The Blue Devil WISP: Expanding the Frontiers of the Passive RFID Physical Layer

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- Sensing, computing, and actuation
  - Physical layer design + optimization
  - On-chip sensors and actuators
  - Tag localization
  - RFID aided perception
- Robotics + biomedical instrumentation applications

Dragonfly tracked with UHF tag
Tagged object localization and fetching
Array processor for tag localization

Vector signal generator (VSG)

Array processor front-end
8 antenna ports
I/Q demod to baseband

Power amp

Mobile robot base

6-antenna array
Particle filter to estimate tag location
Indoor localization results

Tag tracking in 10m x 10m room

Exploring the WISP design space

- Actuation Component
  - Piezoelectric speaker -> Piezo motor
- Planar omnidirectional antenna
- 4-QAM passive backscatter modulation
- RFIC - companion chip for microcontroller
SmartHAT safety warning system

- WISP + actuator for construction site safety
- Passive operation allows unlimited lifetime
- 4” x 4” size constraint
- Omnidirectional radiation pattern needed
- > 3m range needed – can transmit > 1W
Crossed Dipole with Capacitance Hats

- **Design Goals**
  - Planar PCB antenna
  - Smallest practical area
  - Integrate matching network into antenna
  - Maximize bandwidth
Power Harvesting

- 100 μW @ 6 m
- 10 μW @ 20 m
- Assumptions
  - Friis Path Loss Model
  - No Polarization Loss
  - 6 dBi, 1 W Transmit
  - 2 dBi (dipole) Receive
  - 915 MHz

- Real environments have lots of multipath
- Polarization diversity helps
Convert RF power into stable DC

• Based on Dickson Charge Pump
• Uses Schottky Diodes
• Stores Charge on Stage Capacitors
• Designed in stages
Accuracy of ADS diode models

ADS simulation and experimental data plotted together for 4-stage voltage multiplier circuits using HSMS2852 diodes and 5 pF stage capacitors.
Efficiency vs load and n_stages

85 kΩ Load Efficiency  200 kΩ Load Efficiency

Efficiency curves for differing number of voltage multiplier stages. For a given load, a poor choice for the number of stages can have a large, adverse affect on overall performance.
Optimal number of stages

- Maximum efficiency at 1.8V output versus load resistance
- ADS simulation for the HSMS285x diode family
- Optimal number of stages is determined by equivalent load resistance
Typical ASK/PSK Backscatter Link

- Data transfer via ASK/PSK modulation
  - Single RF switch
  - Resistance -> ASK
  - Capacitance -> PSK
- Avg. power transfer determined by duty cycle and modulation depth
  - Ex: 250 kHz, 50% square wave
  - 2 μs of Power Harvested
  - 2 μs of Power Reflected
QAM modulation via backscatter

- Readers already employ I/Q demodulation for phase rotation as tags move
- QAM increases throughput for given tag oscillator frequency
- Multiple FET switches 4 load impedances to generate each backscatter modulation state

Measured load impedances seen by the antenna for each of the 4 IQ states.
ADS Reader + QAM-Tag Model

I/Q Demod.

Directional Coupler

Power Source

4 Complex Load Impedances
WISP Companion RFIC

- Retain general purpose computing from WISP – TI MSP430 uC
  - Flexible protocol + sensor development
- Reduce system complexity vs discrete AFE
- Include QAM functionality
- MOSIS / AMI 0.5u process
Full-wave and half-wave rectifiers are compared. The output voltage is the voltage delivered to a 200 kΩ load. The performance is the same for a constant number of diodes.