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Wireless Power for Battery-Free Wireless Sensors

powercastco.com

wireless power for a wireless world

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Overview

- Powercast technology overview
- Applications for wireless sensors
- Battery-free reference design

About Powercast

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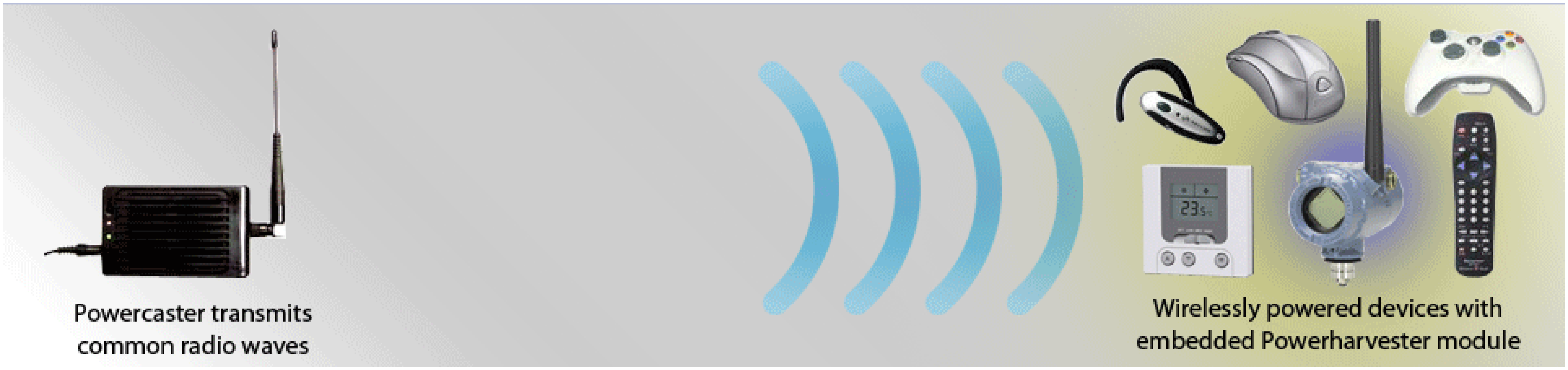
- Driving innovation and commercialization of wireless power based on RF energy
- Custom engineering and components
- Applications / Markets
  - Wireless sensors and devices
  - Defense
  - Aerospace
  - Manufacturing
  - Others

2009 Product Showcase

Wireless Power (over distance)



- Dedicated source transmits common radio waves
  - Ambient sources augment when available: Cellular, TV, Radio, etc.
- Receiver
  - Captures the RF energy with an antenna
  - Converts the RF energy to the appropriate DC voltage
  - Stores the DC energy
- Energy transfer is controllable and predictable by design

Multiple forms of “wireless power”

Proximity

Induction

Micro-Contacts

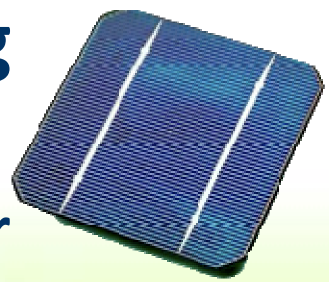
Wireless

Batteries

Radio Waves

Laser / Infrared

Harvesting



Solar

Vibration

Thermal

Radio Waves

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Ambient Energy Harvesting

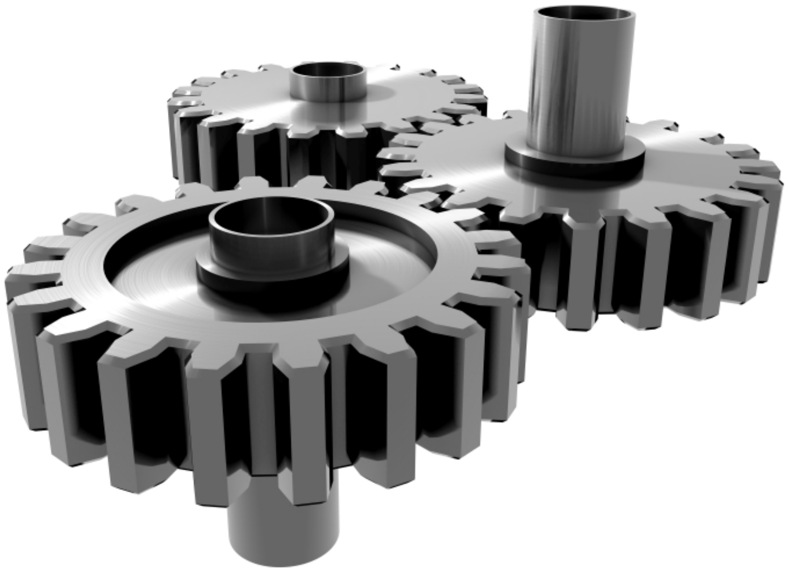
Benefits	Drawbacks
• "Free" Energy • Multiple methods with many sources – Solar – Vibration – Thermal – RF	• Energy received is dependent on the source • Sources may be predictable but they are uncontrollable • No source = No energy

EH is fine for some applications, but not all.

Dedicated Source – Controllable by Design

System Parameters

- RF Power Level
- Frequency
- Transmit Antenna
- Number of Transmitters
- Distance
- Receive Antenna
- Device Duty Cycle
- Cost



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Wireless Power Transfer with Radio Waves…

Governed by Friis Equation

$$P_R = P_T \frac{G_T(\theta_T,\phi_T)G_R(\theta_R,\phi_R)\lambda^2}{(4\pi r)^2}(1-|\Gamma_T|^2)(1-|\Gamma_R|^2)|\hat{\mathbf{p}}_T \bullet \hat{\mathbf{p}}_R|^2$$

P_R – received power

P_T – transmit power

$G_R(\theta_R,\phi_R)$ – angular dependent receiver gain

$G_T(\theta_T,\phi_T)$ – angular dependent transmitter gain

Γ_T – transmitter reflection coefficent

Γ_R – receiver reflection coefficent

$\hat{\mathbf{p}}_T$ – transmitter polarization vector

$\hat{\mathbf{p}}_R$ – receiver polarization vector

r – distance between the transmitter and receiver

λ – wavelength

…Simplified

After parameter selection equation simplifies to:

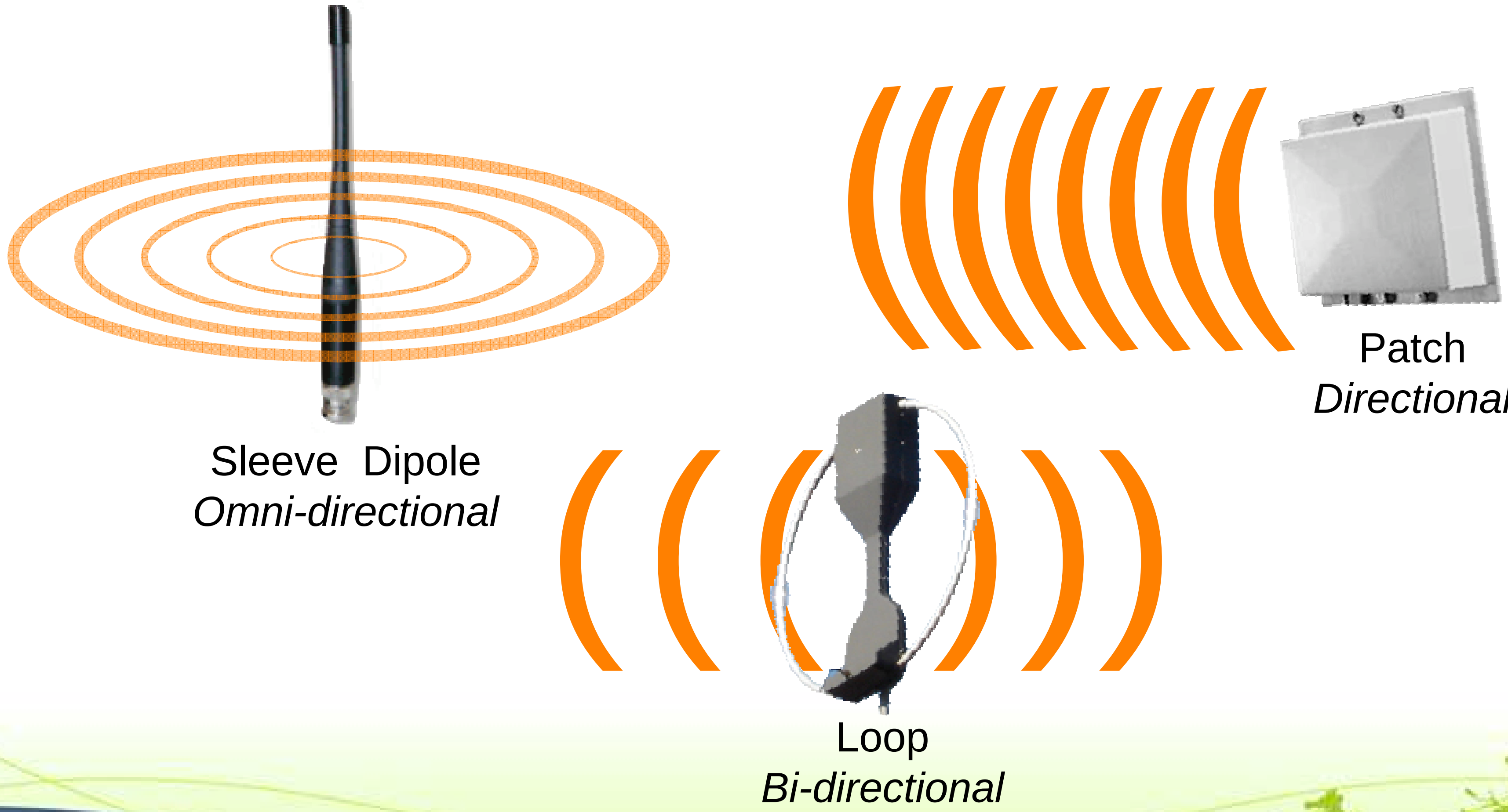
$$P_R = \frac{e\,C}{r^2}$$

C – System level constant

e – Efficiency of the harvester

∴ There are many parameters to adjust for system optimization but after selection, calculations are straight forward.

Antennas have a significant impact on power transfer

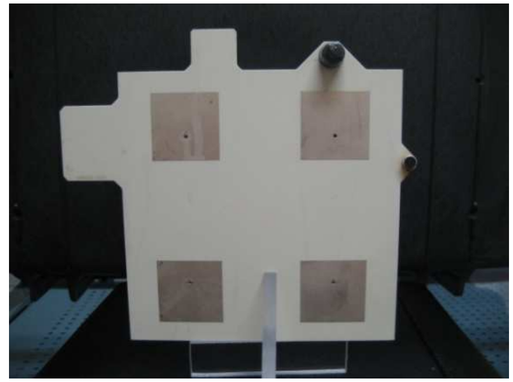


Sample Antennas Designs

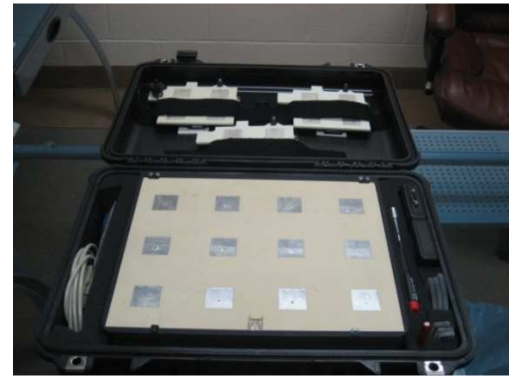
915 MHz
Sleeve Dipole

7.26 x 5.78cm

2.45GHz Patch
Gain =4.9
Beam= 32deg



2.45GHz Rx Array
Gain =12
Beam=~90deg



2.45GHz Tx Array
Gain =43
Beam = ~20deg

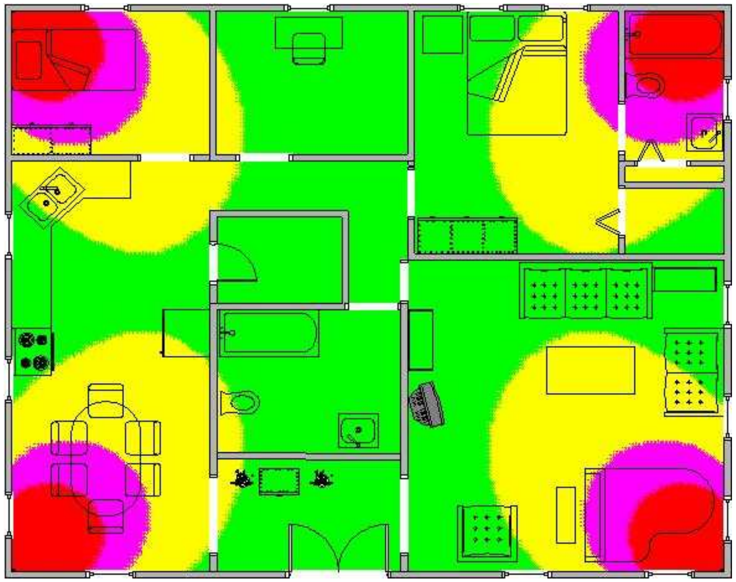
915 MHz Yagi
Gain = 6

915 MHz Short
Dipole

915 MHz Dipole

System Comparison

Achieving Higher Performance with Lower Power



- Single Tx
- One-to-Many
- Uneven coverage
- Higher Tx Power

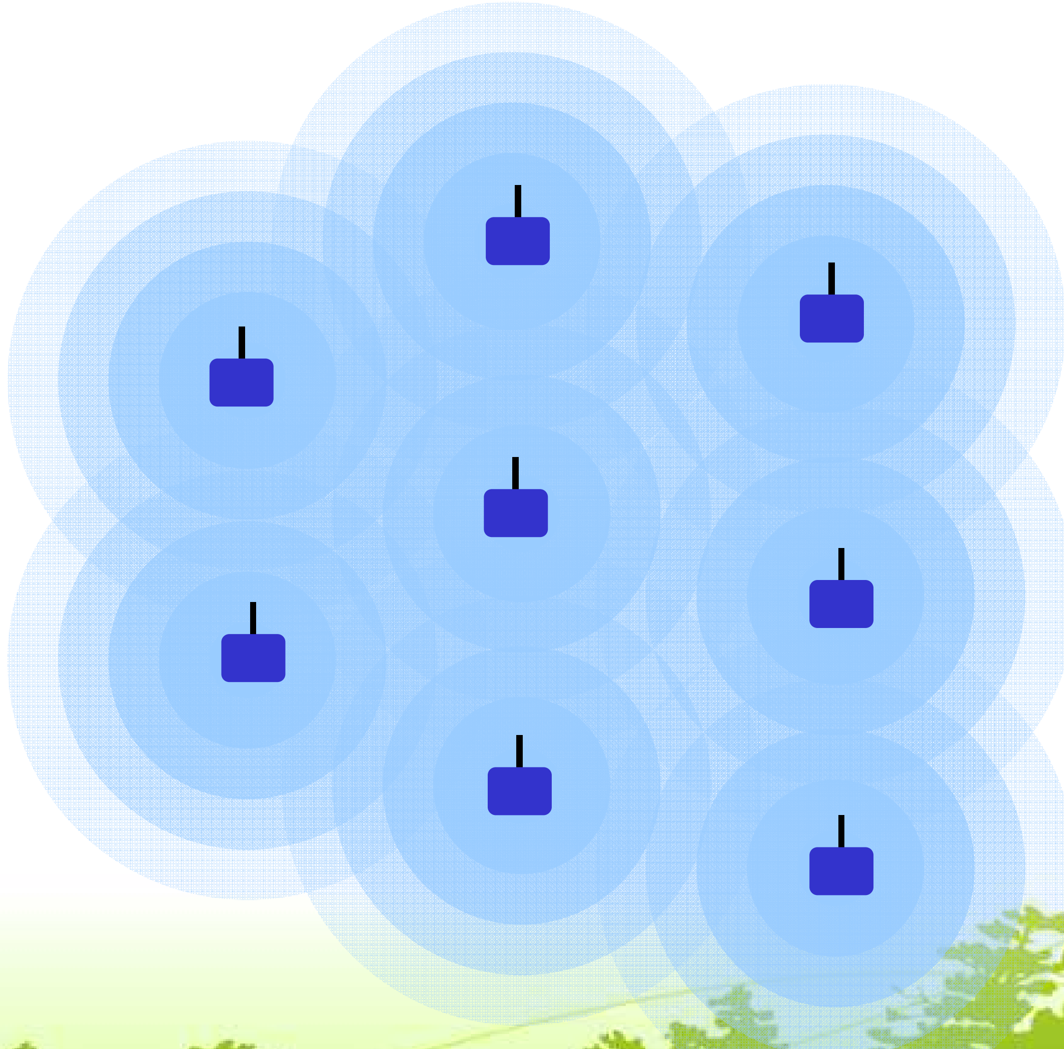
Minimum desired power

Not enough power

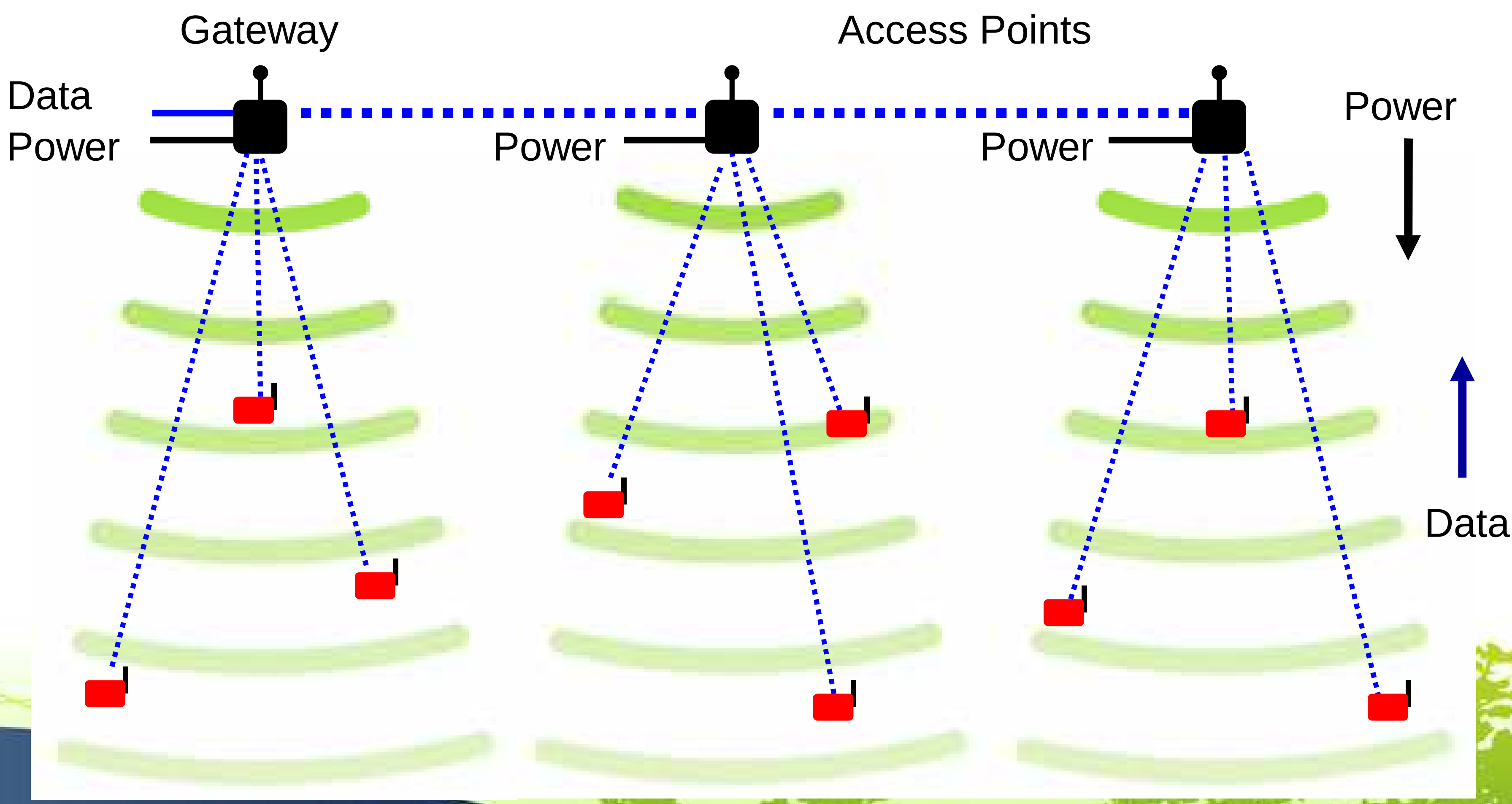
- Multiple Tx
- Any-to-Any
- Even coverage
- Lower total Tx power
- More robust

Wireless Power distribution is similar to a cellular network

- Any to Any
- Redundancy
- Enables Mobility
- Distributed
- Area Coverage



Vision: Unified Power and Communications for a Ubiquitous Sensor Network



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The Opportunity – Wireless Sensors

Applications	Benefits of Wireless Power
• Building automation	• Reduced wiring
• Energy management	• Sealed devices
• Location tracking	• Reduced maintenance
• Condition monitoring	• Controllable power
• Rotational Machinery	• Difficult locations

Application – Building Automation

- Indoor sensors
- Low light areas
- Behind walls
- Above ceilings

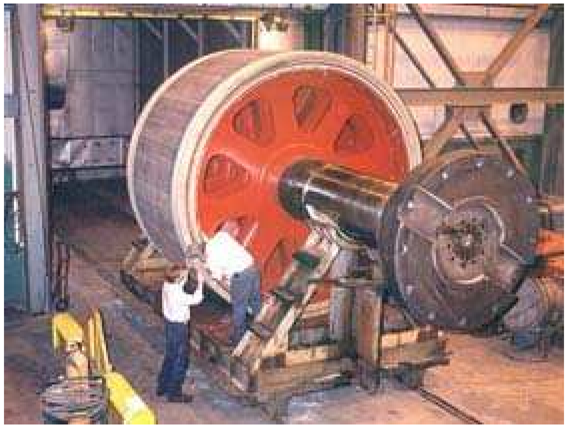
Application – Location Tracking

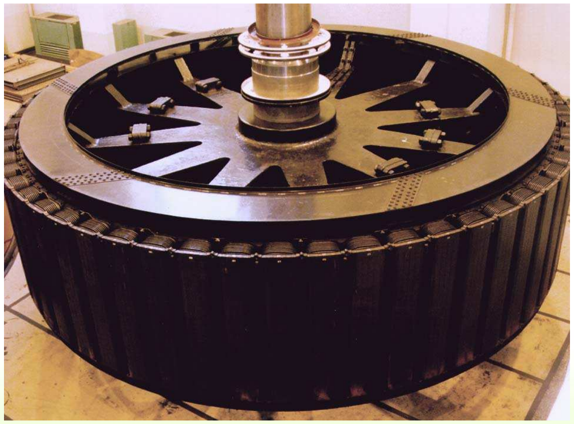
- Battery-Free Beacons
- Active Inside
- Inactive Outside
- Longer range "RFID"
- Battery-Free "RTLS"

Application – Industrial Monitoring

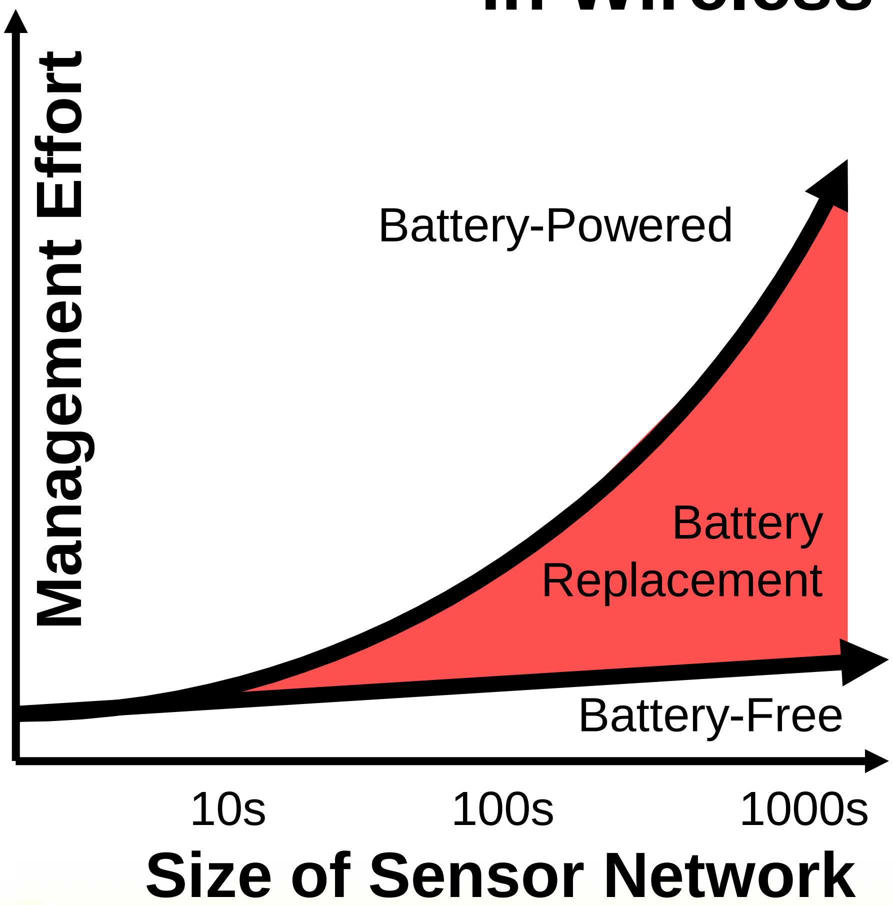
- Lack of vibration or heat source
- Hazardous areas
- Distance
- Battery trickle-charge
- Non-critical

Application – Rotating Machinery



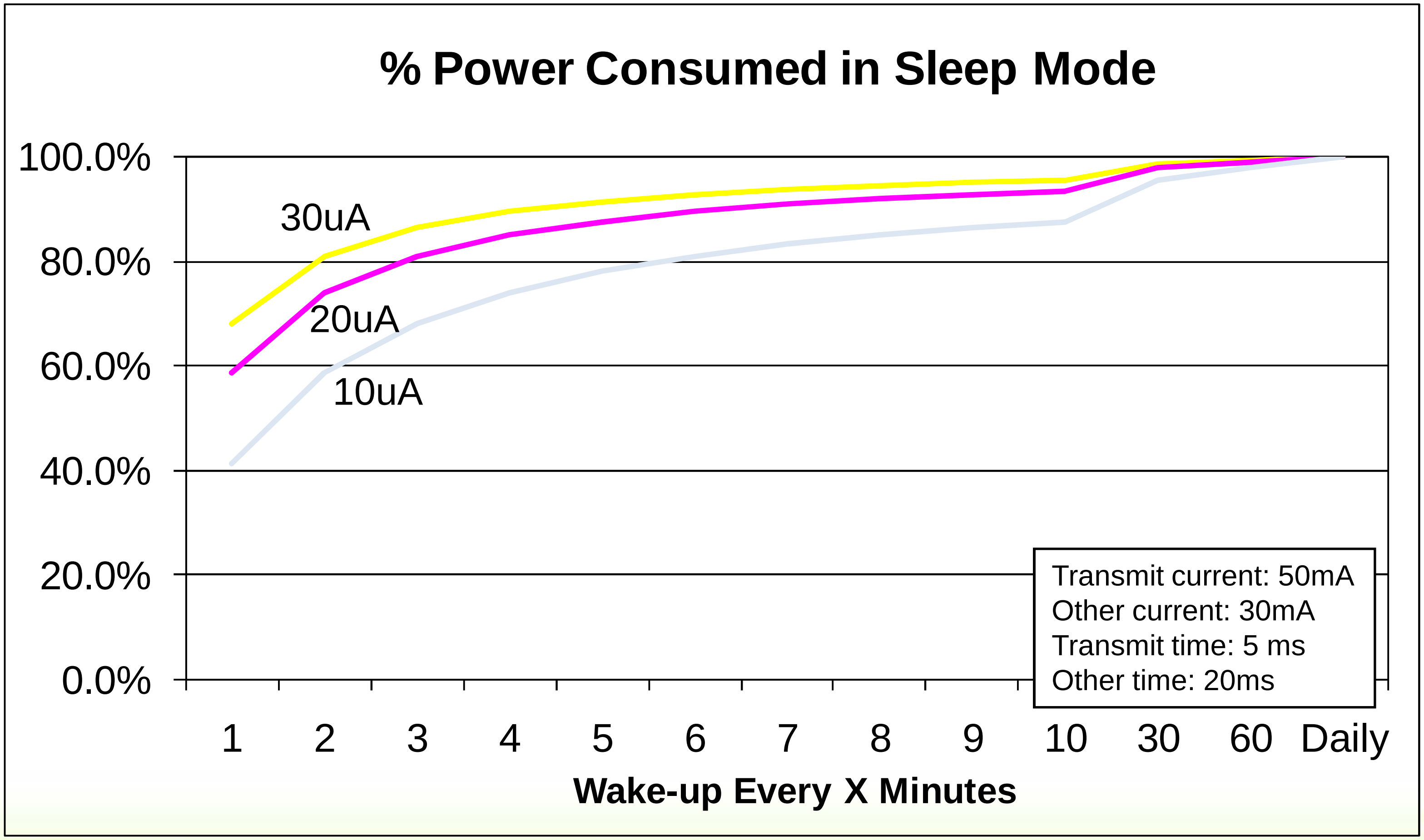


Issues with Primary Batteries in Wireless Sensor Networks



- Intentional constraints to save power
  - Design, Operation, Implementation
  - Majority of energy consumed sleeping
- Reliability
  - Retransmissions
  - Lifetime vs. cell/pack size
  - Shelf life?
  - Temperature performance
- Battery replacement cost
- Device location / placement
- Ecology
- Limitations of scale

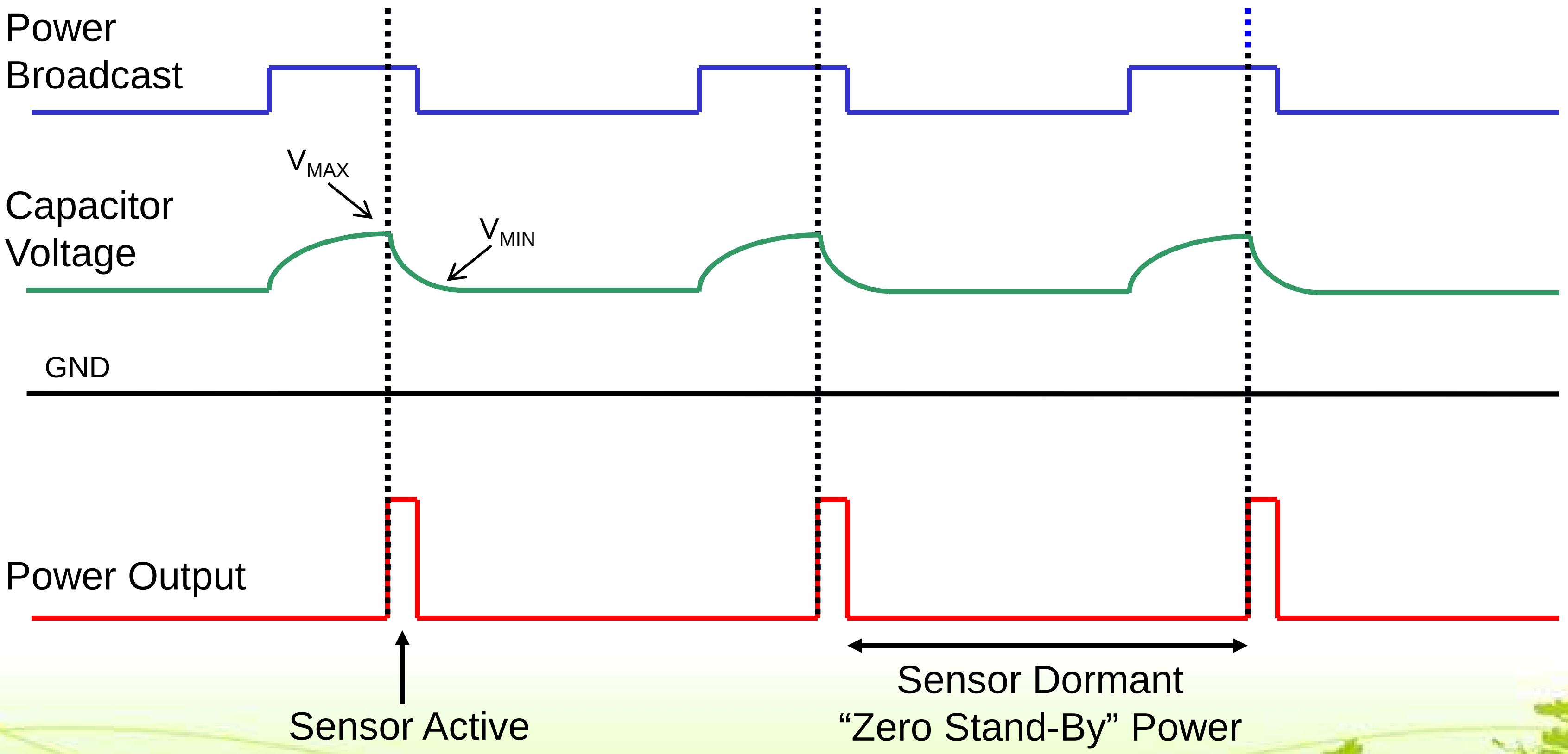
Majority of battery life is consumed in sleep mode



Average energy ≈ Sleep energy

Battery-Free Concept

Send power as needed - 1) On-Demand, 2) Scheduled, or 3) Continuously



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Battery-Free Reference System

Simple “2 wire” hardware integration for any RF module

Sleeve Dipole Antenna

Integrated, 915 MHz

P2100 Powerharvester™ Module

High Efficiency

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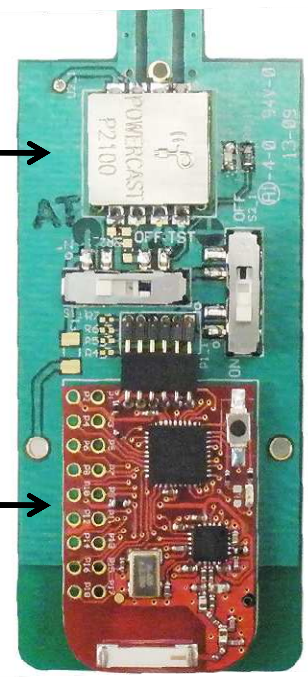
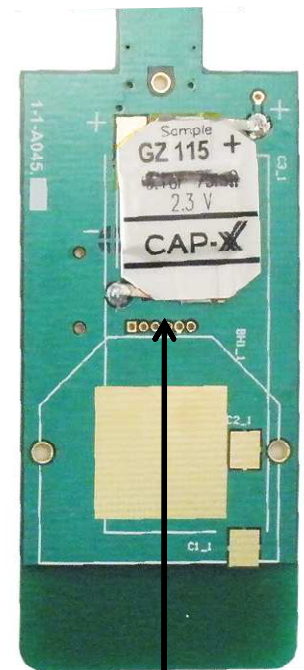
Front



Back



TI eZ430-RF2500T

Low Power

CAP-XX GZ115

Small Form Factor

Powerharvester™ Module

P2100 – 915MHz, Charge & Fire

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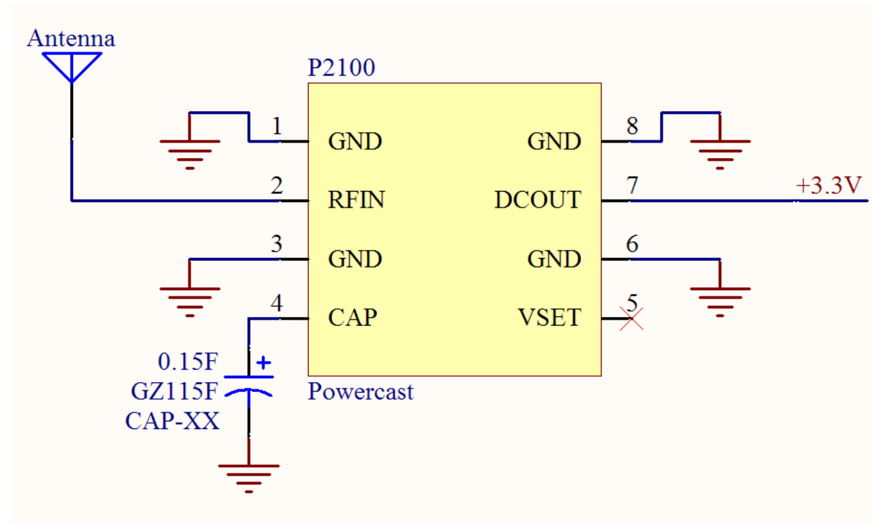
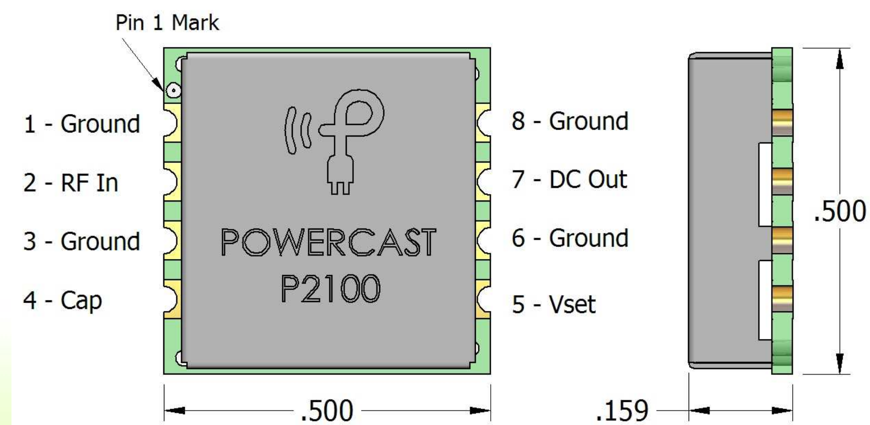
Features

- High Conversion Efficiency
- Internal Charge Management
- High Sensitivity
- Configurable Output Voltage
- 50mA Output Current
- Capacitor Overvoltage Protection
- Internally Matched to 50 ohms
- Low Quiescent Current (<1µA)
- Simple Integration
- Small Footprint





Energy Storage

Choosing the Supercap Value

Energy Available

$$E = \frac{1}{2}C\left(V_{MAX}^2 - V_{MIN}^2\right) = \frac{1}{2}C\left(1.16^2 - 1.03^2\right)$$

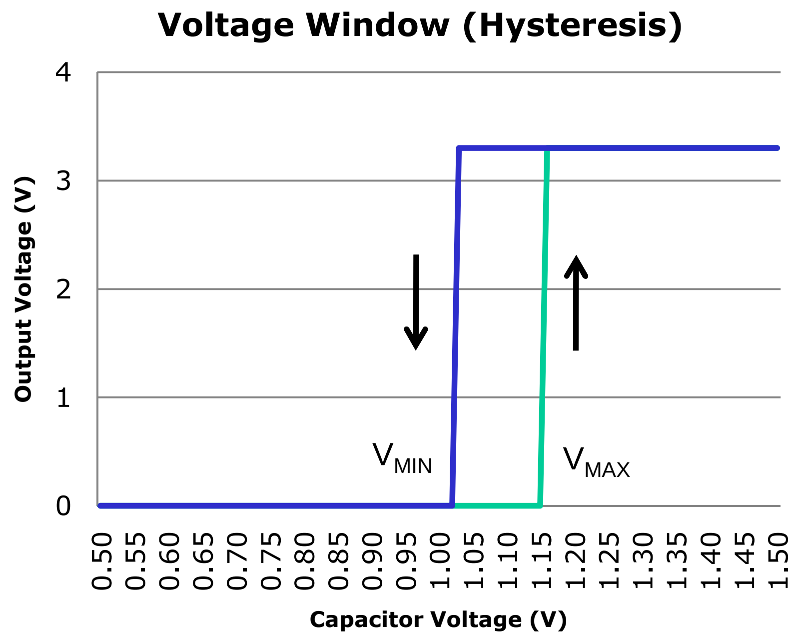
$$E = 0.142C$$

Capacitor Value

$C = 7.02E/e$ $\quad e \approx 0.82$ DC-DC conversion efficiency

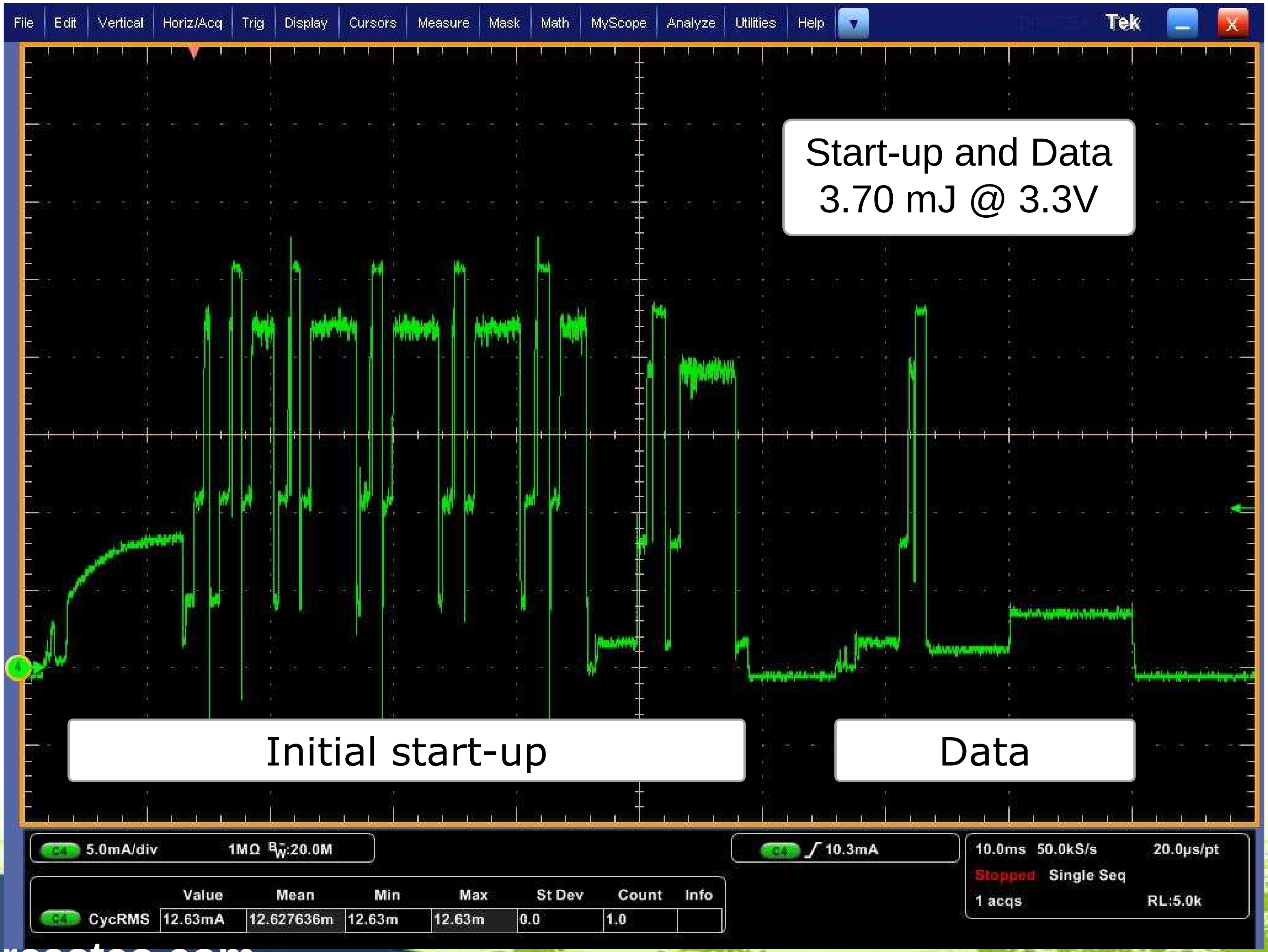
$C = 8.57E$

E = required load energy



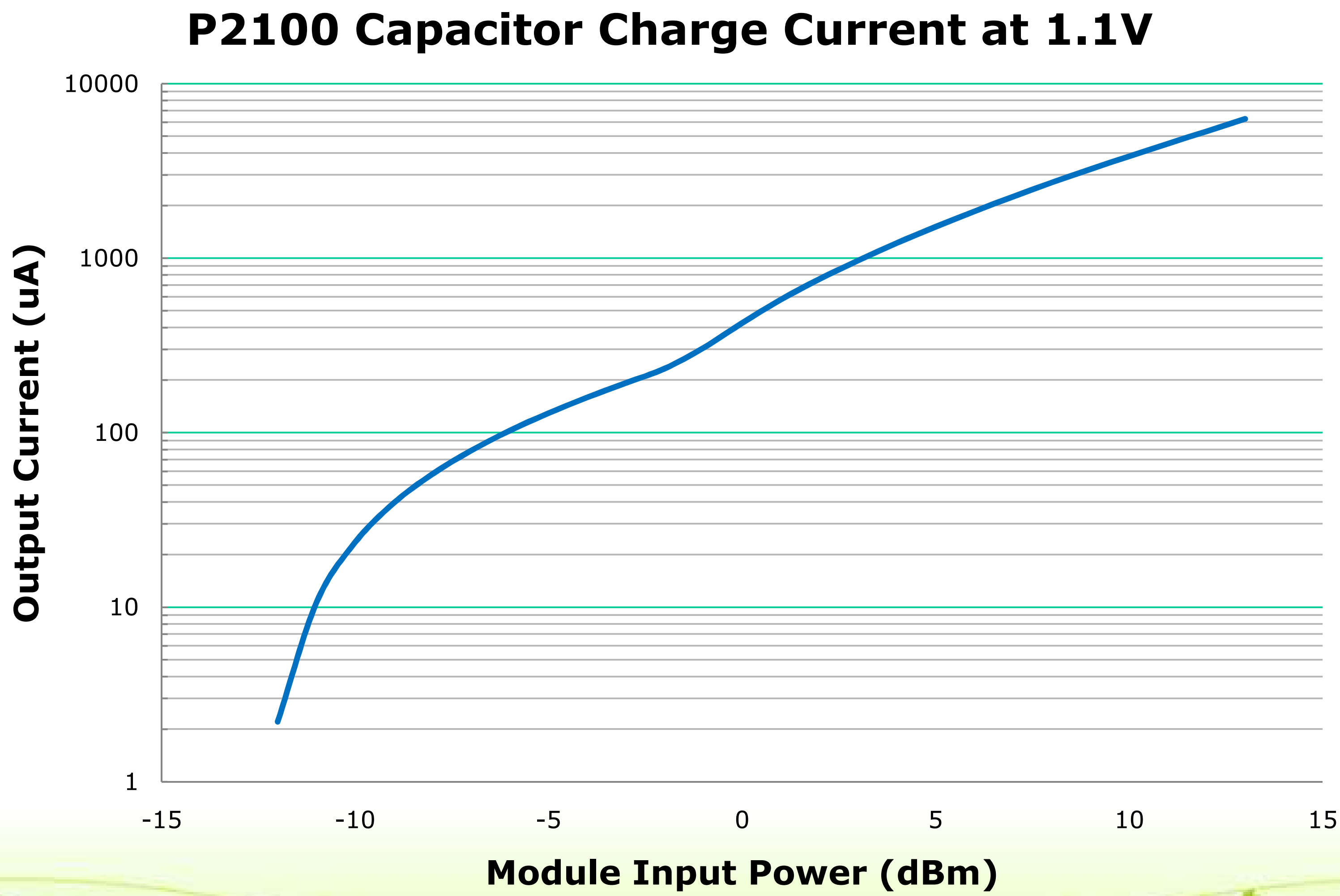
GZ115 cap size = 0.16F (measured)
Stored energy = 22.7 mJ

TI eZ430-RF2500T

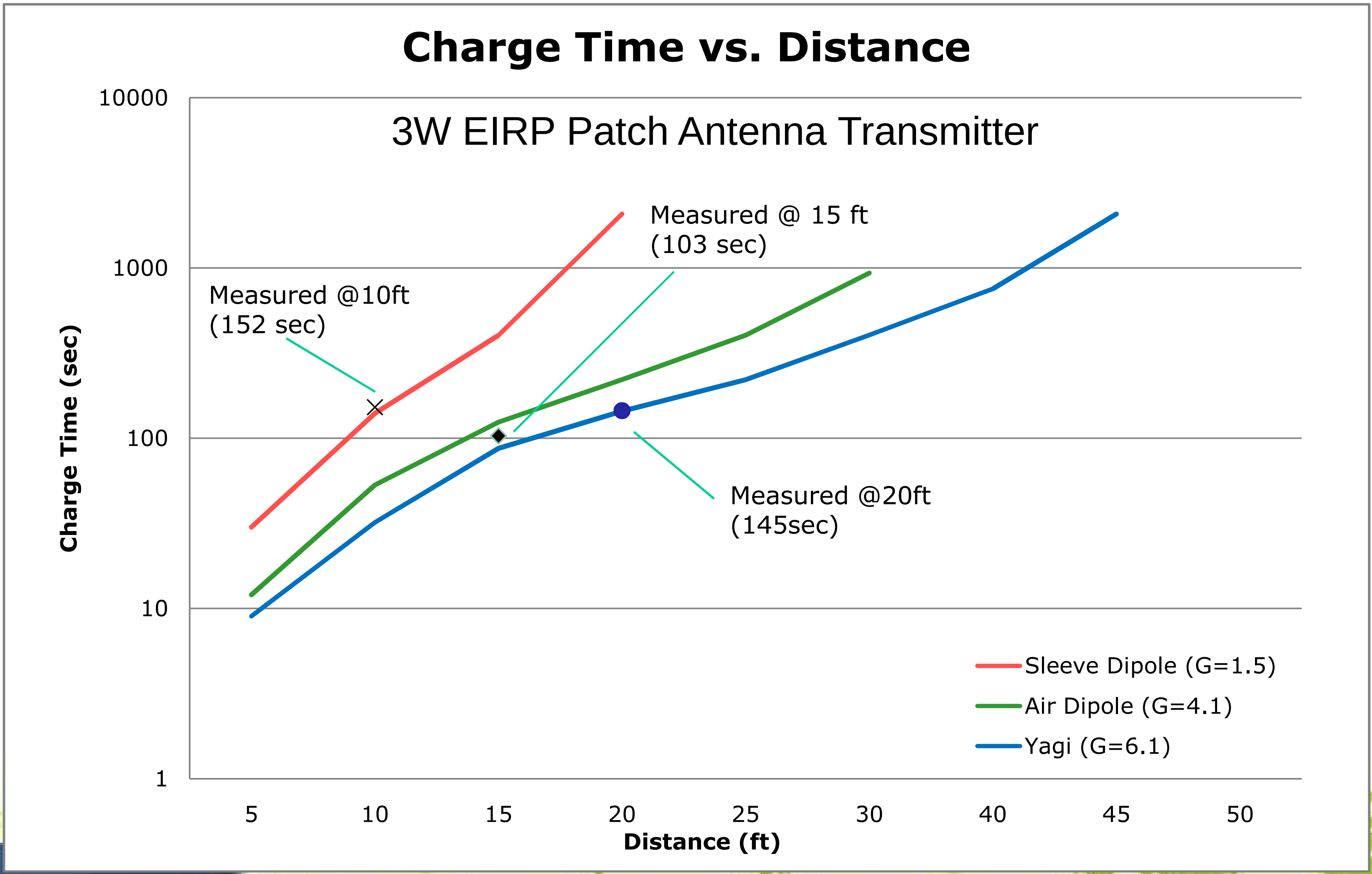


Note: V1.5 Software

P2100 Charge Current

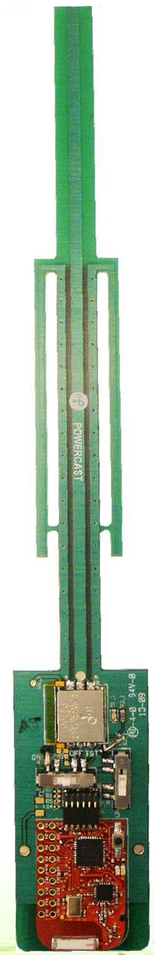


Energy Harvesting Performance



Reference System Summary

- Stored energy = 22.7 mJ
- Usable energy = 18.6 mJ (current design)
- Initial start-up and data transmission = 3.7 mJ
- 20ft range (3W source, sleeve-dipole Rx antenna)
- Temperature and voltage sensing
- Extremely long life – NO BATTERIES!!!



Reference System On-Going Efforts

Optimizing Performance

- Reduce the capacitor size by modifying the software start-up sequence
  - Target joule usage of 100uJ will require less than 1000uF capacitor
- Improve charge management efficiency
- Lower the harvester sensitivity to extend range

Targets

- 100uJ per activation
- Credit card form factor
- 100+ ft range (2-4X increase)
- 3Q09 timeframe

Summary

- Wireless power via RF energy harvesting is capable of powering wireless sensors over distance
- Capacitors offer an attractive alternative to disposable batteries
- Wireless power uniquely provides controllable power options: on-demand, scheduled, continuous
- Zero Stand-By operation eliminates design concerns of driving down sleep current:

  Average Current ≈ Sleep Current ≈ 0

Thank You

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