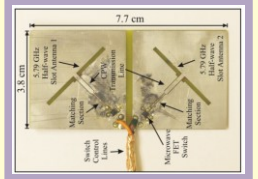
Josh Griffin kicked off the microwave backscatter research with his famous "Radio Assay" -- custom hardware that could measure link degradations experience by RFID tag antennas when placed upon cardboard, wood, metal, etc.

Spread Spectrum Backscatter Tag



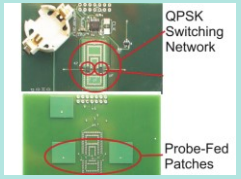
Anil Rohatgi builds a 915 MHz spread spectrum multi-tag system that demonstrates polarization and space diversity in a real backscatter communications link.

5.8 GHz Griffin Modulator



Josh Griffin built a custom 5.8 GHz down-converter and demonstrated tag gains at 5.8 GHz when small, multiple tags are modulated jointly. Thus, Griffin modulation was born!

Koo-Lu Modulator 5.8 GHz Tag

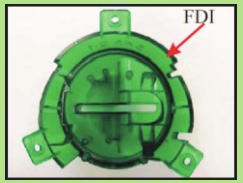


Designed by Greg Koo and Albert Lu, this microwave modulator demonstrated retrodirective backscatter with 4-ary Phase Shift Keying.

TMGW 5.8 GHz Shock Sensor Tag

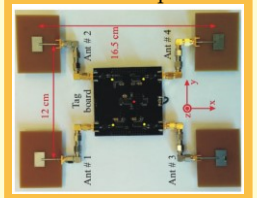
Chris Valenta and Bashir Akbar built a 5.8 GHz backscatter semi-passive system for detecting real-time shocks in helmets. The primary use was concussion detection in sports.

NCR Anti-Skimmer



A team of GT students develop an anti-skimming solution for payment terminals using microwave backscatter. Successful demonstration is shown on various payment devices.

HIMR 5.8 GHz Motion-Capture



Bashir Akbar demonstrates Hybrid Inertial Microwave Reflectometry (HIMR) motion capture system. Orientation sensor shown above.

Non-Planar, Space-Time Apertures

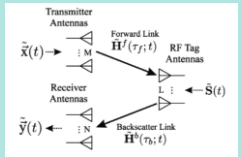
GT researchers working with Honeywell develop segmentable retrodirective structures that backscatter at upper-microwave and mm-wave frequencies for enhanced data rates.

2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020

915 MHz RF Downconverter

Albert Lu builds the group's first direct downconversion receiver box for backscatter, allowing ground-breaking experiments and a template for operating at higher frequencies.

MIMO RFID

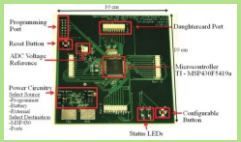


Josh Griffin lead authors the immensely influential paper on the use of multiple antennas in a backscatter link for readers and tags. His work predicts big gains in both data rate and reliability.

High-Voltage Fault Detection System

A team of GT students design and build a 5.8 GHz backscatter system for high-voltage fault detection. Southern States deploys the system across North America.

R.E.S.T. Platform

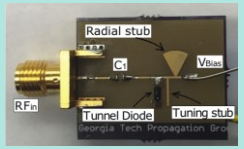


Chris Valenta designed the R.E.S.T platform, a modular 5.8 GHz backscatter platform with a software radio reader that could be configured for a limitless combinations of sensors, antennas, and modulation schemes.

Wireless Diaper

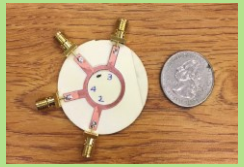
Blake Marshall designs an inset for "wireless diapers" -- a passive, low-cost inset that can relay moisture measurements to a 915 MHz RFID reader.

Quantum Tunneling Tag at 5.8 GHz



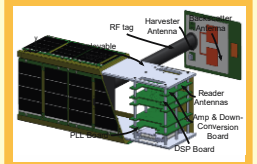
Francesco Amato builds the first microwave Quantum Tunneling Tag (QTR). This 5.8 GHz tag will scatter a signal over a kilometer across midtown Atlanta, consuming only 23 microWatts in the process.

Alhassoun Retro-Directive Modulator



Mohammad Alhassoun invents a retrodirective modulator with a "rat race" hybrid. The devices is the first example of retrodirectivity that can use a single integrated circuit.

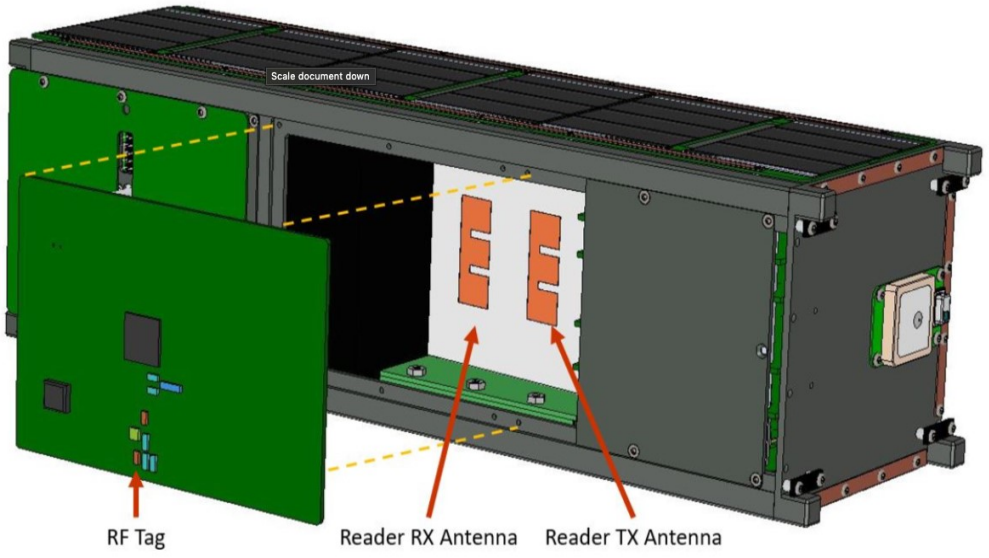
RFT Sat Engery-Harvesting Sensor

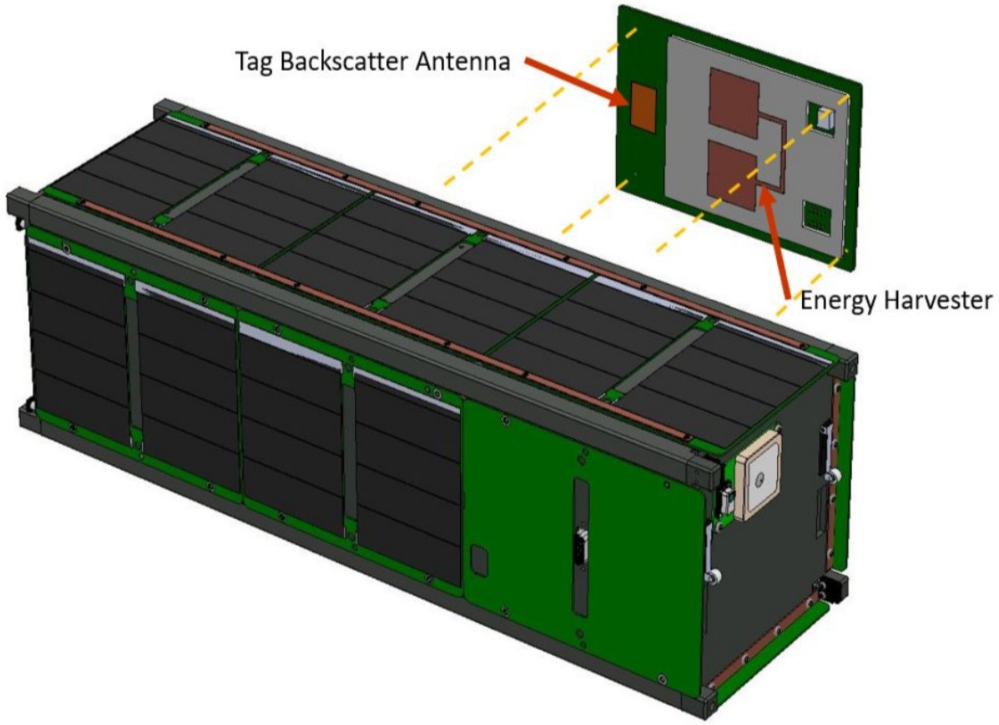


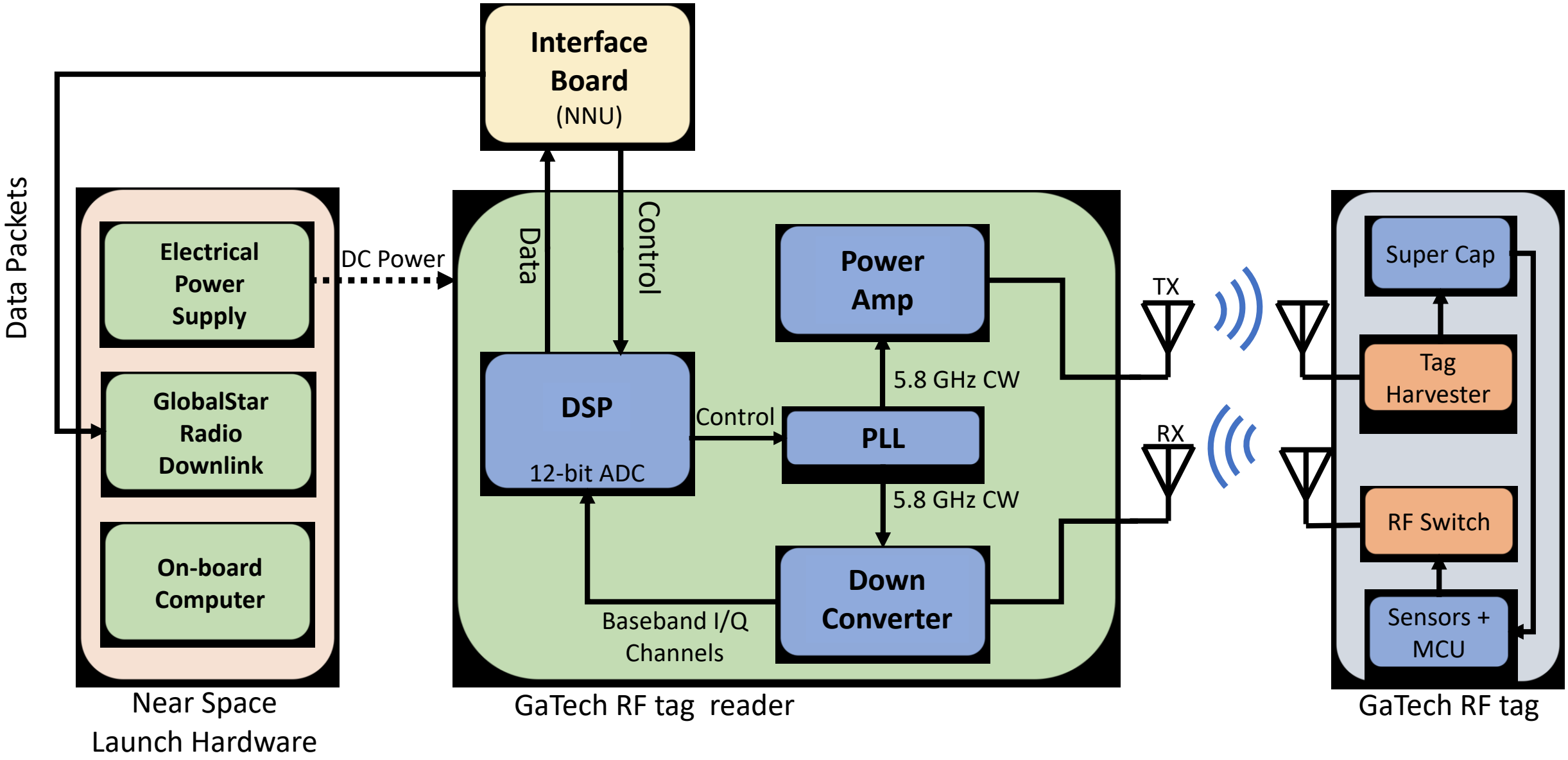
Cheng Qi builds a 5.8 GHz energy-harvesting backscatter sensor tag and reader science package. The system successfully launced in 2019 on Northwest Nazarene U's RFTSat.

Final RFTSat Concept

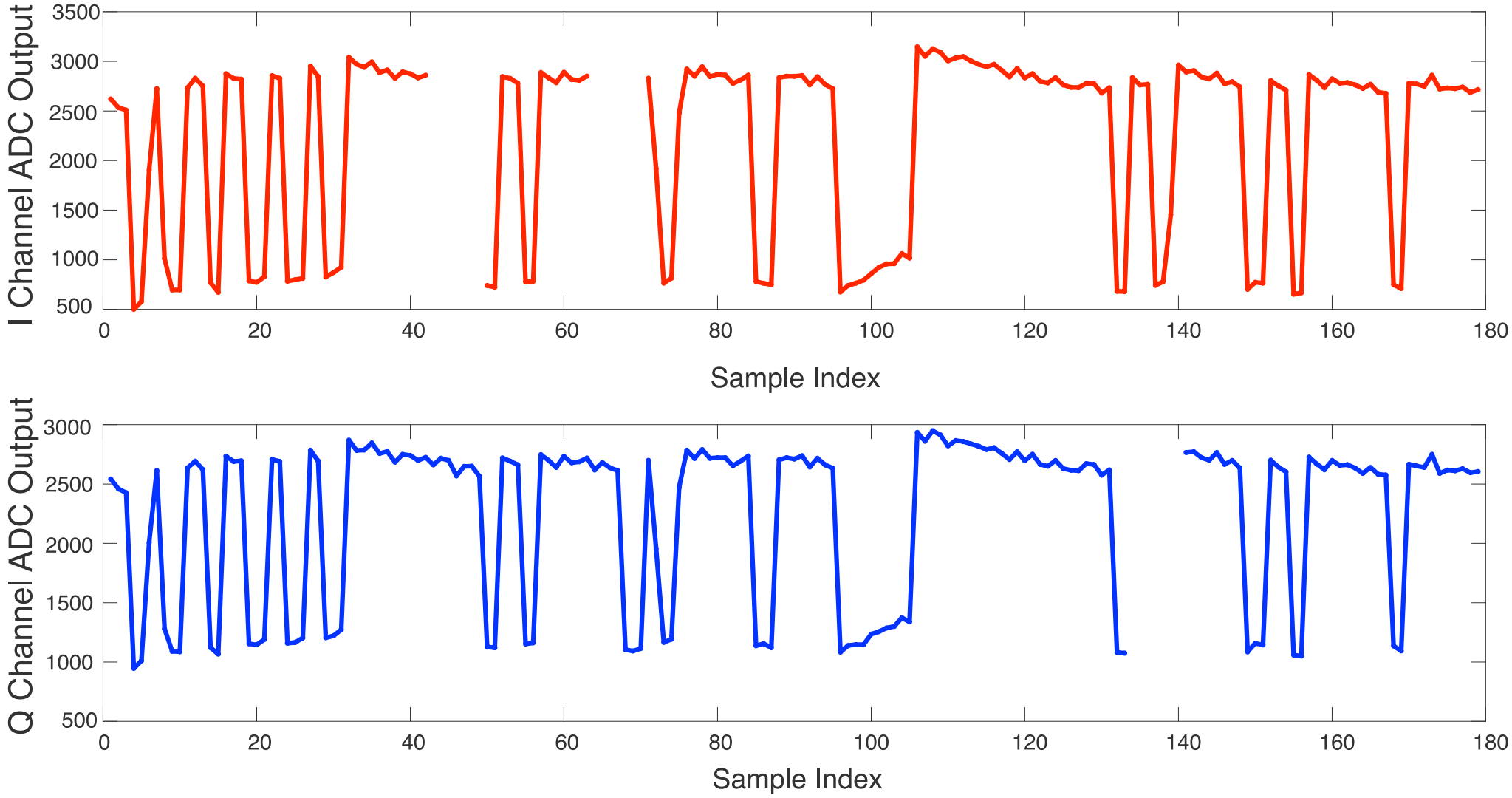
- The deployable boom failed during functional testing. Due to schedule constraints, it was removed and the tag fixed to the side of the satellite.
- The separation distance between the reader and the RF tag is now ~ 4cm






Interface Board
(NNU)
Data Packets
Electrical Power Supply
GlobalStar Radio Downlink
On-board Computer
DC Power
Data
Control
Power Amp
DSP
12-bit ADC
Control
PLL
5.8 GHz CW
5.8 GHz CW
Down Converter
Baseband I/Q Channels
TX
RX
Super Cap
Tag Harvester
RF Switch
Sensors + MCU
Near Space Launch Hardware
GaTech RF tag reader
GaTech RF tag

Live Sensor Data Sent to Earth on 8 Oct 2019



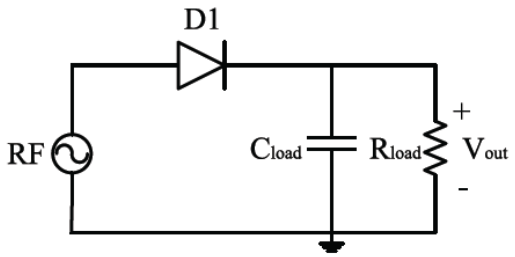
II. State-of-the-Art

How to Rectify RF Power

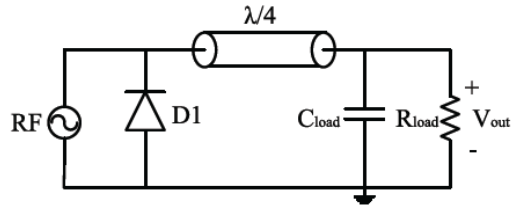
Lots of different circuits, but they all have the same limitation … diodes.

Diodes must turn-on before rectification, so they have a power “overhead”

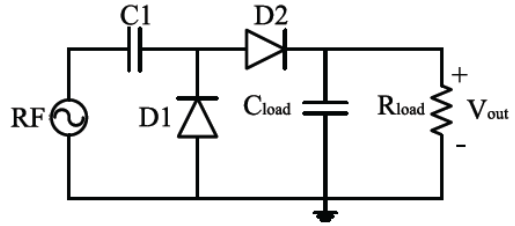
Curvature of a Schottky Diode:



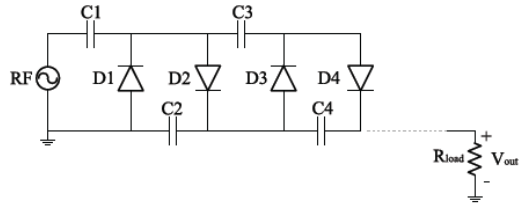
(a) Half-wave rectifier.



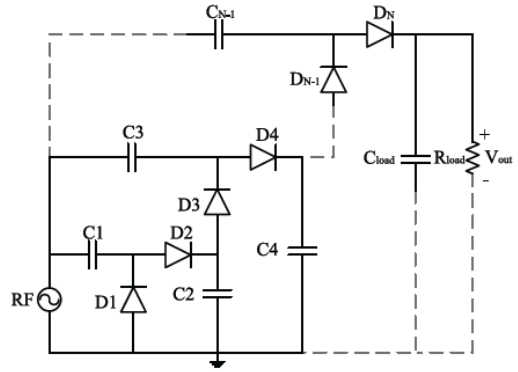
(b) Single Shunt Rectenna.



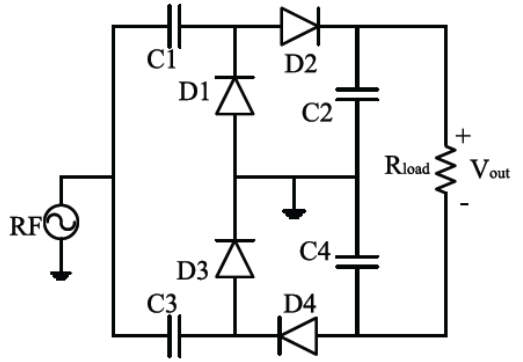
(c) Single Stage Voltage Multiplier.



(d) Cockcroft-Walton/Greinacher/Villard Charge Pump.



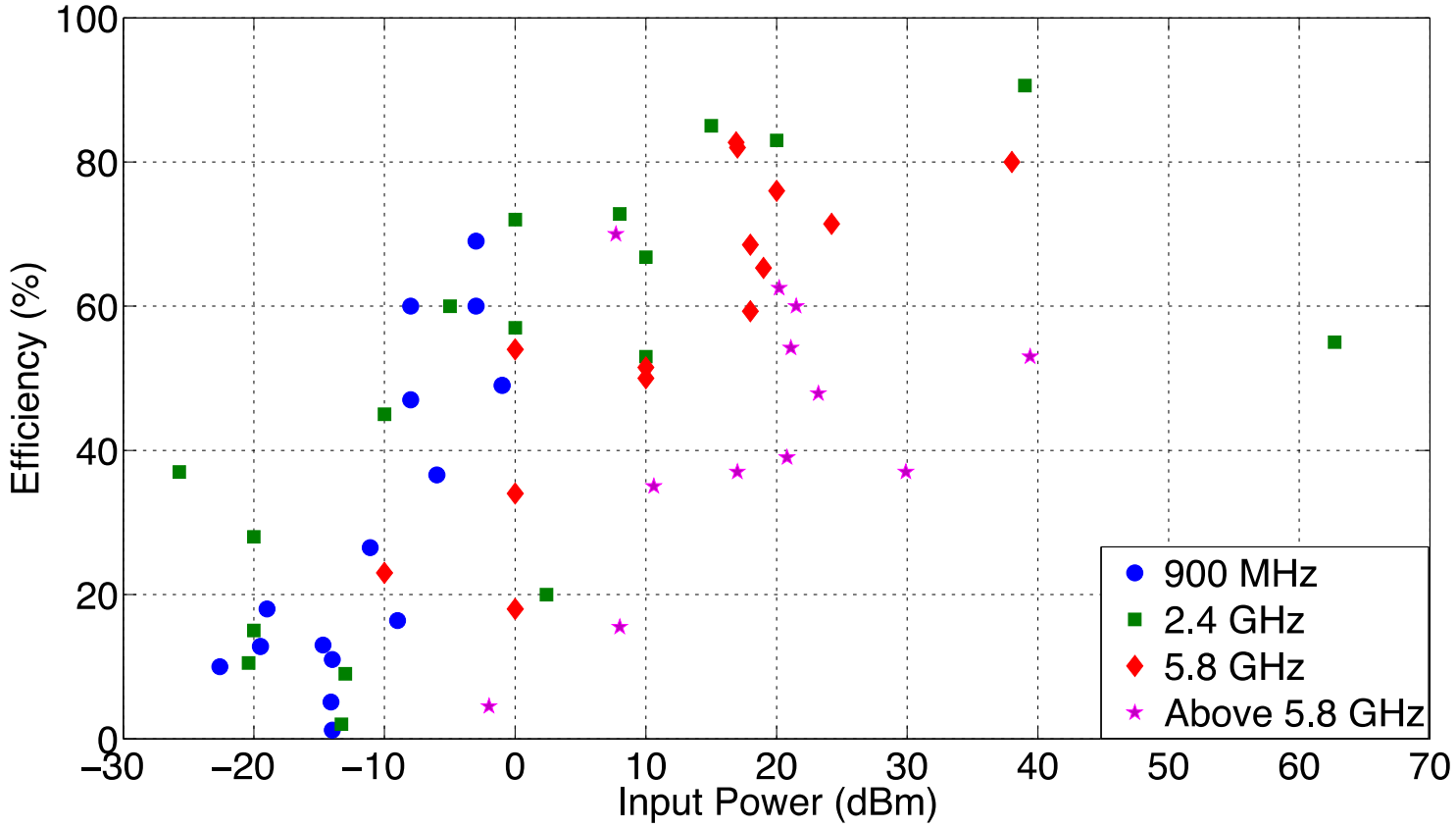
(e) Dickson Charge Pump.



(f) Modified Cockcroft-Walton/Greinacher Charge Pump.

C.R. Valenta, G.D. Durgin. “Survey of Energy-harvester Conversion Efficiency in Far-field, Wireless Power Transfer Systems.” *IEEE Microwave Magazine*. vol 14, no 4, June 2014. 10 pages.

Survey of RF Harvesting Efficiencies



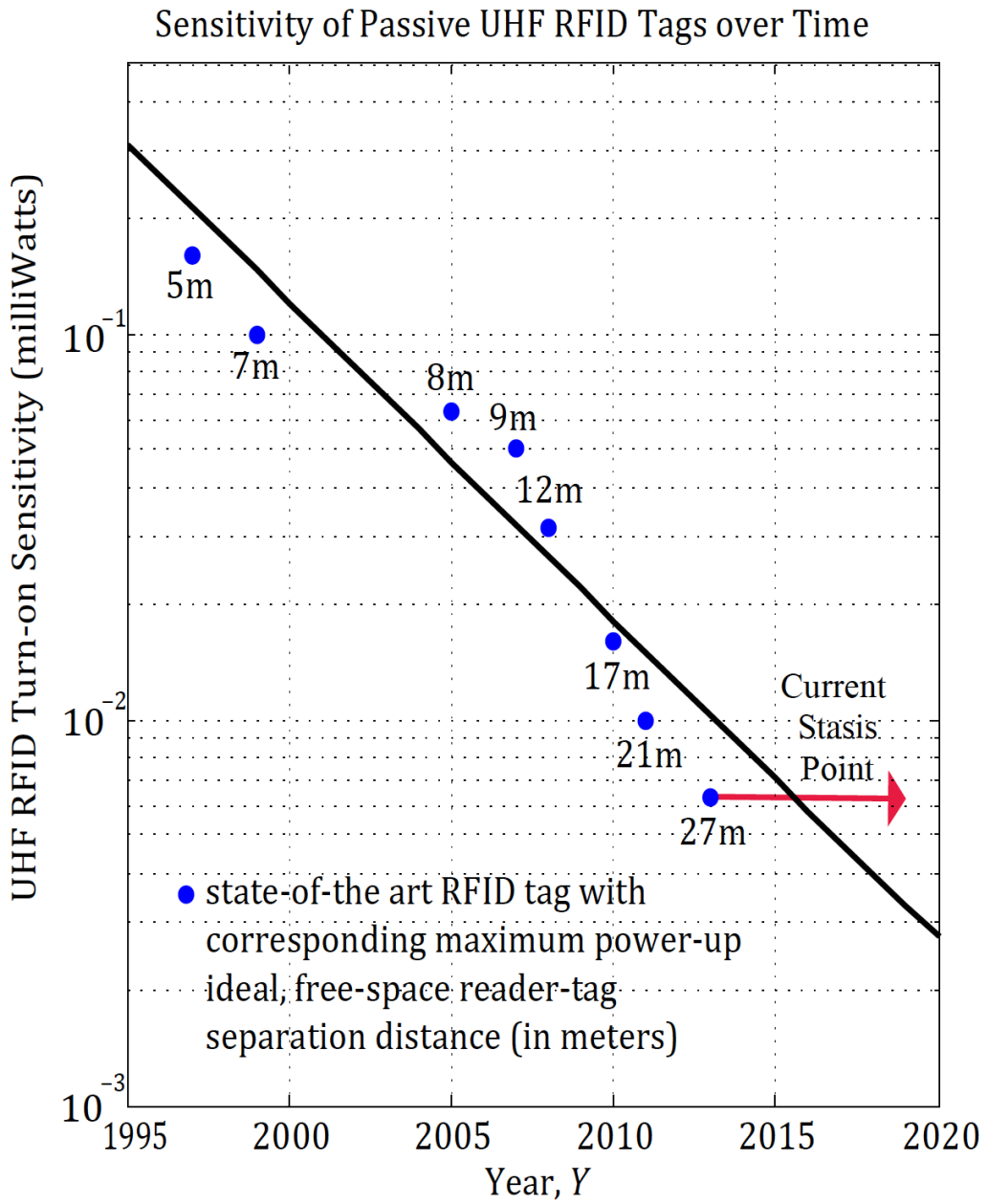
C.R. Valenta, G.D. Durgin. "Survey of Energy-harvester Conversion Efficiency in Far-field, Wireless Power Transfer Systems." *IEEE Microwave Magazine*. vol 14, no 4, June 2014. 10 pages.

Trends in Electronics: UHF RFID

This trend is driving the current buzz around the Internet of Things (IoT) and related technologies.

This energy efficiency doubles every 46 months.

The 100m tag is supposed to arrive in 2020 … but requires inventive leap out of standard SiCMOS



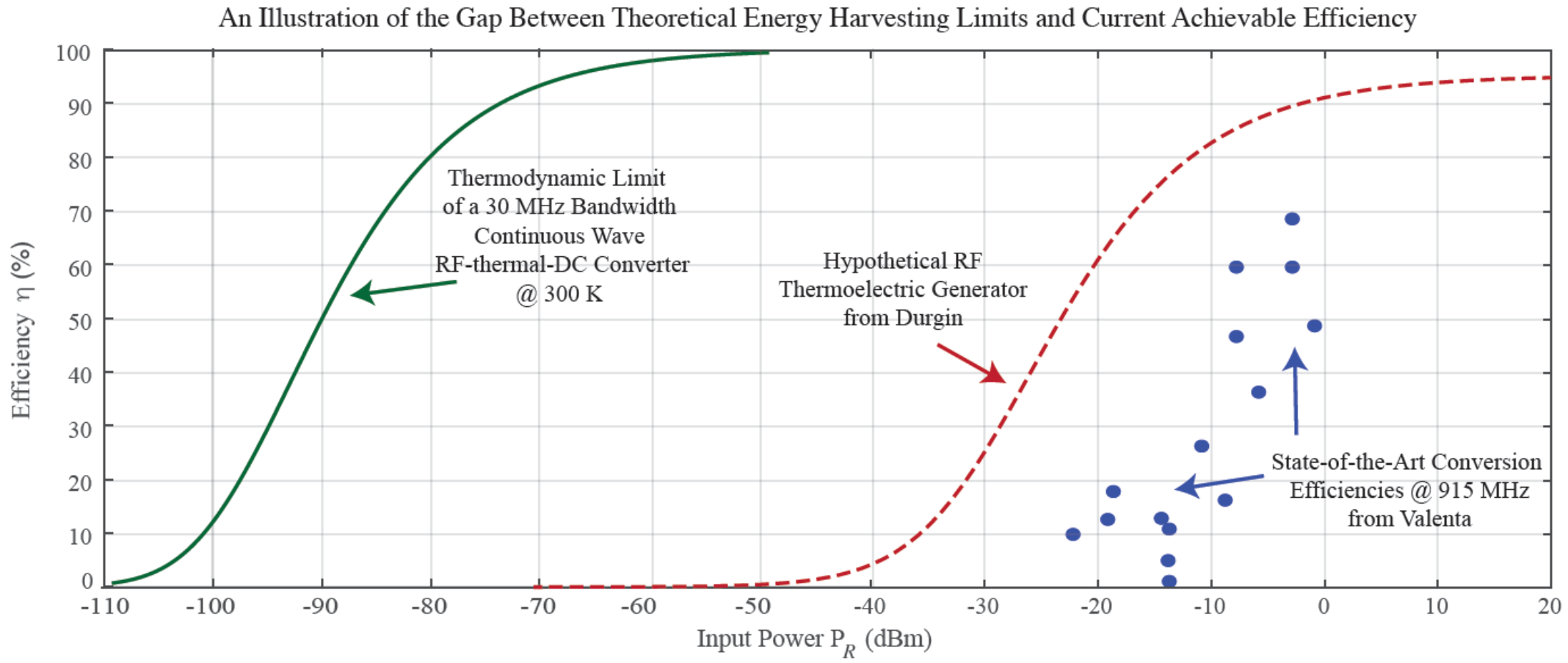
P. Nikitin, KVS Rao, S. Lam, "UHF RFID Tag Characterization: Overview And State-of-the-Art". AMTA Conference, Seattle, Oct 2012.

III. Technology Projections

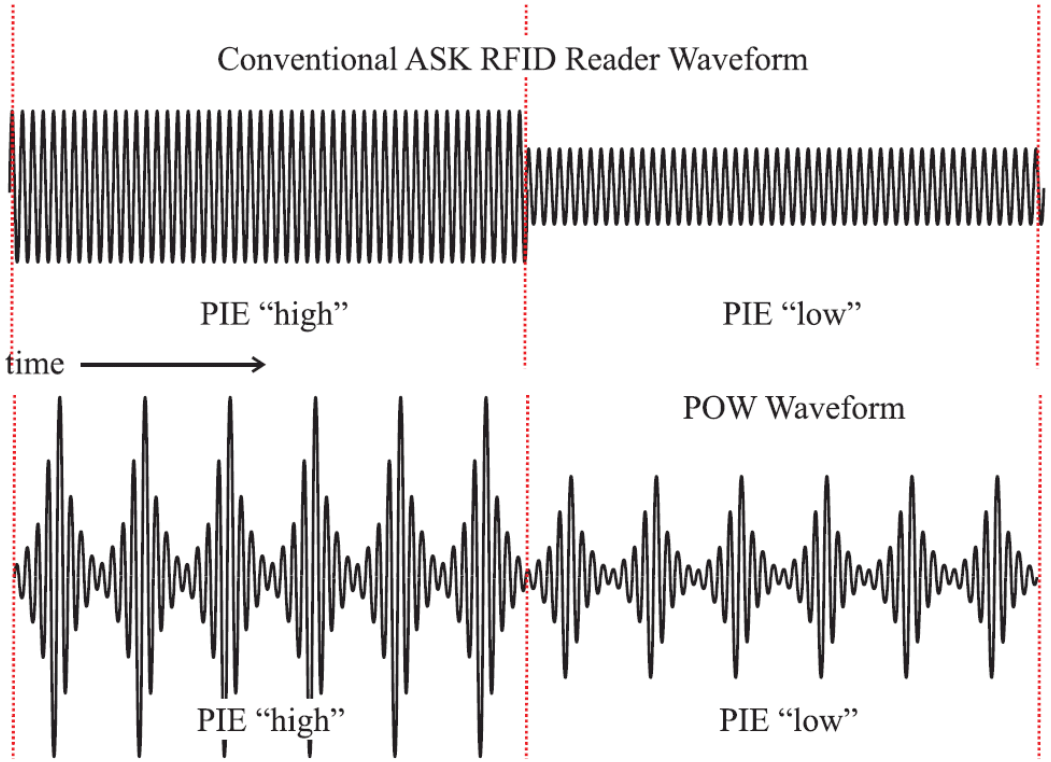
How to Improve Range

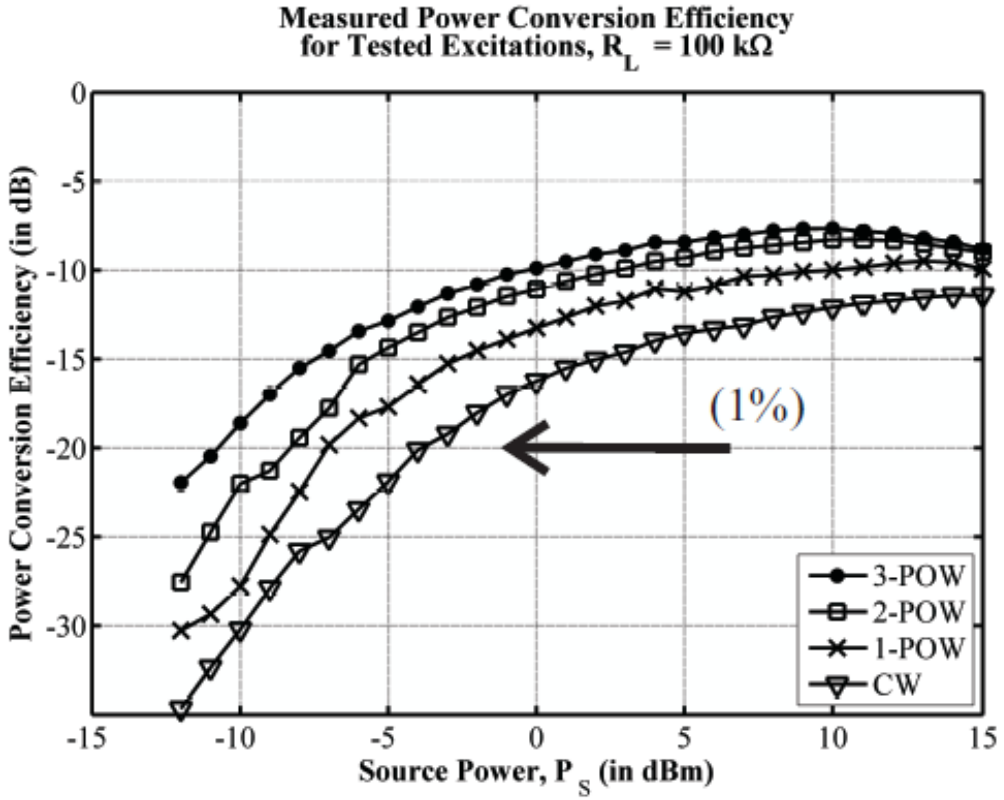
- Reduce Power and Voltage of the Sensing Electronics
- Change the Energy-Harvesting Devices
- Change the Energy-Harvesting Waveform

Theoretical Limits of Devices



Power Optimized Waveforms (POWs)

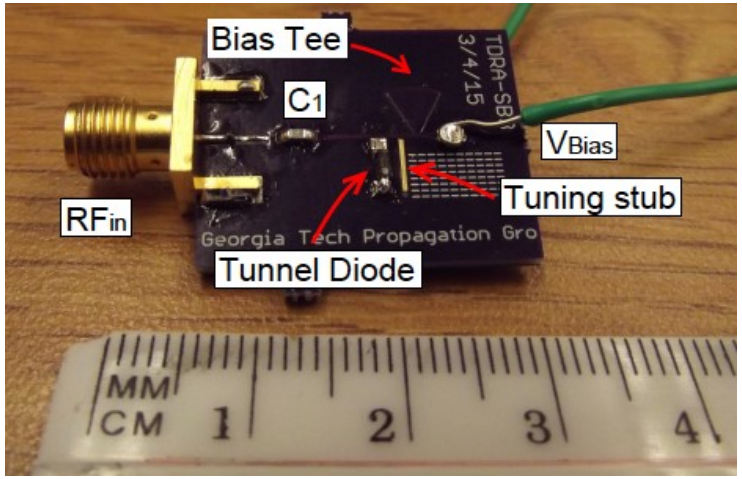


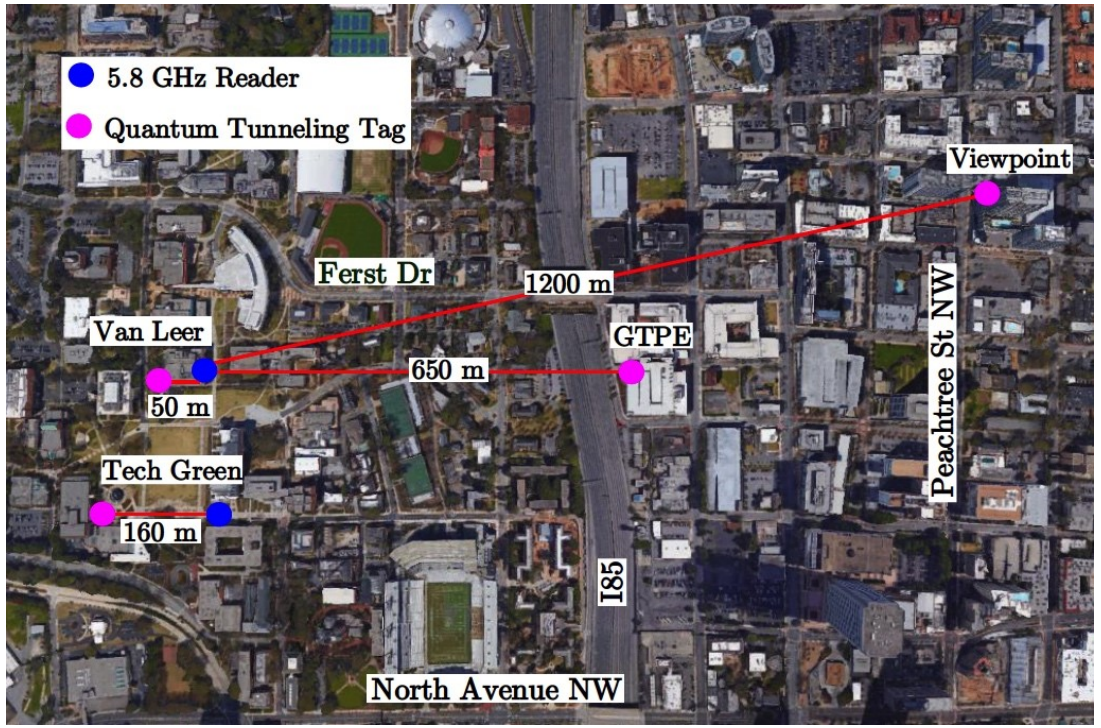


IV. Applications

Quantum Tunneling Tags

- Uses tunnel diodes to modulate and amplify backscatter
- Capable of extremely long-range transmission (1.2 km example shown on right)

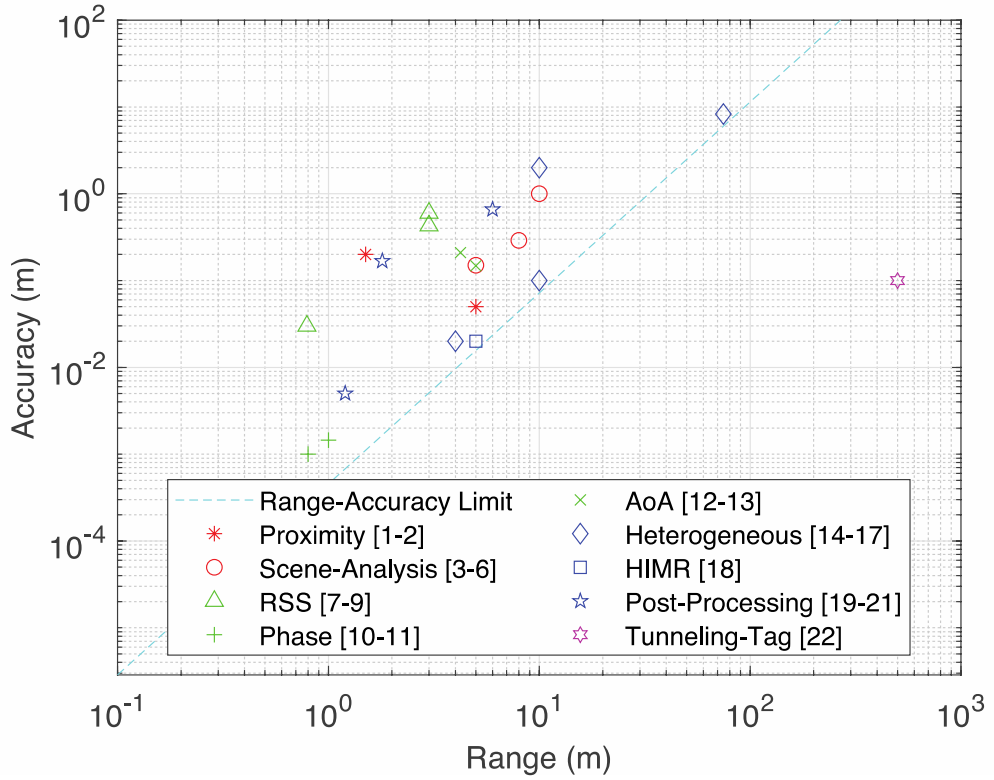




Francesco Amato PhD Dissertation, Georgia Tech, 2017

Accuracy of Localization with Backscatter

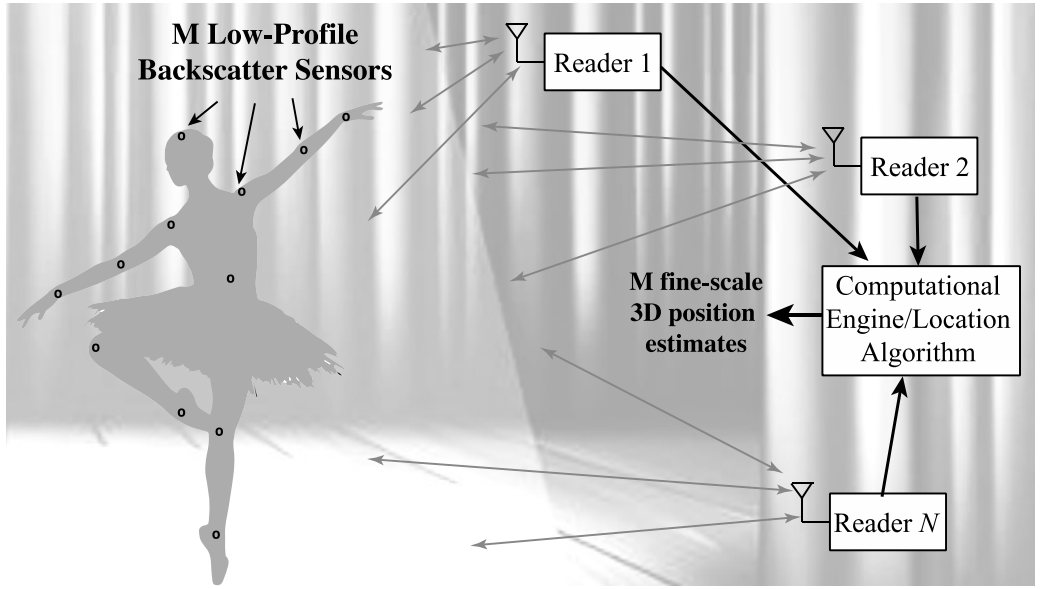
- Existing techniques cannot break the 100:1 limit of range:accuracy
- Quantum tunnel tags with frequency hopping project far past this barrier
- Promising results show that technique even works in multipath

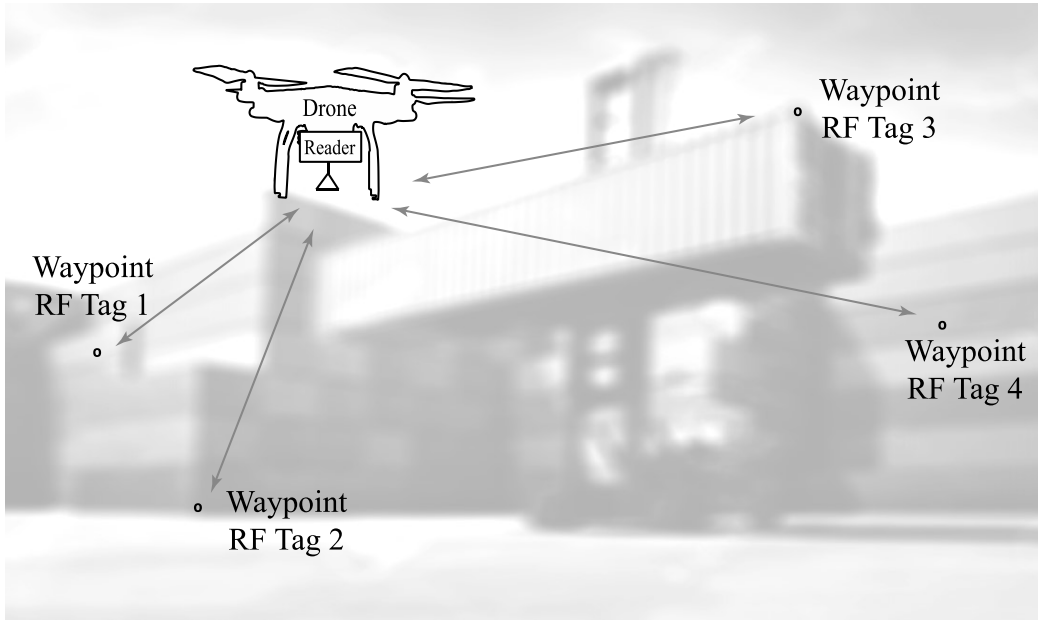


C. Qi, PhD Proposal, May 2019

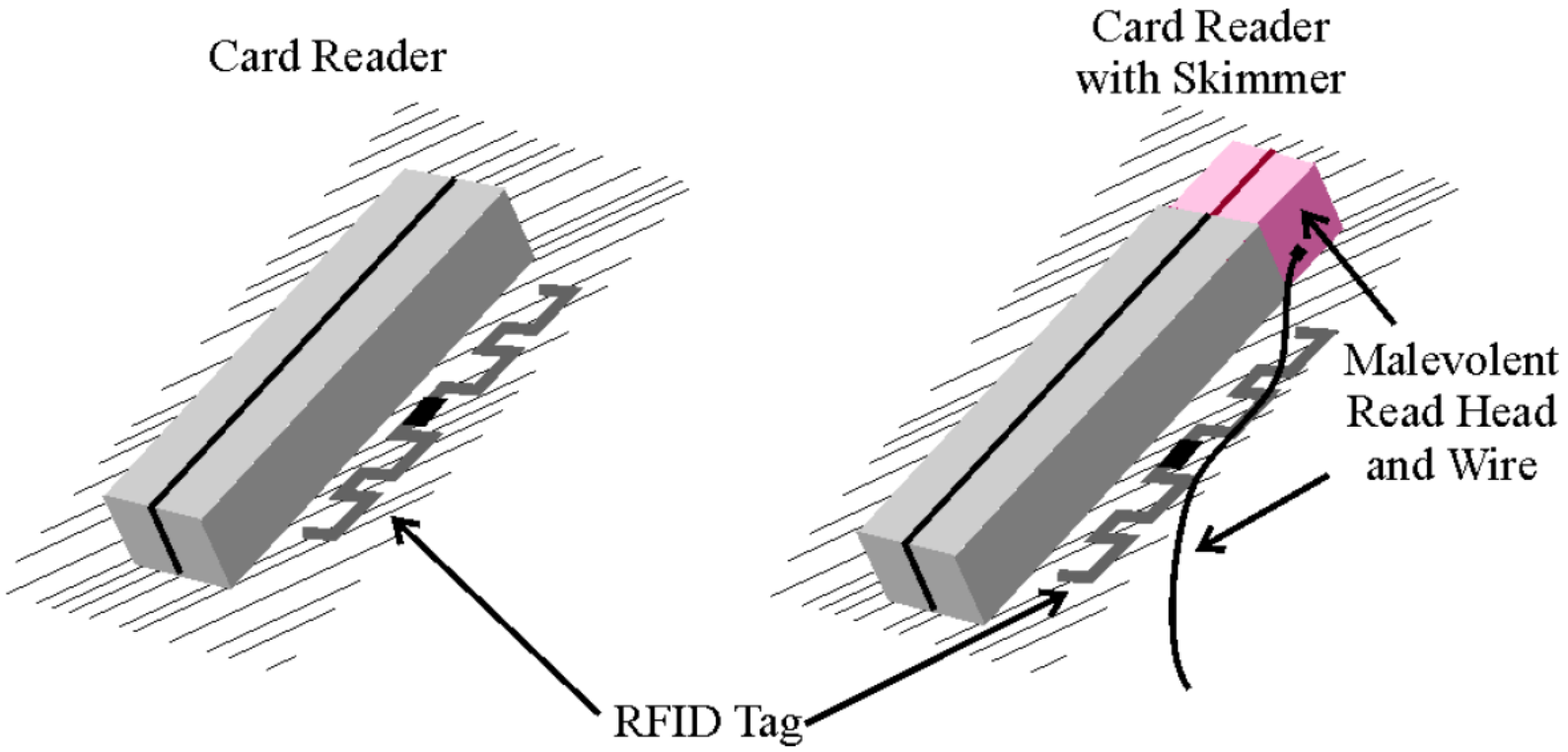
Ultra-Precise Localization

- Demonstration of mm-scale precision localization using backscatter + inertial sensing
- Flexible Configuations
- Very low-powered reader; could be integrated onto spacecraft or drone





Remote Sensing of Tamper



CONCLUSIONS

- Digital Microwave Backscatter Has Promising Future
  - Flexible Technique for Sensing
  - Currently Performs Well Below Theoretical Limits
  - Roadmap for Long Ranges
- New Applications on the Horizon
  - Ultra-long range backscatter
  - Wireless Motion Capture
  - Remote Sensing Applications