TOP ELECTRONICS

‘Battery-Free’ IoT with Lowest Power Wireless Technologies

Forever Connected, Anywhere

TOP-electronics, Arco Snoey

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About TOP-electronics

Markets for battery-free IoT, battery challenge & Energy Harvesting Products

Redefining battery life by using 3 technology vectors

SoC with Energy Harvesting & Power Management Unit - PMU

Energy Harvesting Source options

Summery: how to start your battery free design

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TOP ELECTRONICS

About TOP-electronics

Technology-provider

TOP-electronics is a technology-provider, specialized distributor and representative in electronic components, modules and solutions in several product groups, such as:

- ► Wireless and IoT
- ► Sensors
- ► Precision Analog
- ► Motion Control
- ► and more …

Motivated, experienced team

TOP-electronics has a motivated, experienced team which works directly with our customers' engineers. TOP-electronics can support on technical and logistic level at local markets.

Global local partner, with offices in:

- ► The Netherlands
- ► Israel
- ► Hong Kong
- ► USA

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We love to connect… engineers and technology

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Markets for battery-free IoT

The battery challenge for IoT

Billions of IoT devices are already deployed with many more IoT devices soon to join them

Many will be mobile or deployed where wired power is not feasible

Reliance on batteries is a huge environmental and operational issue

A few billion IoT devices with a three year battery life = 2 million batteries replaced every day!

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Energy Harvesting Products

Energy Harvesting is out there today in products across the consumer, commercial and industrial sectors

Products that are battery free or never require a battery change

As power consumption for devices drops, adding energy harvesting becomes more feasible

Energy Harvesting is not all or nothing – even extending battery life has real benefits for the end user.

Solar power harvesting keyboard

Watch
Thermal harvesting by body heating

Use of PV cells to eliminate batteries from desktop calculator

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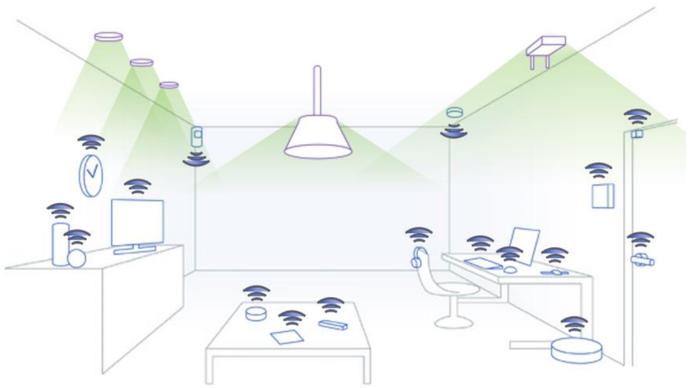
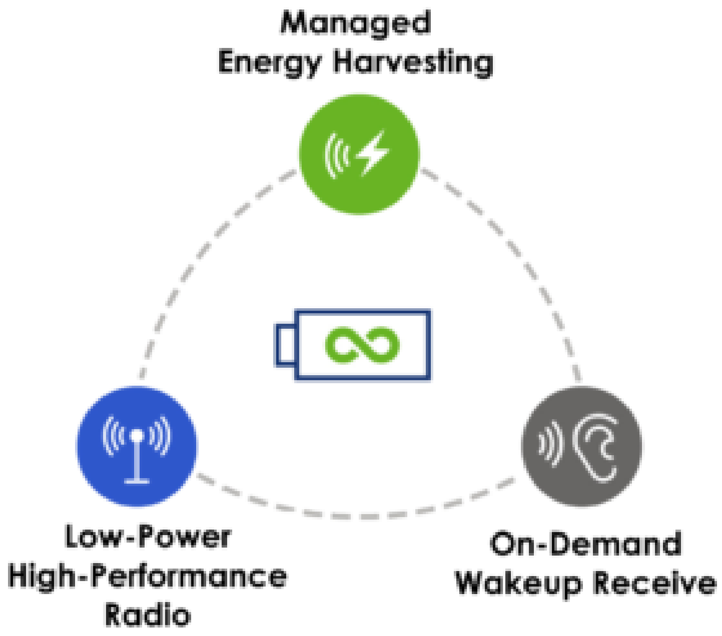
Redefining Battery Life





How can we create the longest battery life solutions for IoT?

By using three technology vectors:

Lowest Power Radio
Lowest System Power, 5 – 10 x Lower Power

On-demand Wake Up
10 – 100 x Lower Power

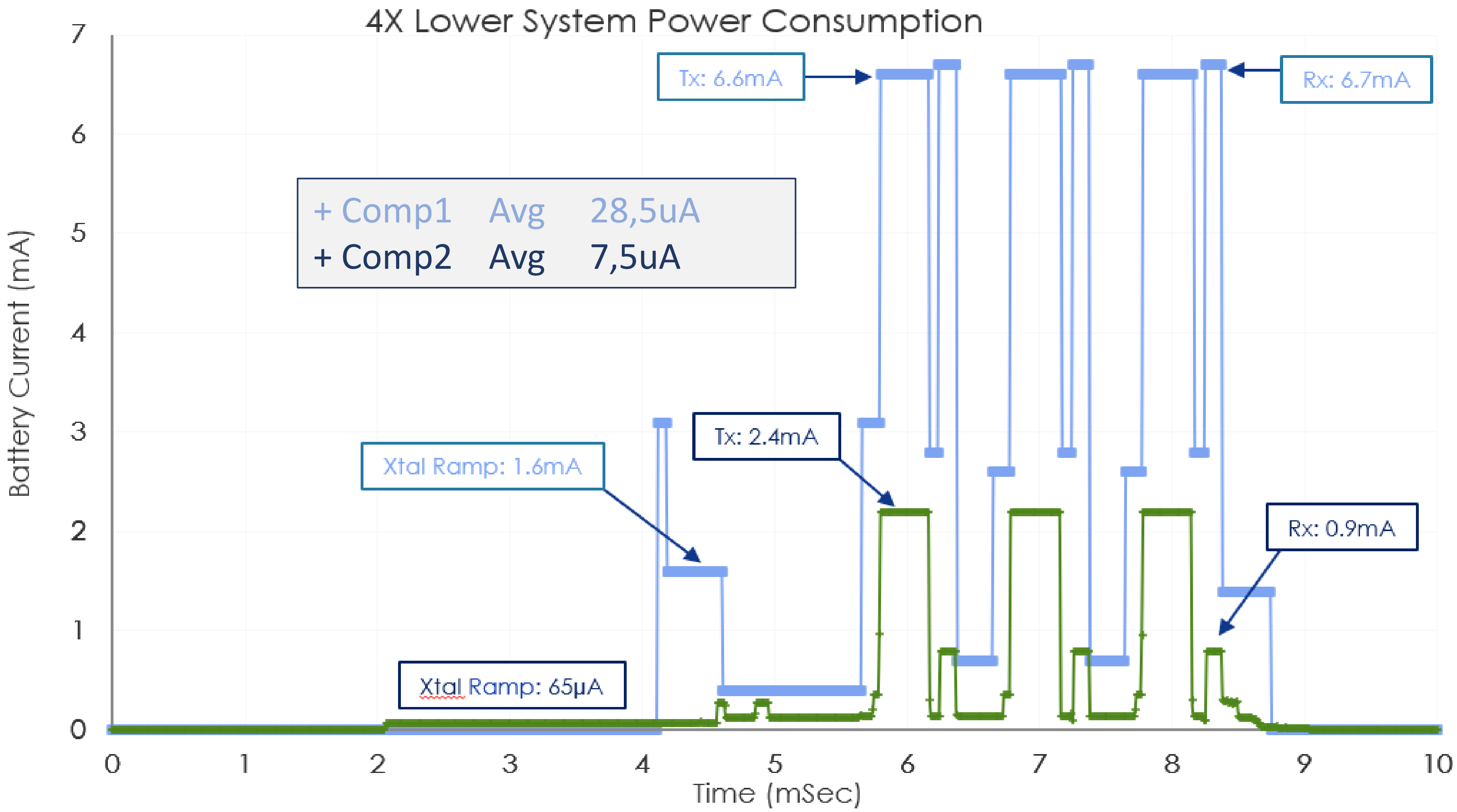
Managed Energy Harvesting
Managed Harvesting Forever Battery Life

A technology inflection point has been reached.

The power usage is so low that Energy Harvesting is a viable power source for standards-compliant wireless IoT devices.

Lowest Power Radio

The first technology is the ***Lowest Power Radio*** implementation of the new Bluetooth 5 wireless platform, to achieve radical power performance improvements while maintaining full standards compliance.



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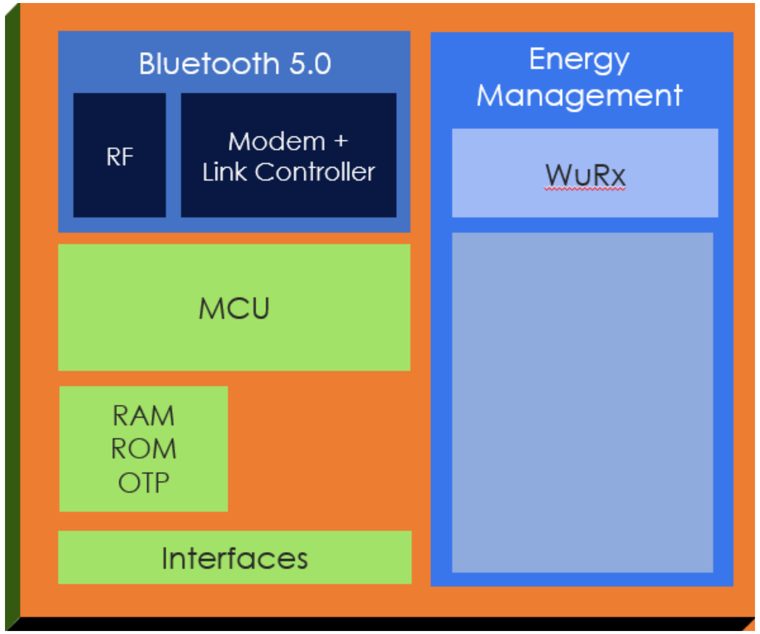
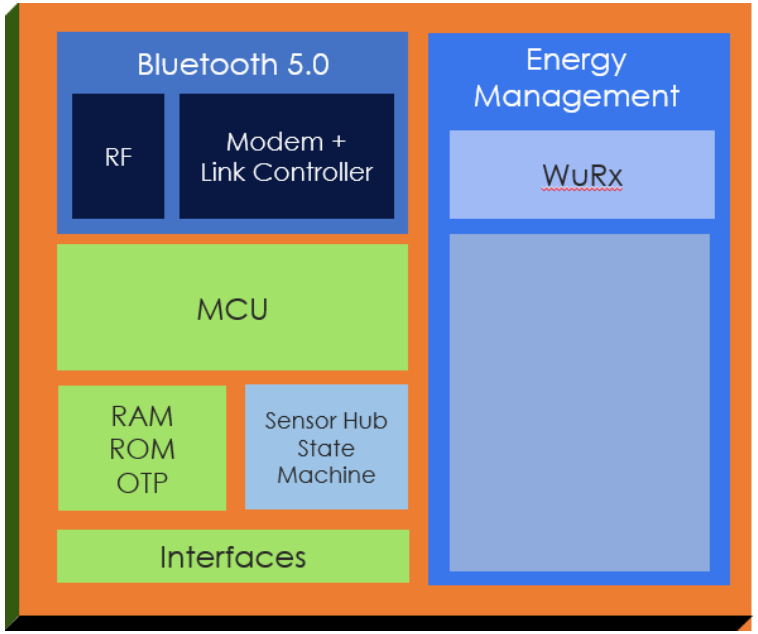
On-demand Wake Up

The second technology is the **On-demand Wake Up** and is created by implementing two levels of listening (two sets of ears).

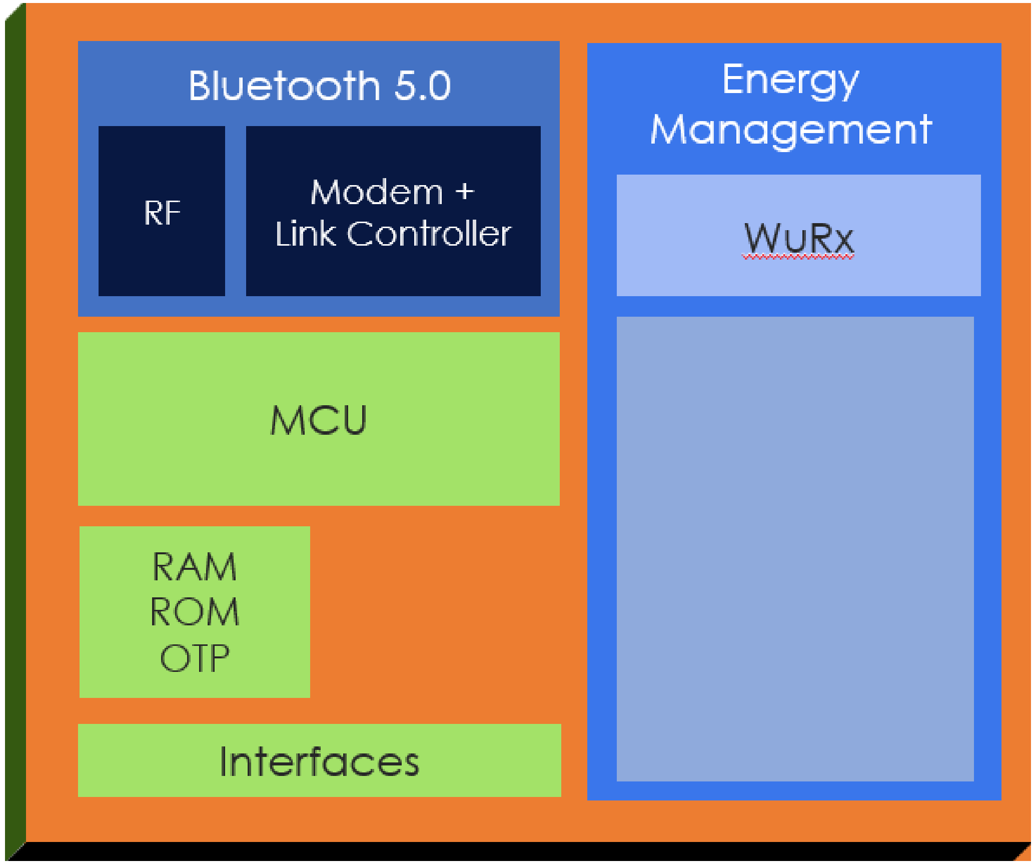
- One set provides the lowest level of “radio consciousness”.
  Listening in a very slight “conscious” state to perceive incoming transmissions.

- The other set is a deep sleeper, waking infrequently.
  Only alerted to incoming signal transmissions by the light sleeping partner.





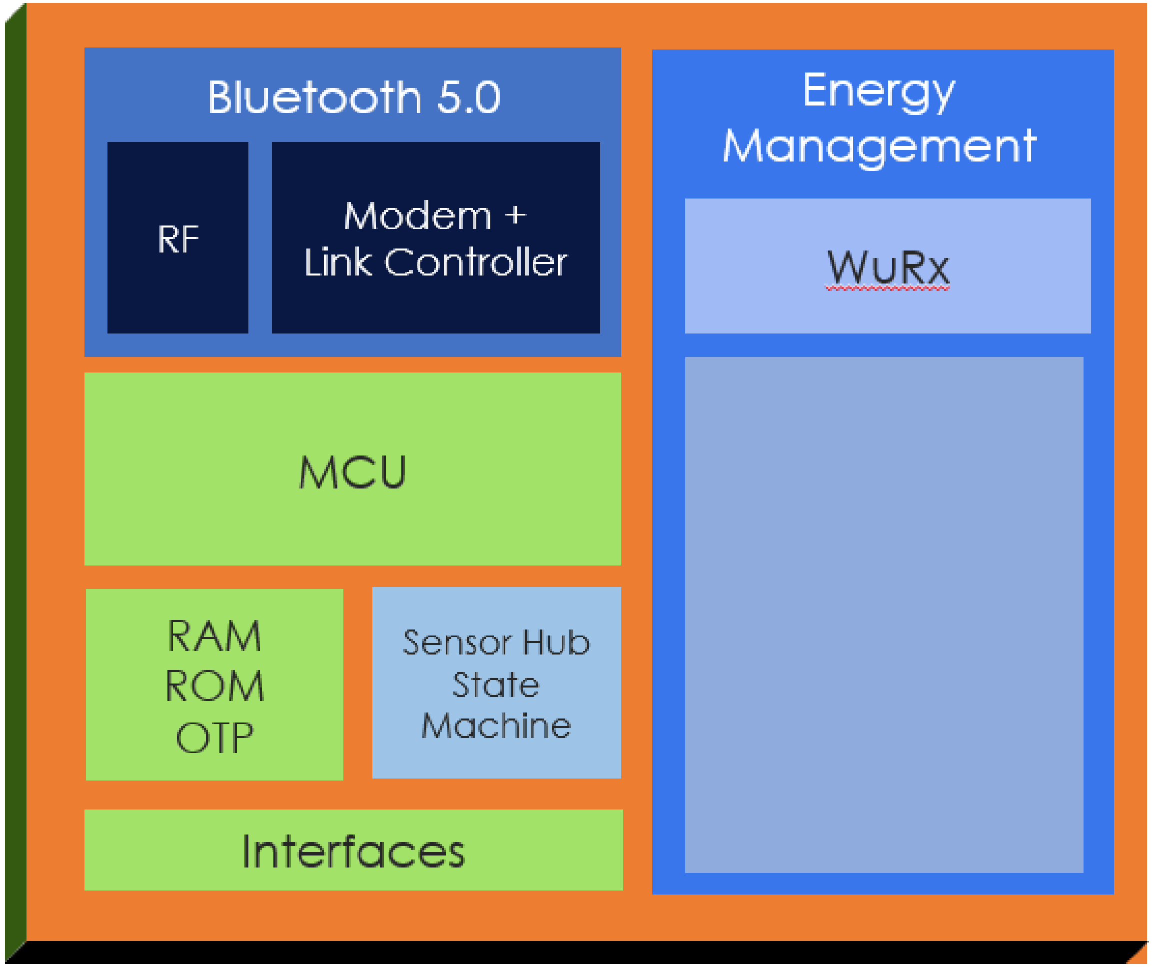
Differentiator – Advanced Power Management



- WuRx -- On Demand Nearfield Wakeup Receiver
  - Runs when the system-on-a-chip (SoC) solution is in Hibernation Mode (800nA)
  - except for…

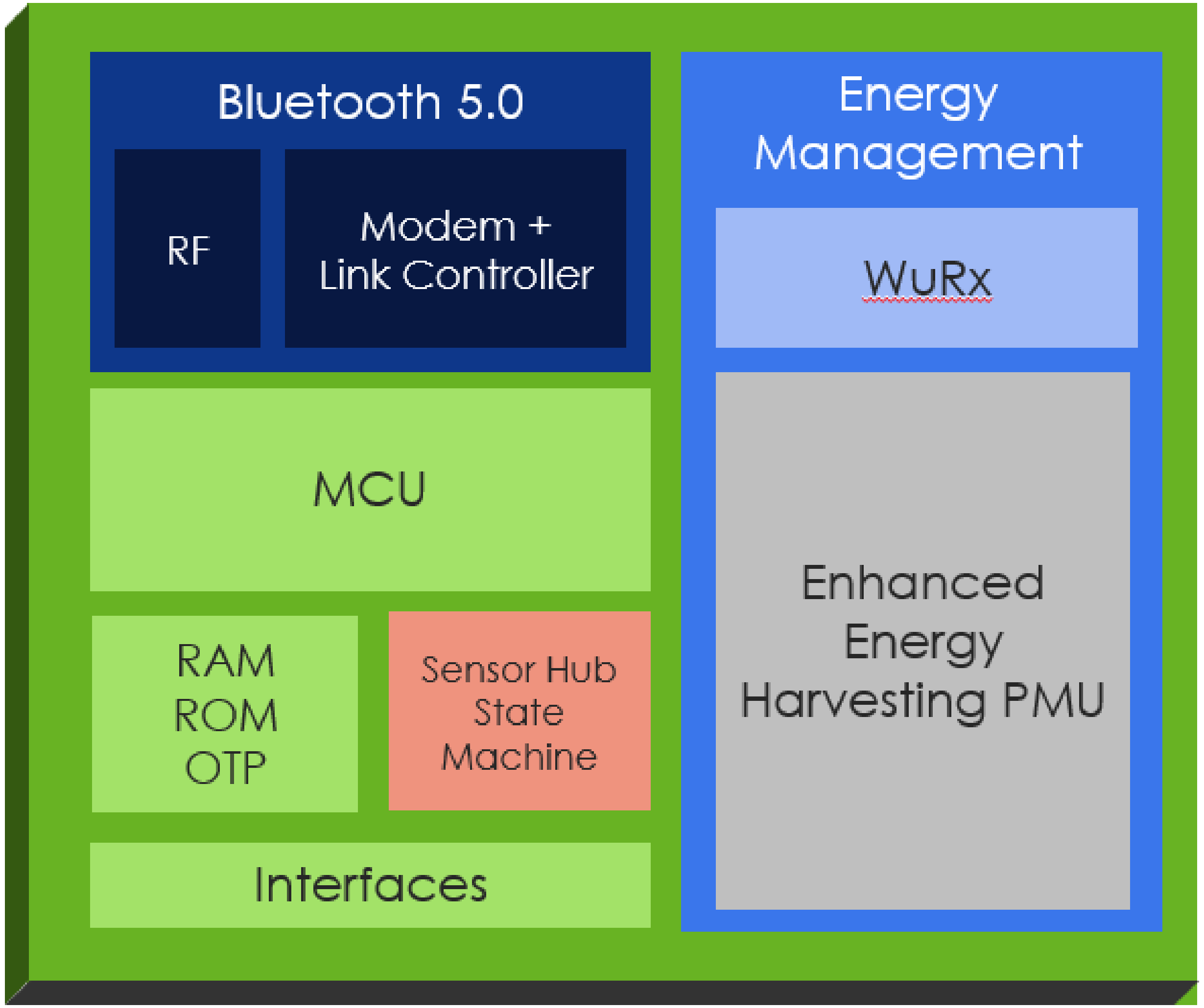
    a specialized ultralow power receiver (300nA)
- Continuously listens for a "magic" packet
  - A standard BT packet transmitted from any BLE chip – with a specific payload
- When received the WuRx will wake up the solution
- Fine level of node addressing granularity
- Huge improvement in response time in densely beaconing environments
- Distance operation dependent on Tx power from sending device

Differentiator – Advanced Power Management



- Smart Sensor Hub : Event Based Sleep & Wake Up Optimization
  - Only blocks that interface to sensors are powered (800nA)
  - Write to flash without full power up
  - KEY: Exception events (high or low out of bounds) can wake entire chip
- Useful in home and industrial automation applications which require occasional connectivity

Differentiator – Energy Harvesting



- Integrated Power Management Unit (PMU) manages all energy sources and storage elements
- On-chip RF harvesting rectifier and separate external harvesting source input
- Interfaces for battery (regular or rechargeable) and capacitor/supercapacitor storage

Managed Energy Harvesting

The third technology is **Managed Energy Harvesting** and this brings a new level of **battery performance**, adapting system alertness to the environment.

Instead of relying on ambient energy harvesting, which is inherently less predictable, we favor a known energy source that can be controlled to guarantee robust functionality while minimizing the system dependence on battery power. The SoC supports Multiple Types of Harvesting.

- **RF** — Sub GHz to 2.4GHz, 10s of ft away
- **Light** — Low indoor (<200 lux) to outdoor light levels
- **Thermal** — Thermal gradient from any heat source
- **Mechanical** — Single button press generates multiple beacons

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Summery: how to start your battery free design

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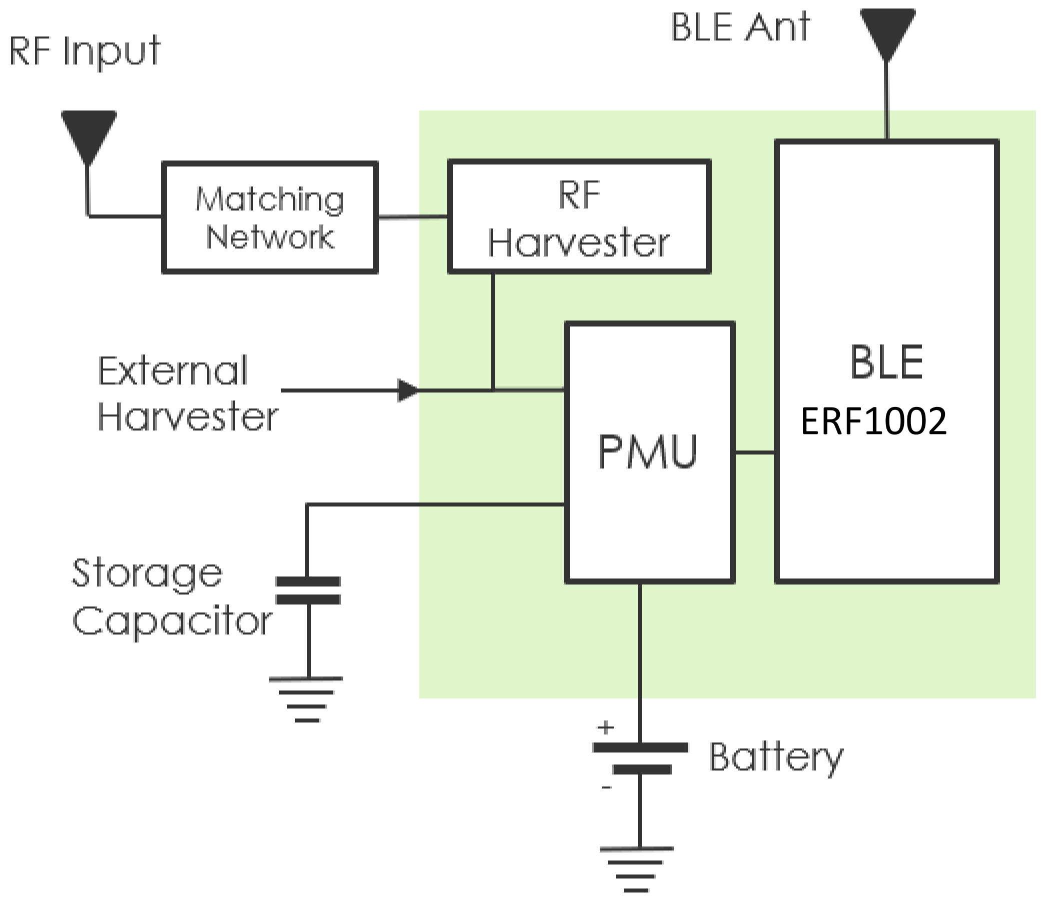
SoC with Energy Harvesting and Power Management Unit

- Power Management Unit manages multiple energy inputs
- On-chip RF Harvester can be tuned to frequencies between 800 MHz and 2.5 GHz
- Separate input for harvested energy from external sources (PV, Thermal, Mechanical)
- Storage capacitor (or rechargeable battery) collects excess harvested energy
- Standard or rechargeable batteries between 1.1V and 3.3 V supported
- PMU prioritizes energy requests across available sources to maximize battery life :

Harvested → Stored → Battery



Energy Storage Options

First, we will discuss the supported energy storage options before describing the operation of the PMU for each storage option.

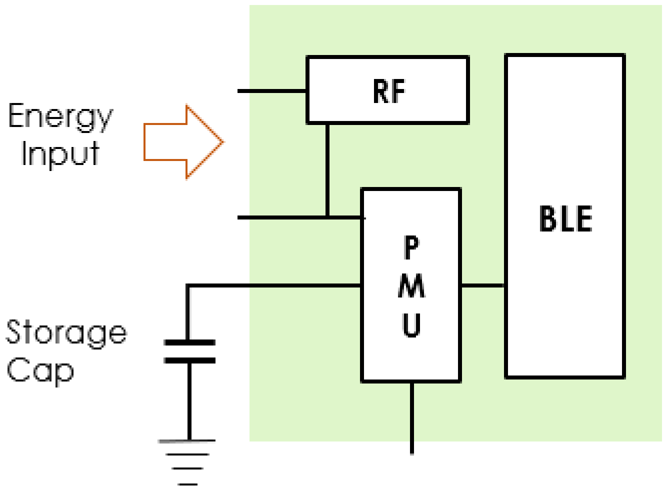
There are three possible energy storage configurations for the PMU:

- battery free
- standard battery with extended life
- rechargeable battery

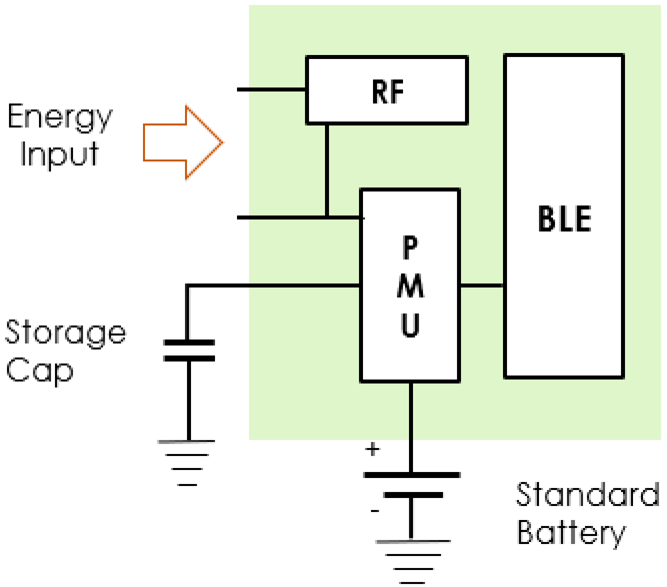
Factors such as the amount of energy available from harvesting, storage requirements, and the power profile of the application determine the feasibility of one or more of these configurations.

SoC - Energy Storage Configurations

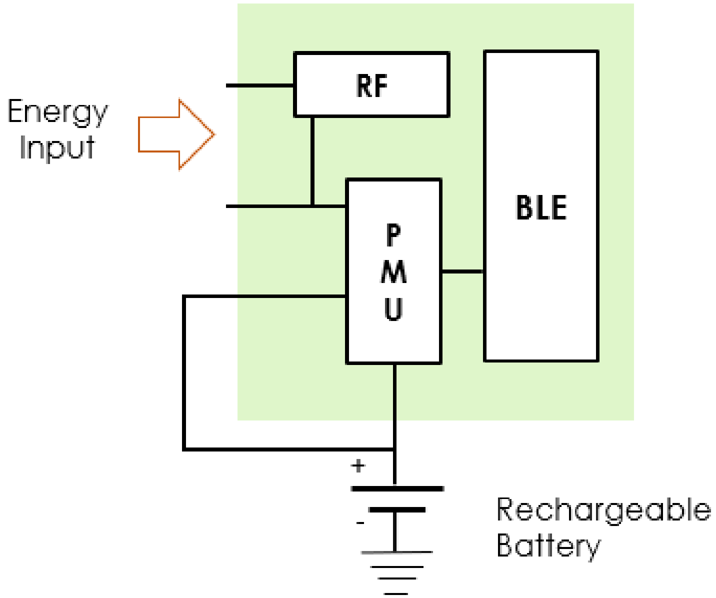
Battery Free



Extended Battery Life



"Forever" Battery Life



Temporary storage of harvested energy in capacitor

Good for beacon applications

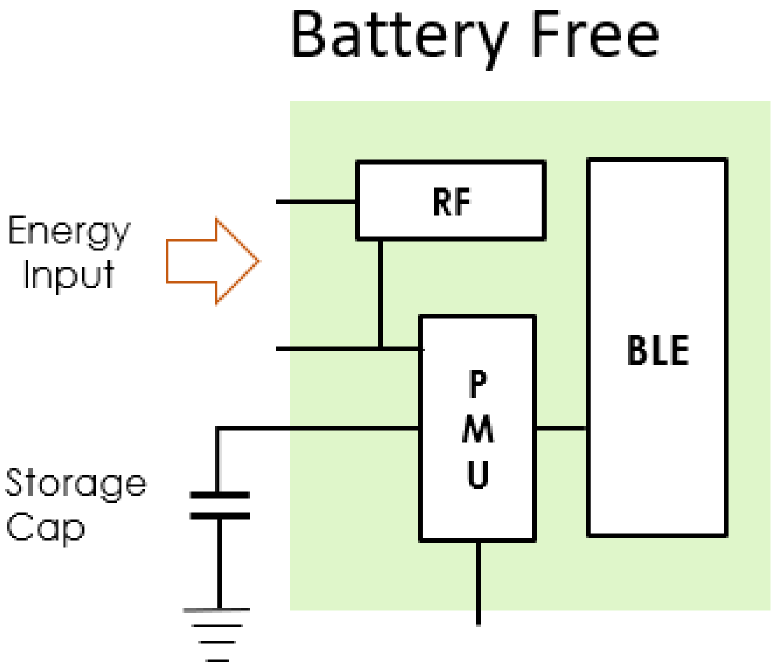
Extending battery life with harvesting

Harvested and stored energy used before battery

Excess harvested energy recharges battery

PMU manages battery charging

Battery Free



Being able to completely eliminate the battery from a product is only possible when sufficient energy is available through harvesting to meet both the startup and steady state power requirements of the application.

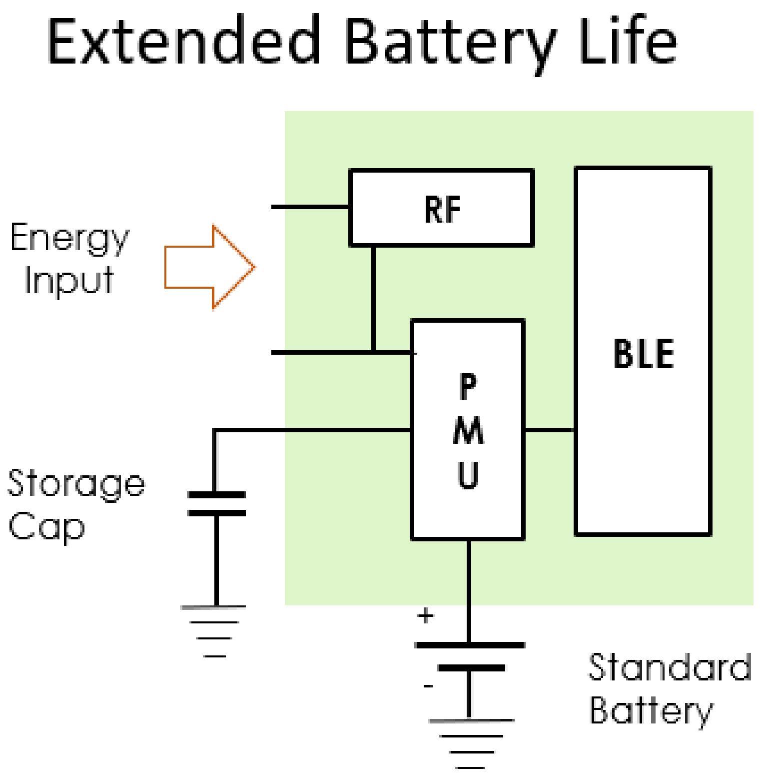
When there is no battery connected to VBAT, the PMU will rely only on energy harvesting to run the SoC and charge a storage capacitor connected to VSTORE when excess energy is available.

During periods of insufficient energy harvesting the PMU will operate the SoC from the energy available on VSTORE until such time as the VSTORE level drops below a threshold sufficient for Bluetooth LE transmissions.

Once this happens the PMU will shut the CPU down until sufficient energy has been harvested to continue operation. In a battery free configuration sizing of the storage capacitor is an important design consideration.

A larger storage capacitor will require a longer time to reach the SoC's operational threshold.

Standard Battery - Extended Battery Life



The PMU also supports operation from single or dual cell battery voltages between 1.1V and 3.3V in conjunction with energy harvesting.

In this configuration the PMU will use harvested energy to operate the ATM3 and store excess energy to a capacitor connected to VSTORE just as in a battery free configuration.

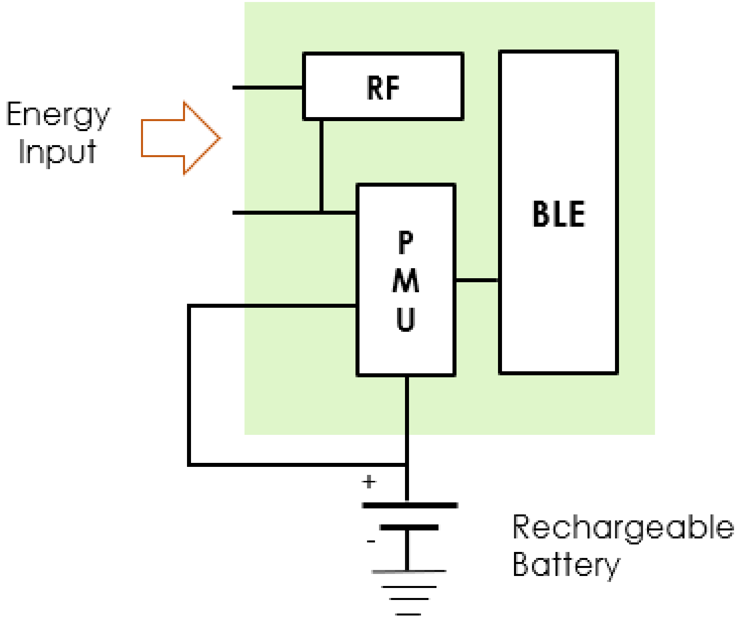
The battery is only used when there is insufficient energy available from VSTORE and energy harvesting.

The battery will also cold start the ATM3 immediately instead of waiting for sufficient VSTORE energy as required in battery free designs.

The primary application for using a standard battery with energy harvesting is for battery life extension.

Rechargeable Battery

“Forever” Battery Life



Using a rechargeable battery in conjunction with energy harvesting offers the possibility of removing the need to ever change the battery or plug in the device periodically for recharging.

Use of rechargeable battery as a storage element is preferred in cases when the harvested energy source may be too intermittent to ensure a capacitor will always have sufficient charge to startup and run the application, or where the startup time requirements do not allow enough time for energy harvesting to charge a capacitor in a battery free configuration.

The rechargeable battery is connected to VSTORE through a series resistor for charging when excess harvested energy is available, and to VBAT directly as the power source when harvested energy is not immediately available.

When the PMU is set for rechargeable battery operation there are configurable settings for operational and charging levels that ensure proper operation and protection of the battery.

The PMU is only able to support single and double cell rechargeable batteries up to 3.3 V.

Support for charging at higher voltages requires additional charging hardware external to the SoC.

Cold Start behavior of the PMU

PMU Operation

Booting and operation of the SoC requires a specific level of available energy at either VBAT, VSTORE, or HARV_OUT.

Cold Start

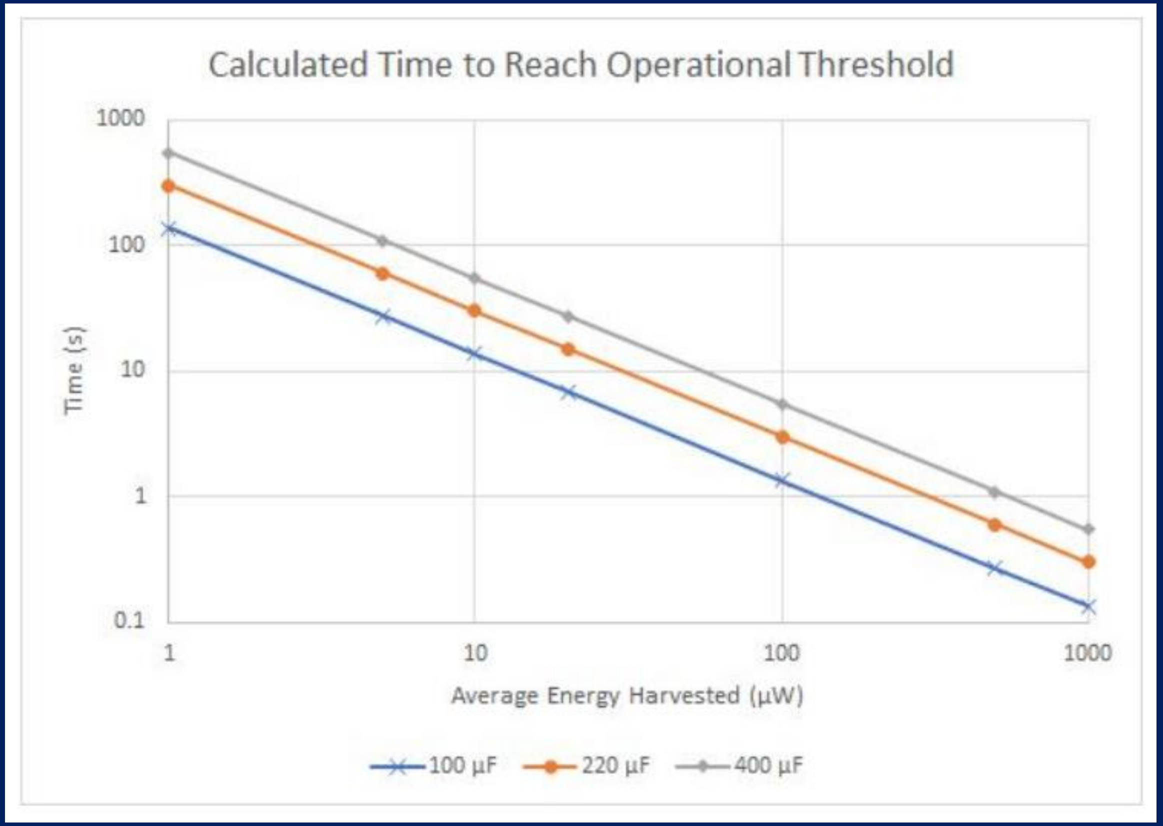
In a battery free configuration, the PMU can cold start if the voltage level at HARV_OUT is above 1.65V and the available input power is at least 30μW.

The PMU will begin to harvest and direct energy to VSTORE until it reaches its operational threshold.

The time it takes for VSTORE to reach this threshold will depend on the size of the capacitor connected to VSTORE and the amount of energy harvested.

As different applications will have different start up time requirements, it is important to understand how the sizing of the storage capacitor and the expected level of harvested energy will impact the behavior of the end product.

The figure below is a calculation of the time for VSTORE to reach this threshold, based on the capacitor size (100, 220, and 400 μF), the rate at which energy is harvested (in μW) and the PMU's storage efficiency.



Configurations including a battery

The PMU will start without any latency or input power requirement.

When VBAT is insufficient, the PMU will need some harvested energy to begin operating.

Configurations including a non-rechargeable battery

Undervoltage on VBAT / the battery is "dead" and need to be replaced.

The PMU will operate in a battery free mode relying on energy harvesting & capacitive storage on VSTORE.

This may severely limit or even prevent operation of the device.

Note that in this state the rechargeable battery may require a significant amount of time for the battery to recharge to an operational level.

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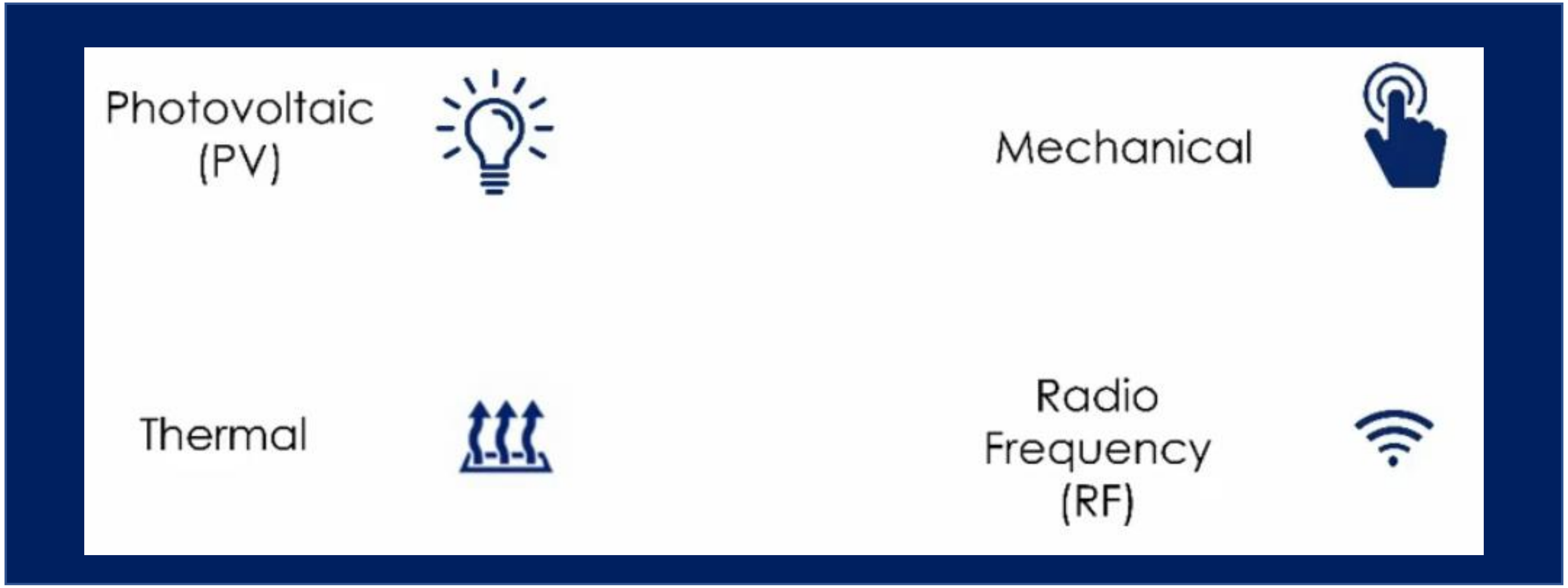
Energy Harvesting Source Options

There are several methods of powering an embedded system by harvesting energy from environmental sources.

The four harvesting source options supported for the specific SoC we are talking about, are:



The purpose of energy harvesting is to increase lifetime of field nodes and devices.
It helps in on-site charging of rechargeable batteries, traditional and super capacitors.

There are two design goal in energy harvesting device:

- Select very low power electronics
- Harvest energy and store energy efficiently

PV - Photovoltaic Harvesting

Where there's light – there's energy !

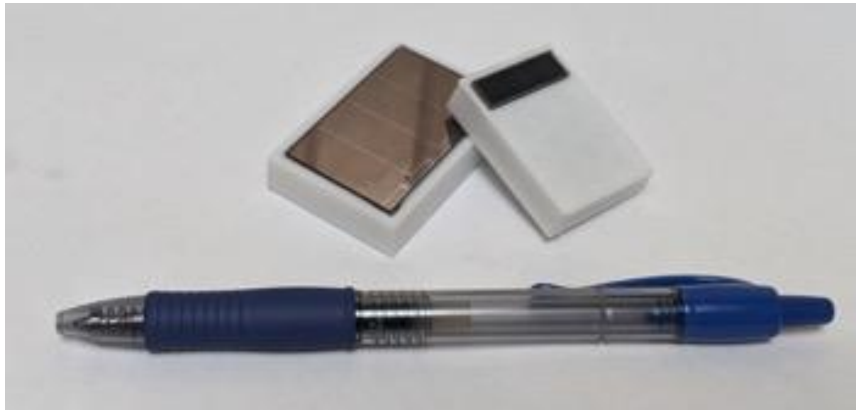
Many examples in commercial products today –

Also being added into beacons, sensors and tags for IoT applications

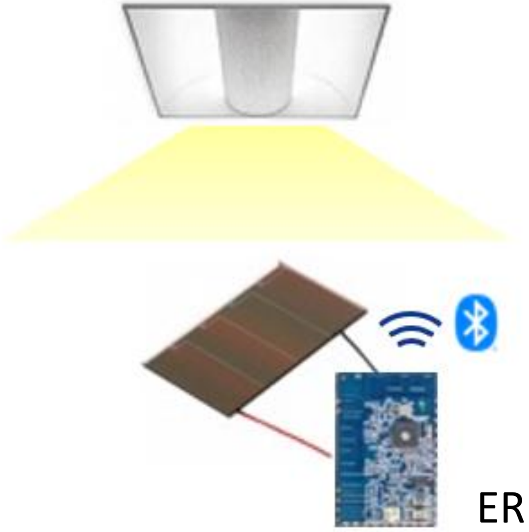
PV is not just about silicon anymore –

New technologies, like dye-sensitized and organic materials are viable options

Features like flexible substrates and custom form factors make adding PV to existing applications easier



Photovoltaic (PV) Harvesting



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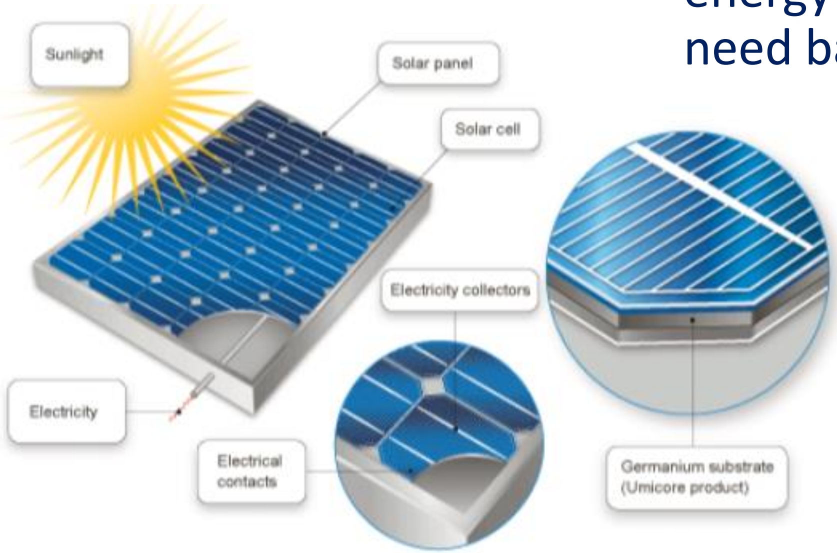


The use of PV cells to power wireless devices has typically required large cell arrays to provide enough operating power at indoor light levels.

Applications can now operate battery free by leveraging ambient light.

Devices with rechargeable batteries like electronic shelf labels or remote controls can now capture enough light energy to effectively have forever battery life and never need battery replacement.

How much energy can you harvest from PV

Light Level (lux)	Harvested Energy (μW/cm²)	Conditions
100	3-10	Dim Indoor
200	7-20	Residential
500	20-45	Office
1000	35-90	Bright Office, Retail, Overcast day
20K	2-4K	Full Daylight
100K	15-20K	Direct Sunlight

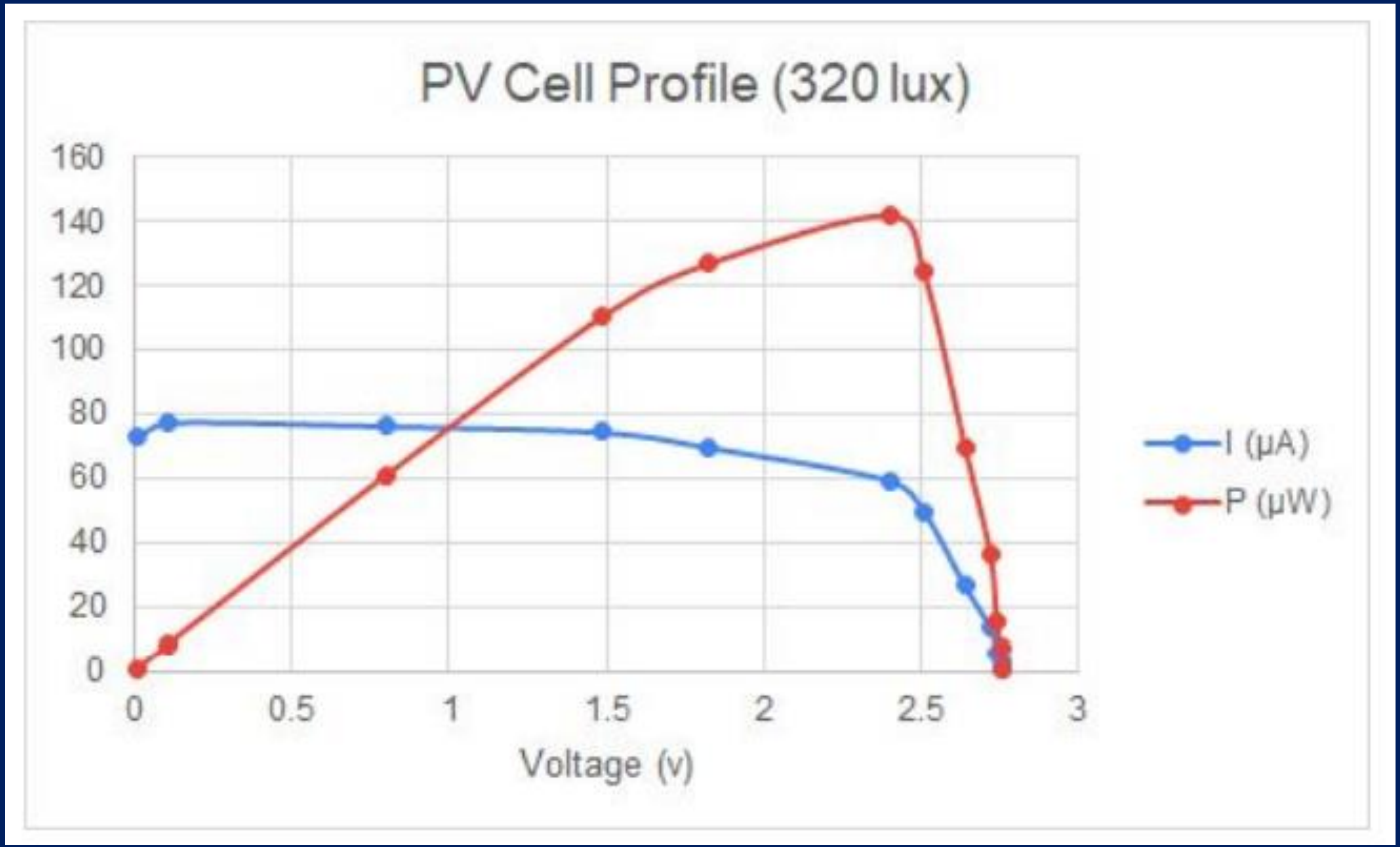
Energy harvested varies based on cell technology and optimal performance range

Light levels are measured in lux and vary from a very dim room (50) to a bright sunny day (100k)

Not all PV cell technologies are equal

- Some work better in low light conditions, other are better outdoors
- Some are more efficient and maybe more expensive

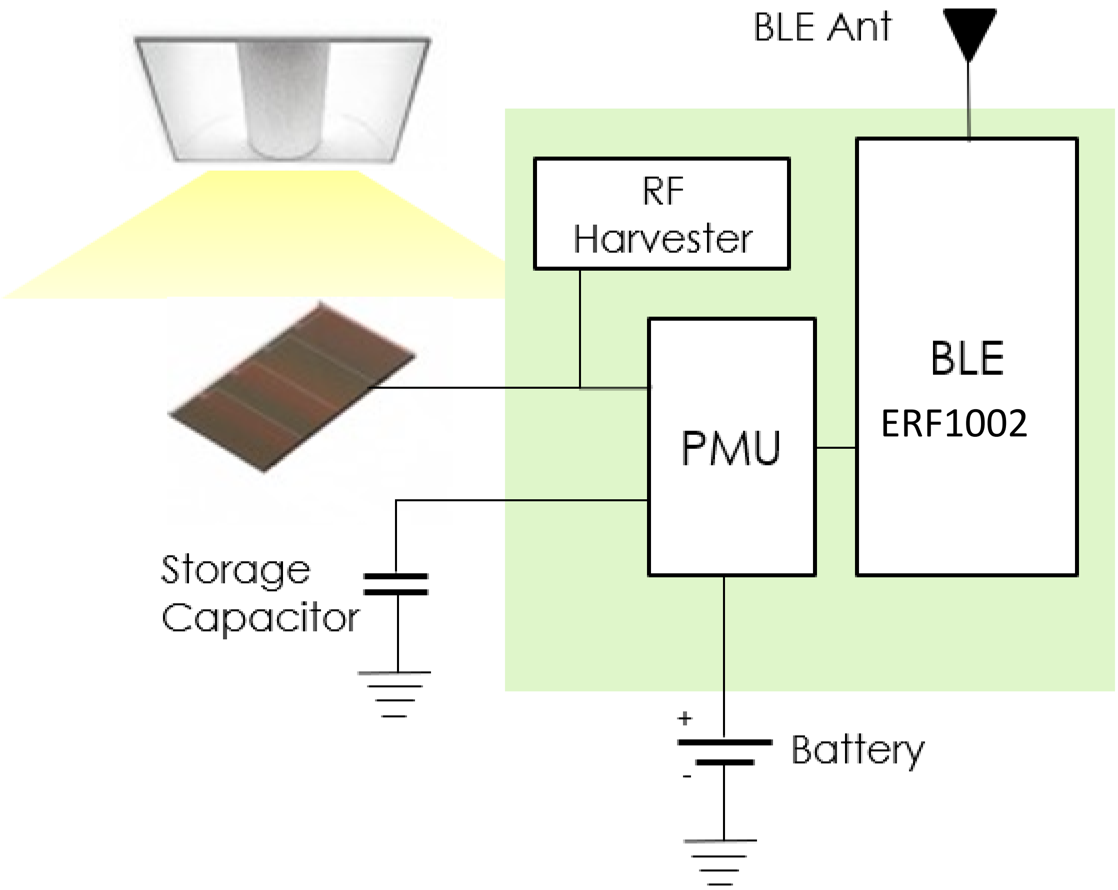
Light profile, available area and budget all factor into PV cell selection



The PMU does not perform maximum power point tracking on the HARV_OUT input pin.

For designs that are battery free or in cases where a depleted rechargeable battery must be charged prior to operation, the PV cell must have an open circuit voltage of 1.65 V or higher with at least 30 μW of energy to meet the cold start requirement.

Summery - Photovoltaic Harvesting

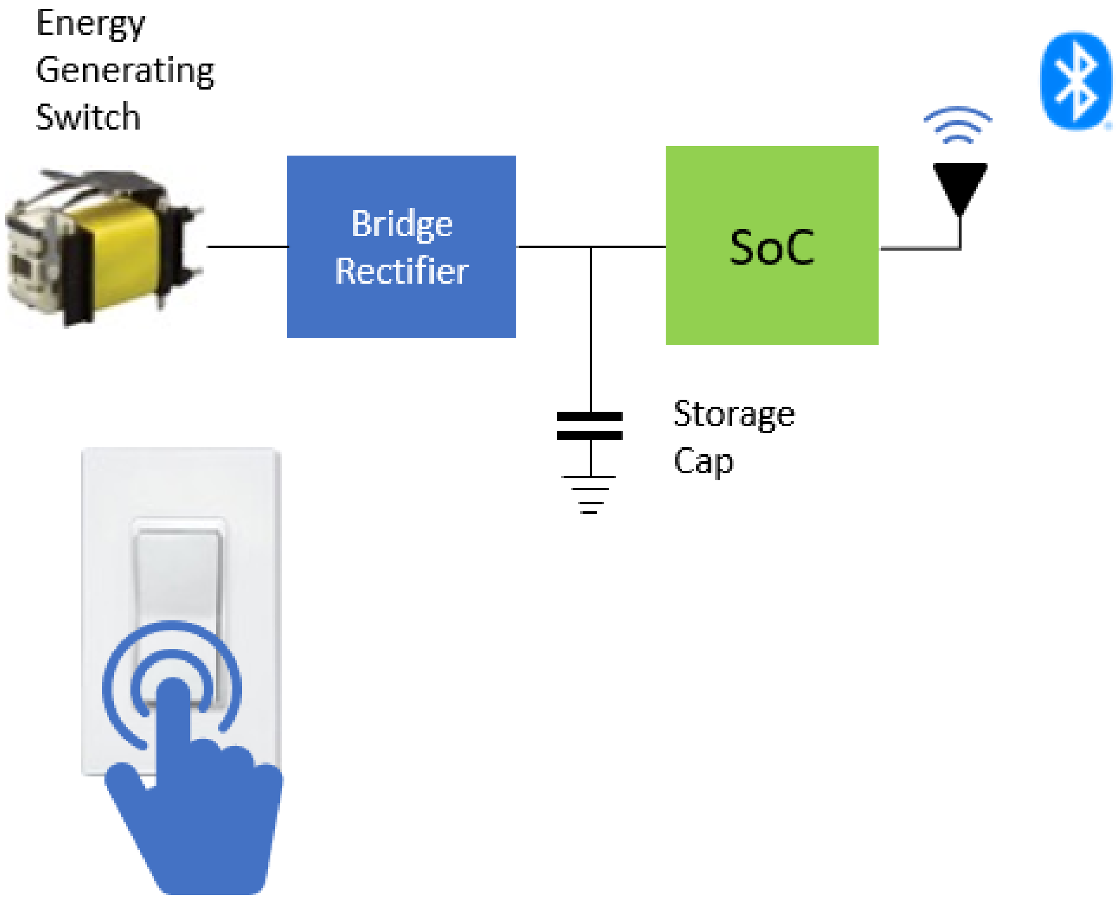


- PV Cell connects directly to SoC
- Battery free, standard battery, or rechargeable battery configurations supported
- Minimum cell voltage of 1.65 V required for battery free or rechargeable battery operation
- Amount of energy available depends on cell technology, cell size, and light level
- 30µW at PMU input needed to sustain battery free once per second beacon

Photovoltaic (PV) Harvesting Applications

- Remote sensors
- Asset tags and tracking
- Locating beacons
- Environmental monitors
- Electronic shelf labels
- Remote controls

Mechanical Harvesting



Mechanical energy harvesting produces energy either based on:

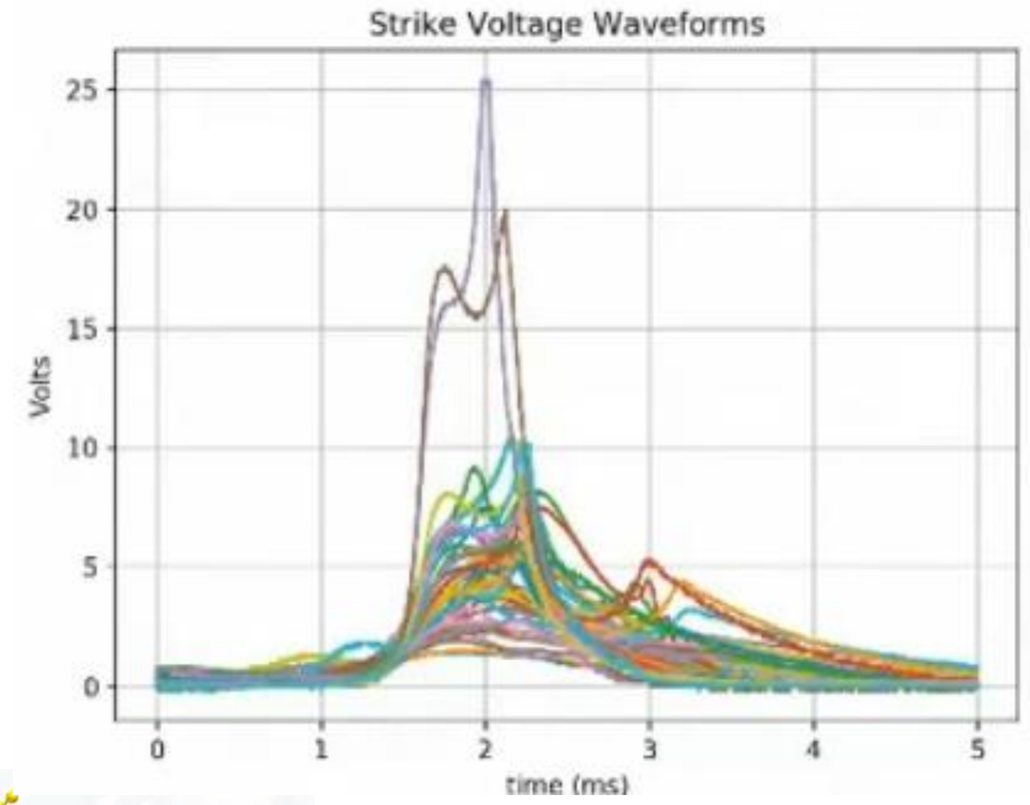
- a single mechanical motion or
- more continuous motion, like the vibration of a motor

Energy Generated by Mechanical Switch

- Actuation of switch generates ~0.3mJ
- Button implementation can capture energy on both press and release

Simple Battery Free Implementation

- Single capacitor stores enough energy for multiple beacon transmissions



Mechanical energy harvesting switches rely on the actuation of a switch to create a burst of enegy

Motion of a magnet through a coil converts mechanical to electrical energy

Actual amount of energy harvested is in 100s of µJ – enough power for multiple wireless transmissions

Mechanical Harvesting Applications

- Smart Home
- Connected Office
- Simple Remote Controls

Challenge is the design of the device: how many buttons can you support?

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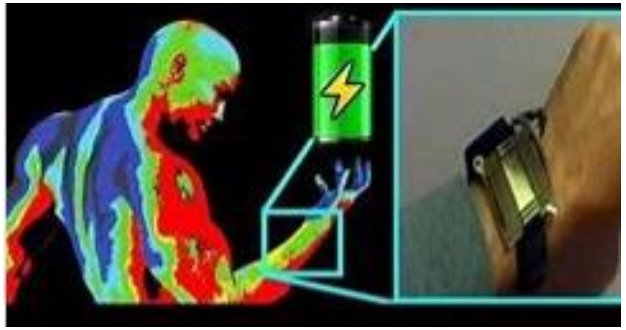
Thermal Harvesting

TEG – Thermo Electric Generator (TEG) technology

TEG is capable of generating enough energy from even small temperature differences to power devices.

Thermal harvesting can be considered anytime there is an available heat source or air flow generating a temperature gradient.

Heat sources like:



- the human body for consumer and healthcare applications;
- motors and machines for industrial environments;
- water and gas pipes;
- or forced air through a heating and ventilation system in commercial or residential buildings

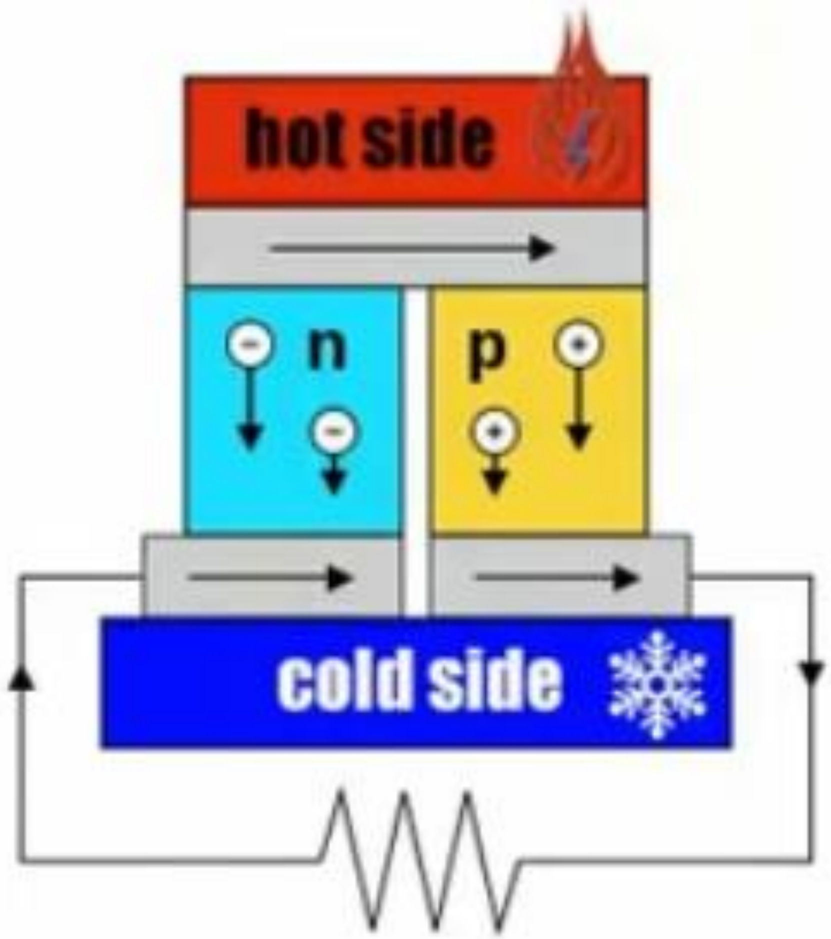
Thermal Harvesting

Harvesting of heat energy with Thermo Electric Generation (TEG) devices.

Requires a heat source (hot side) and heat sink (cold side) to generate electrical energy.

Outputs in the 10s to 100s of mV – boost circuitry is required to provide a usable source of energy.

Phenomena first documented over 200 years ago



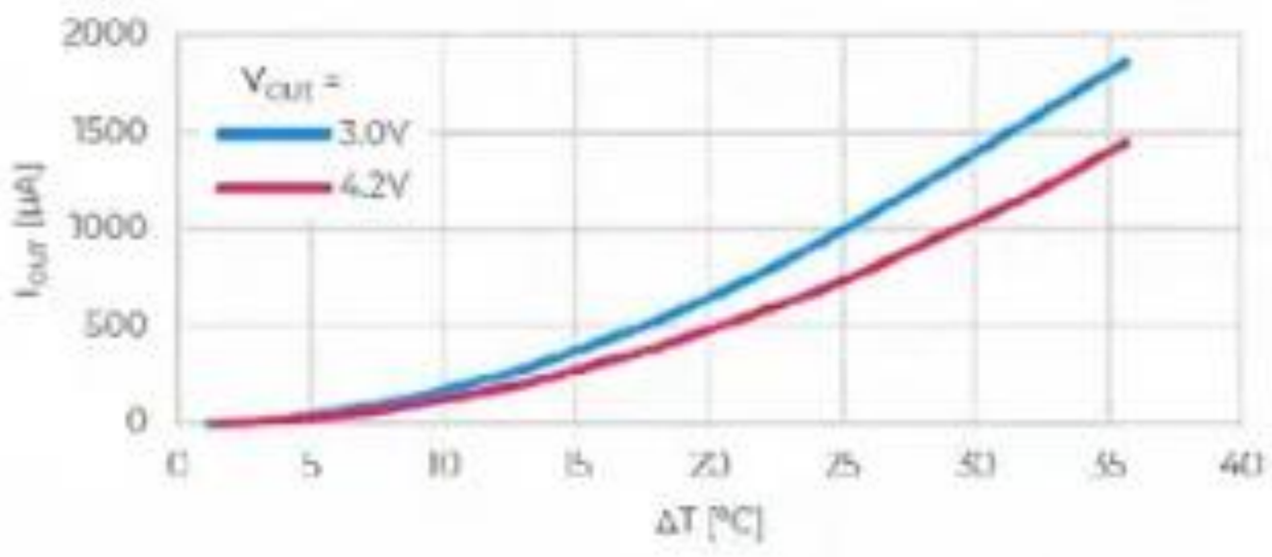
Thermal Harvesting Modular Solution

Capable of generating 0.8mW of power from a 10°C temperature delta.

Supports industrial applications harvesting from motors, furnaces, radiators, or other industrial equipment.

Small form factor can also support wearable applications (18 x 30 mm) (50mm).

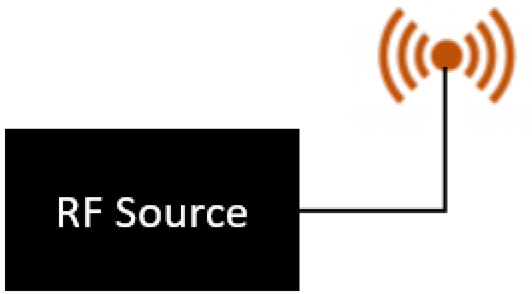
Must have a heat source and heat sink to be effictive

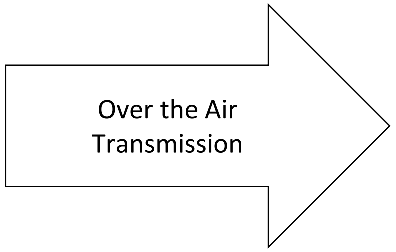


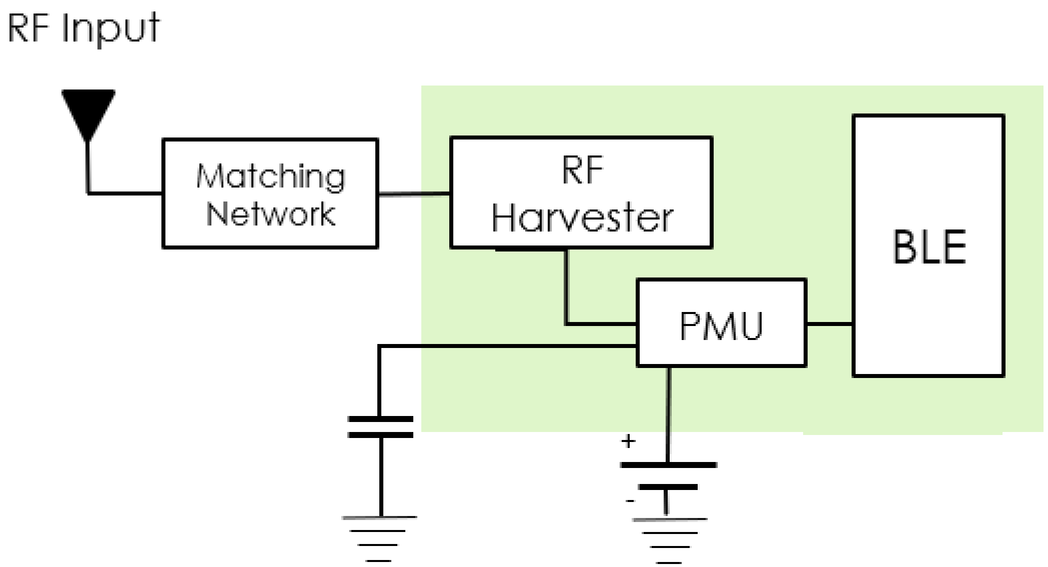
Thermal Harvesting Applications

- Fitness Bands and Smart Watches
- Wearables/Tracking Beacons
- Industrial/Building Automation
- Remote Sensing
- Environmental Monitoring

RF Energy Harvesting







Regulatory limits on frequency bands and output power

2.4 GHz band is universal, but max output power is more restricted in some countries

Sub-GHz band frequencies vary but fewer output power restrictions

Transmission loss depends frequency and distance

Lower loss at sub-GHz frequencies

Received Power:

-60dBm = 1nW

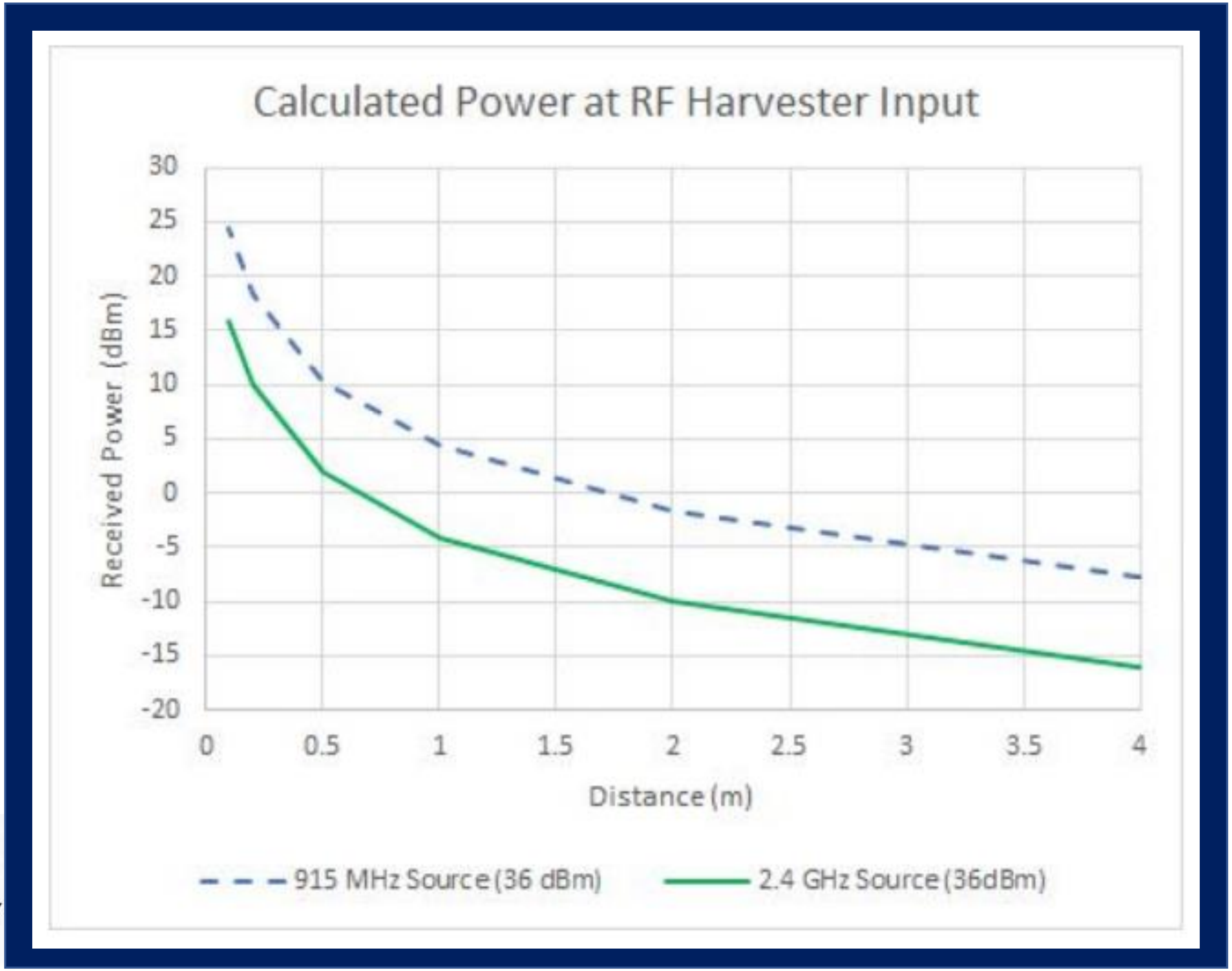
-30dBm = 1μW

Power available depends on efficiency of matching network, harvester, and PMU

Overall efficiency 20-30%

Minimum threshold of -7.5 dBm at harvester input for battery free operation

RF Energy Transmission



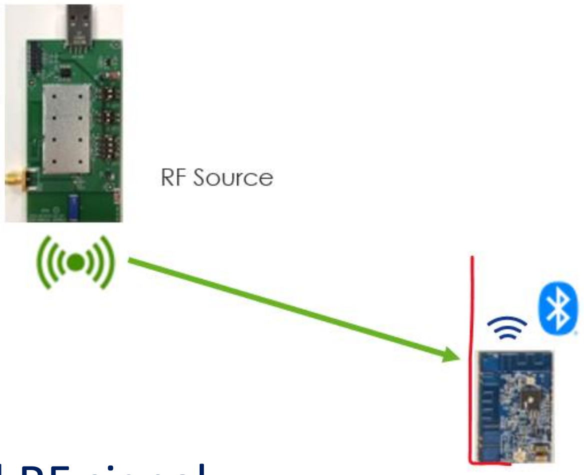
- Source Frequency
- Source Strength
- Duty Cycle
- Range

SoC Energy Harvester - Formula

The following formula calculates the RF signal strength received at the RF harvester based on the strength of the source, distance, and frequency. While energy stored in a capacitor at VSTORE will have an efficiency of 70% vs. energy used immediately.

Where:
Er = Energy received (dBm)
Es = Source energy (dBm)
d = distance from source (m)
f = frequency of source (Hz)
c = speed of light (m/s)

$$E_r = E_s - 20\,log\,(\frac{4\,d\,f}{c})$$



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Then, to compute the amount of harvested energy available based on this received RF signal strength the formula used is:

$$E_h = e_h \times D \times 1000 \times 10^{\frac{E_r}{10}}$$

Where:
Eh = Energy harvested (μW)
eh = RF harvester efficiency (0.30 - 0.45)
D = Duty cycle of RF source

This is a calculation of the energy at the output of the RF harvester.

RF Regulatory Limits

Region	Sub GHz Limits	2.4 GHz Limits
North America	902-928 MHz 36dBm EIRP Freq Hopping Req	30 dBm EIRP Freq Hopping
Europe	865-868 MHz, 33 dBm ERP 916-920 MHz, 36 dBm ERP*	20 dBm ERP
Japan	916-920 MHz 36 dBm EIRP Listen Before Talk Required	23 dBm ERP
China	920–924 MHz 33 dBm ERP Freq Hopping Req	20 dBm ERP

Local requirements dictate maximum transmit power and available frequency bands

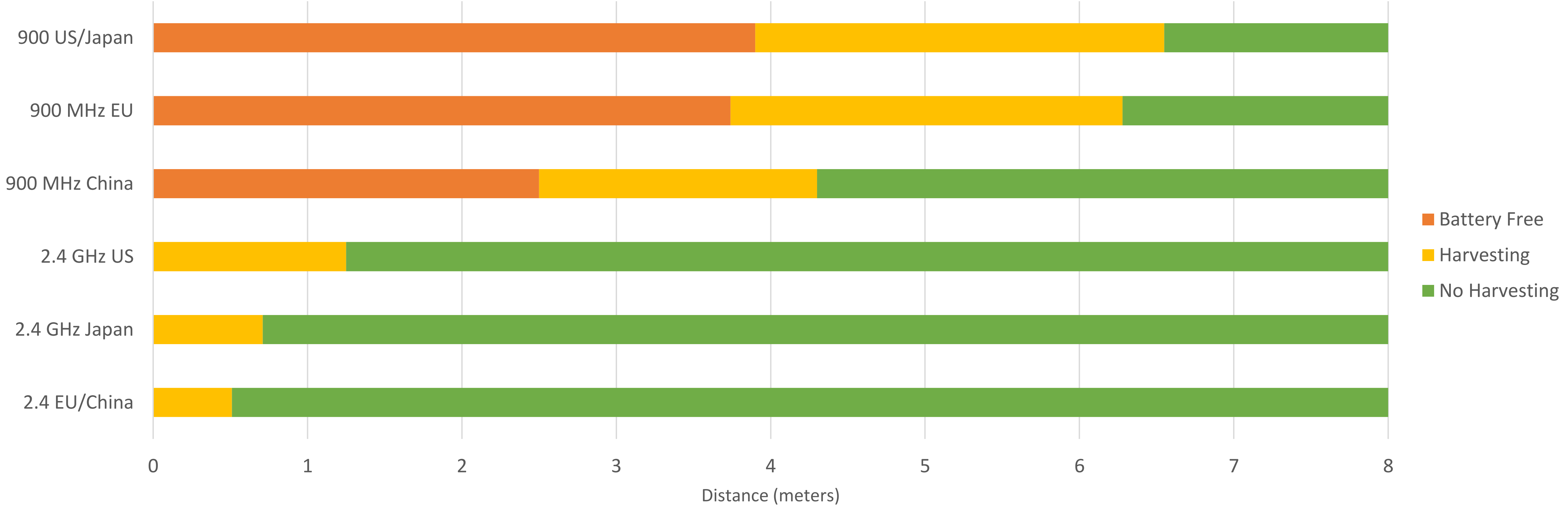
Sub GHz frequency bands vary worldwide but generally support higher TX power limits.

2.4 GHz offers a universal frequency band but with different TX power limits

Lower TX power limits combinede with higher path loss during transmission reduces energy harvesting performance at 2.4 GHz

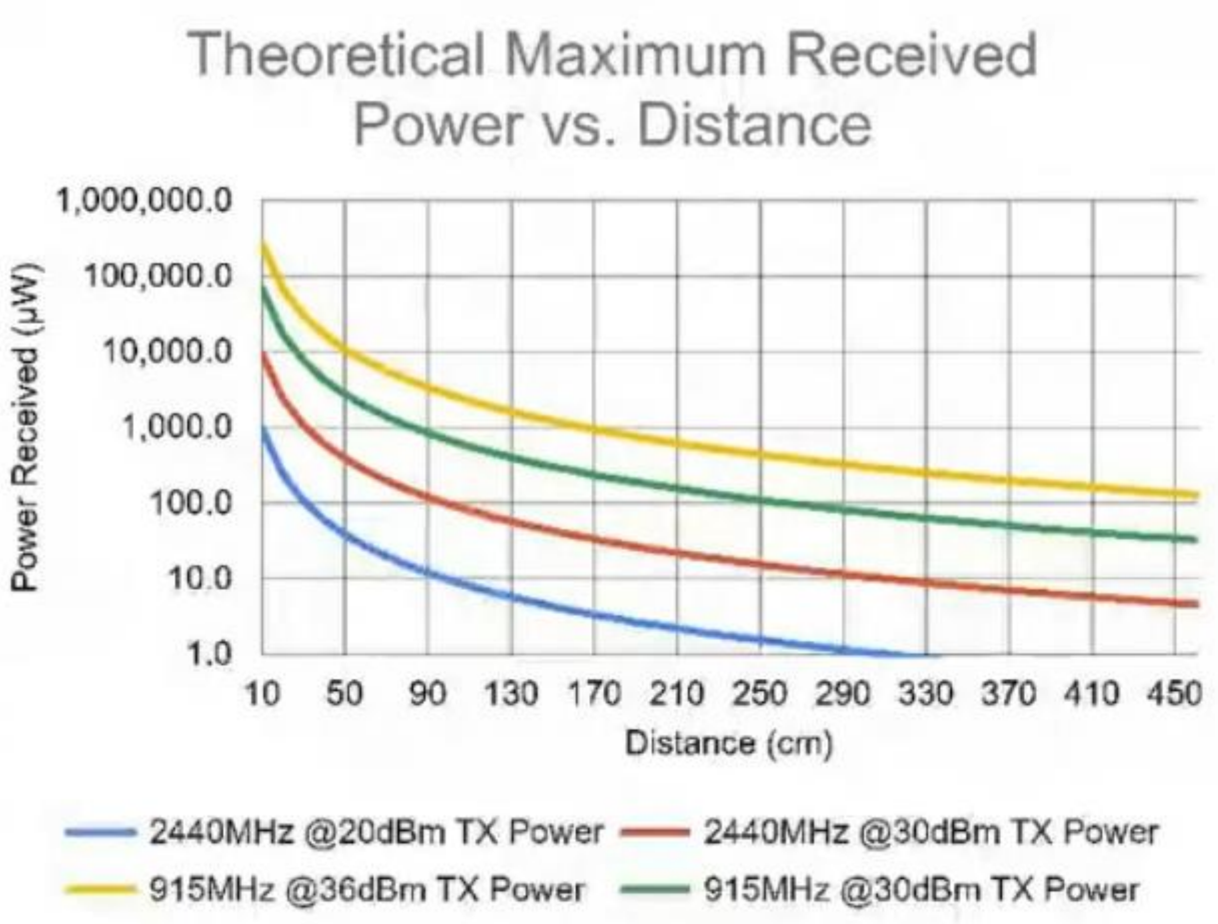
RF Harvesting Zones

Size of each harvesting zone depends on frequency and regulatory limits*



*Assumes maximum TX power, 100% duty cycle

RF Energy available



Theoretical maximum power vs. distance assuming 100% duty cycle

Does not factor in efficiency of harvester and energy storage (40 – 75%

For 2.4 GHz, not much energy (<100µW) available beyond 1m

High duty cycle 2.4 GHz transmissions also introduce potential interference

Sub GHz bands provide energy out past 2 – 3 m

RF: Practical Considerations

You need a consistent source

- Ambient harvesting of RF is very difficult
- 2.4 GHz sources are available, but need to be active and close by!
- Sub-GHz bands offer more power but are not geographically consistent
- Dedicated sources offer controle and consistency – better user experience

Understand the use case

- Does the application need a battery?
- Will the device be operating during harvesting?
- How close can it get to the source?

RF Harvesting Applications

- HID devices like mice and keyboards
- Asset tags
- Security badges
- Remote control
- Electronic shelf label

Agenda

About TOP-electronics

Markets for battery-free IoT, battery challenge & Energy Harvesting Products

Redefining battery life by using 3 technology vectors

SoC with Energy Harvesting & Power Management Unit - PMU

Energy Harvesting Source options

Summery: how to start your battery free design

Thank you, we love to connect at our booth or otherwise in the future

Summery

Direct use of harvested energy instead of stored prior to use

The integrated PMU reduces BOM

Lower power consumption extends energy harvester performance

Examples of beacons from harvested energy – and battery free!

- 5-7 cm² PV @ 200lux sufficient for 1 /s beacon
- 5°C Temperature gradient supports 1 /s beacon
- One button press generates 10 beacons
- 1 /s beacon up to 5m from 900MHz 36dBm source

Examples of Harvesting Applications

- SECURITY BADGES
- ASSET TAGS AND TRACKING
- ELECTRONIC SHELF LABELS
- WIRELESS MICE & KEYBOARDS
- SMART HOME
- BUILDING AUTOMATION

How to start your battery free design

In thinking about the design of a product looking to utilize energy harvesting, one must consider the expected energy consumption and how it matches up to the source availability.

For a given source:

- how much energy will be available?
- will it be continuous or intermittent?
- will the product require continuous operation?
- will the product only momentary action based storing up a sufficient quantity of harvested energy?

Energy Requirements
“How much power is required to run an application on the SoC”.

The answer depends on a number of factors, including the type of application running:

- beacon advertisements only
- connected
- on-chip
- or from external flash
- other sensors used
- or devices used

To get the best possible information about the energy consumption you could use an Evaluation Kit.

Summary

Energy harvesting offers a potential solution to battery waste and device maintenance costs

Multiple energy harvesting technologies available support different environments and applications

The combination we are talking about, the SoC with very low power BLE with integrated energy harvesting PMU can help customers realize a cost-effective high-performance solution

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We are here to help you, feel free to ask questions

- A battery-life game changer
- Tested and available innovation
- Comprehensive documentation and examples
- Responsive FAE and Applications Engineering staff
- Eval boards and reference designs are a great starting point

We will be happy to exchange ideas with you, at the TOP-electronics booth in hall 9, booth B052!

More information can be found at: www.TOP-electronics.com