UWINLOC Energy Harvesting Explained

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Management Summary

In order to accurately track a large number of objects indoor, a low cost location solution is needed. The requirement for a low cost solution and minimal handling overheads necessitates that a battery-less solution be implemented.

Since nothing works without energy, energy has to be harvested from the environment. This whitepaper shows the fundamental limits and choices that guide the quest for such a harvesting solution, and defines a workable solution which can be cost-effectively deployed at scale.

Energy Harvesting

When looking at indoor object tracking, there are four practical ways to harvest energy from the environment :

1. Light, using photovoltaic cells
2. Mechanical, in the form of vibration
3. Thermal, as temperature differences
4. Radio-Energy, either environmental or purposely generated

The table below shows the available power for each of those techniques.

Energy source	**Power Density per** cm^2
Photovoltaic	$10\ \mu W - 10\ mW$
Vibration	$4\ \mu W - 100\ \mu W$
Thermal	$20\ \mu W$ — $10\ mW$
RF	$0.01\ \mu W - 0.1\ \mu W$

Table 1 – Power density per energy source

At a first glance, radio-frequency energy harvesting is a poor choice, given the relative low power available in the atmosphere. However, given the constraints of indoor location, it is the only viable option due to the following :

1. Light is not guaranteed, since the object may be concealed, or in a warehouse without lights.
2. The object may be sitting on a shelf, static, without vibrations nearby.
3. The temperature inside the warehouse is unknown.
4. But radio-energy **is** available everywhere, and can easily be increased using extra energy sources where needed.

Radio energy availability depends on the radio frequency of the source and the distance from the source, as shown in the graph below.

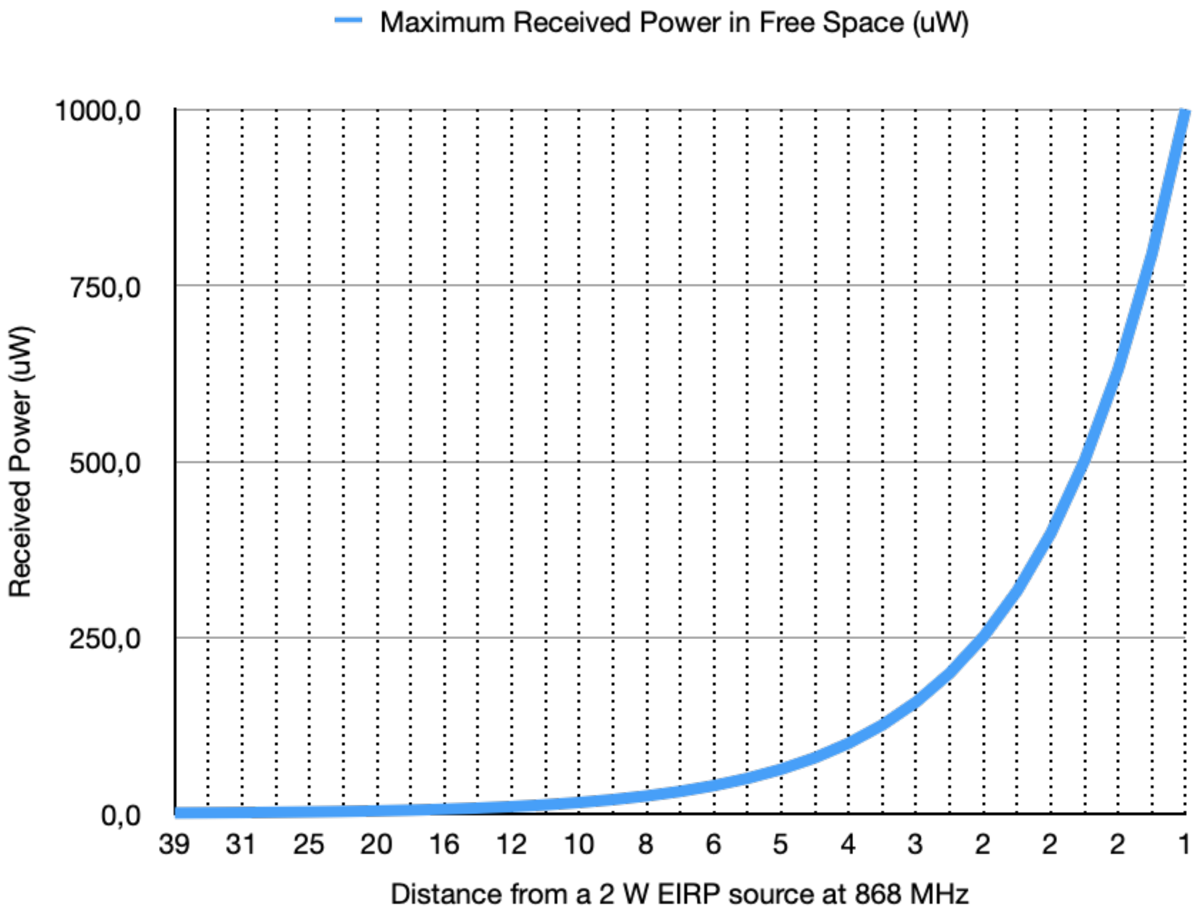

FIGURE 1 – Received Power

| Choice #1 : Use radio-frequency energy |

RF Harvester Efficiency

The RF harvester implementation can not achieve 100% efficiency. In practice, this efficiency increases with received input power. The implementation of the UWINLOC RF harvester favours sensitivity over efficiency, giving an inverse curve, as shown below.

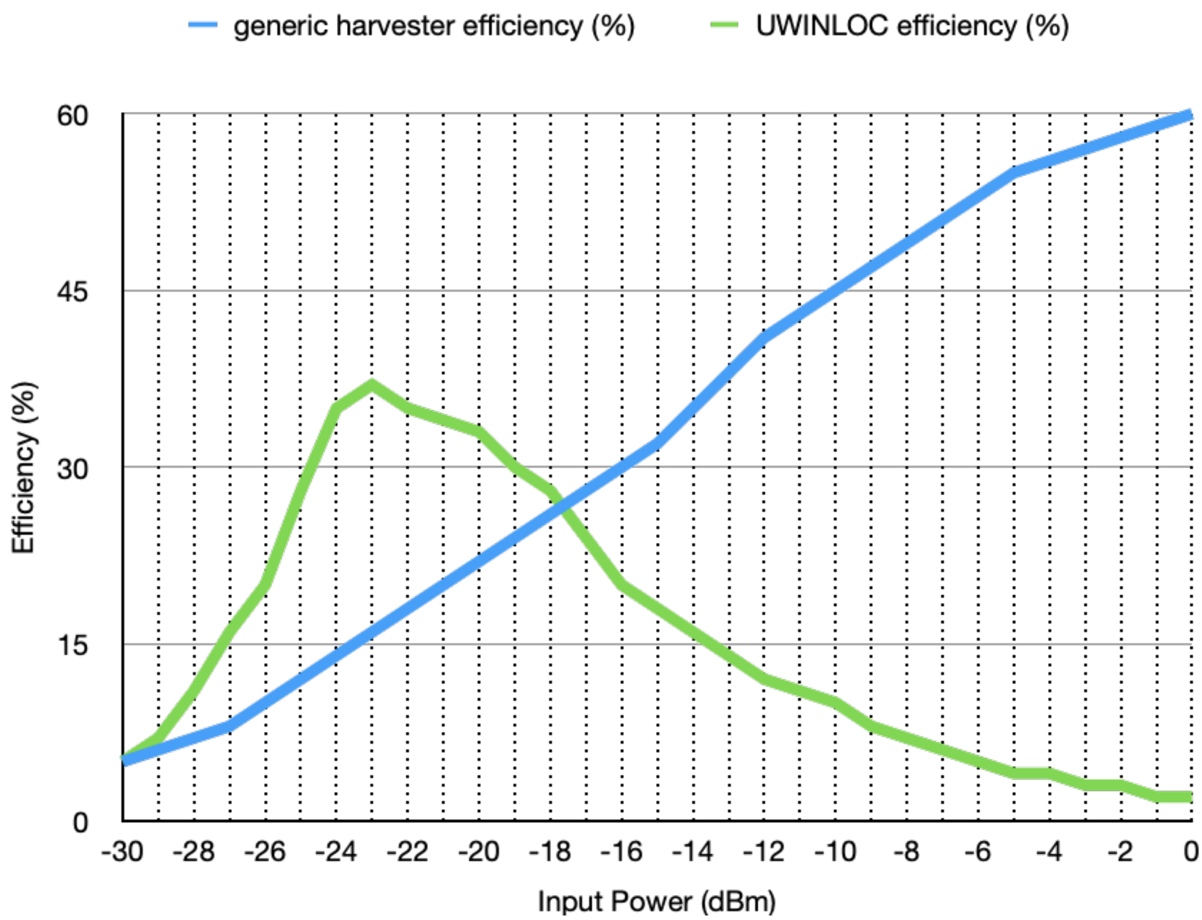

Figure 2 – Harvester Efficiency

The advantage of this inverse curve, is that the actual available energy drops off less dramatically at lower power input levels.

A standard UHF RFID reader in Europe operates at 868 MHz and produces out 2W EIRP. So at around 20 meters, the received power is 4 μW.

Conventional RF harvester efficiency is approximately 10%, with the available power being only 400 nW, whereas the UWINLOC harvester efficiency achieves 33%, delivering 1.3 μW.

Of course, at higher input levels, the non-UWINLOC harvester is more efficient, but in this scenario enough power is available anyway.

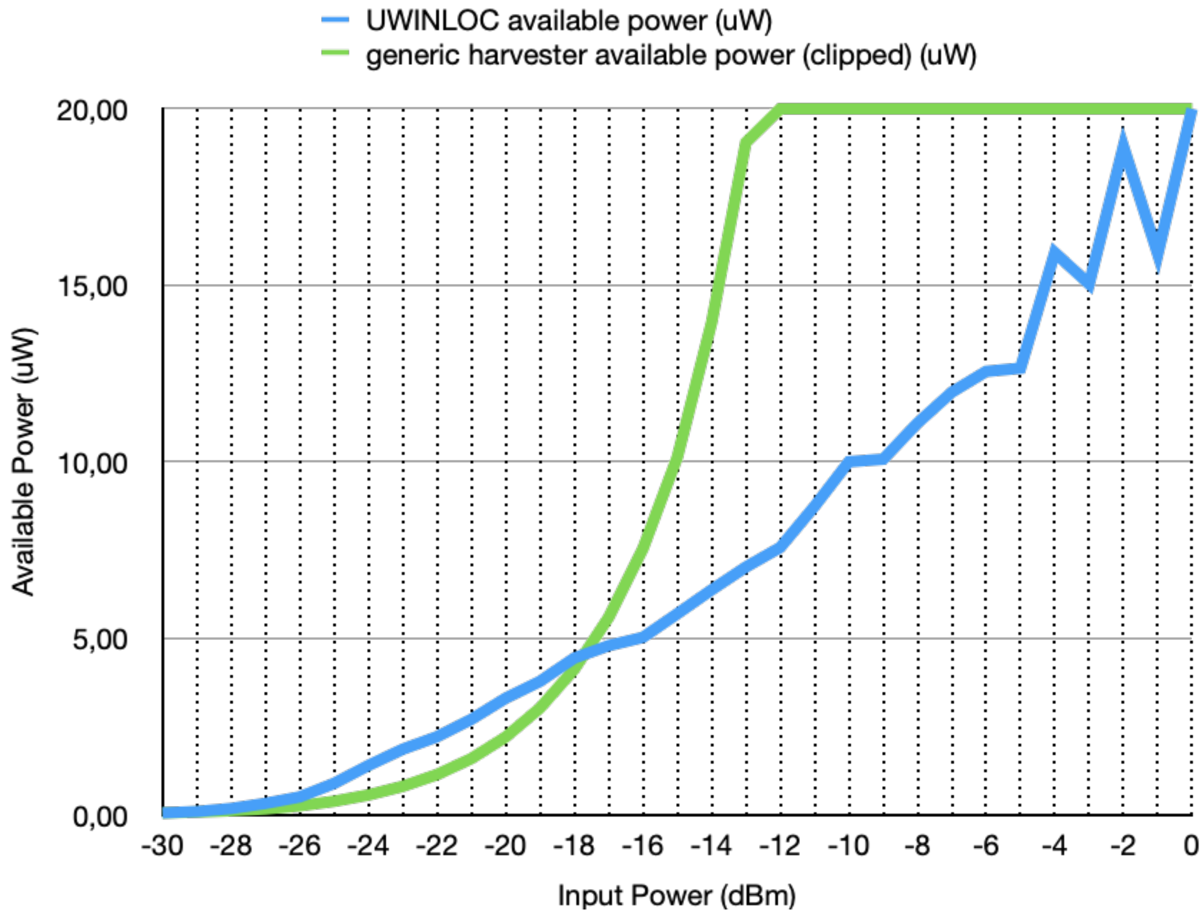

FIGURE 3 – Available Power

| Choice #2 : Favour harvester sensitivity over efficiency |

Energy Use

Nevertheless, around 1 μW of energy is not enough to do useful work. For example, a standard Bluetooth low-energy chip consumes as much just being in power-down mode. The only way around this is to use a low-duty cycle operation, with minimal power consumption during the off-time. UWINLOC has chosen to completely power off the TAG between operations as a way to maximise its powering range. This implies a transmit-only TAG, since (1) the receiver has to be powered on in order to work, and (2) the receive function is not necessary for the intended function, i.e. localisation.

This then means that energy has to be stored between transmissions, and the storage element becomes the limiting factor : no harvesting is possible when more energy is leaking away from the storage element than it receives.

Given the low amount of energy needed for a transmission, a capacitor is sufficient. The leakage of a capacitor depends on the capacitor size : for a good capacitor, the leakage resistor value is $R_{leak} = \frac{500}{C}$.

The table below depicts several capacitor sizes and the equivalent leakage resistance and the corresponding leaked power assuming a capacitor voltage of 2.0 V. The one-before-last column provides the minimal input power needed to compensate this loss. The final column shows the available energy for a single transmission, assuming a capacitor discharge from 2.0 V to 1.5 V during the operation.

Capacitor value (μF)	**Leakage Resistance** ($M\Omega$)	**Leaked Power** (nW)	**Minimal Input Power to cover leakage** (dBm)	**Available Energy** (μJ)
1	500	8	-30	0.9
10	50	80	-29	8.8
15	33	120	-28	13.1
22	23	176	-27	19.3
33	15	264	-27	28.9
47	11	376	-26	41.1
68	7	544	-25	59.5
100	5	800	-25	87.5
150	3	1200	-24	131.3
220	2	1760	-23	192.5
330	2	2640	-21	288.8

TABLE 2 – Available energy per capacitor size

| Choice #3 : Reduce energy consumption during off-periods to absolute minimum |

UWINLOC TAG Implementation

The UWINLOC TAG has an energy need of around 20 μJ for a single transmission. This value is fairly high because the current implementation still employs an off-the-shelf microcontroller, greatly increasing power needs. Nevertheless, this number allows us to have a minimal input power of around -27 dBm using a 33 μF capacitor. The actual value achieved in the field is around -24 dBm due to antenna and other inefficiencies, resulting in a TAG-to-source distance of up to 20 meters.

Next-generation TAGs that are currently under development will lower the energy needed to an estimated 5 - 10 μJ, achieving the -29 dBm range. Practically, we believe -27 dBm to be readily achievable, resulting in a TAG-to-source distance of up to 30 meters. Moreover, with the appropriate technology, the capacitor voltage can be lowered bringing even more gain by reducing the power leakage.

| Choice #4 : Reduce energy consumption during on-periods to absolute minimum |

Choices made

The choices made in the harvester design allow for an unprecedented sensitivity of $-24\ dBm$ in real-life applications.

An overview :

Choice #1 : Use radio-frequency energy ⟶ Operation in all indoor environments possible

Choice #2 : Favour harvester sensitivity over efficiency ⟶ Hugely increased sensitivity of -24 dBm

Choice #3 : Reduce energy consumption during off-periods to absolute minimum ⟶ Useful applications still possible at very reduced input power levels

Choice #4 : Reduce energy consumption during on-periods to absolute minimum ⟶ Reduced storage capacitor size increases the transmit frequency while at the same time reducing power leakage

Conclusion

With the right architectural choices, energy harvesting systems can achieve very high TAG-to-source distances without compromising on cost or reliability, as the UWINLOC implementation demonstrates.