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FRAUNHOFER INSTITUTE FOR INTEGRATED CIRCUITS IIS

RFicient®
ULTRA-LOW POWER RECEIVER
Unleashing the full potential of IoT

WHITE PAPER – EXECUTIVE SUMMARY
Applications in the field of the Internet of Things require low energy consumption and rapid response capability at minimum cost. Many current technologies do not fulfill these expectations. The RFicient® technology developed by the Fraunhofer Institute for Integrated Circuits IIS embraces these challenges as opportunities and offers the adequate solution for numerous wireless applications: RFicient® boasts a power consumption in the order of microwatts and reacts in milliseconds.
This white paper describes the working principles of RFicient® and presents examples how it can be used in IoT applications.

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1 Solving major IoT challenges with RFicient®

The Internet of Things is becoming increasingly popular and will revolutionize our daily life. Although it seems already ubiquitous for each of us, there are problems that could derail progress. IoT devices have specific technical requirements, but concurrently no standard technology offers adequate solutions. Especially power consumption is one of the major challenges that need to be overcome. Therefore, low power usage is high in demand, in particular for mobile applications. However, such IoT devices that run for long periods of time on power sources such as coin cell batteries often require a continuous upkeep.

Unreliable battery lifetime fosters another problem for the Internet of Things – permanent accessibility of mobile applications. Due to the often sporadic nature of incoming radio messages, where the exact time of arrival is either unknown or unpredictable, an always-on receiver is necessary in order to allow immediate response in a wide range of wireless applications. This permanent accessibility requires some kind of standby function and therefore electricity consumption. Overall, it seems to be a vicious circle.

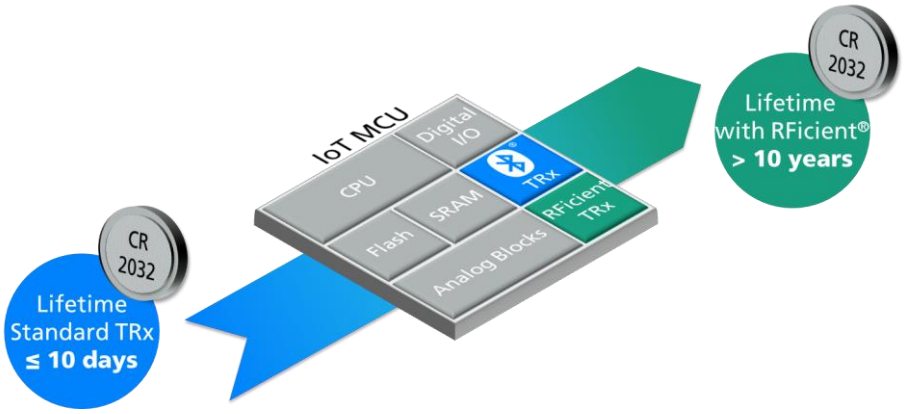
RFicient® enables IoT connectivity via battery for more than 10 years

Imagine a future with a reliable Internet of Things with years of maintenance free operation of mobile applications and connectivity on demand – RFicient® is an ultra-low power technology that was developed for this purpose. Meeting the two requirements of ultra-low power consumption and continuous monitoring wireless channels are challenges we embrace as opportunities. Our RFicient® ultra-low power receiver IPs enable continuous radio reception, very fast reaction in the range of milliseconds and battery operation up to ten years or even fully autonomous operation via energy harvesting.

Just like the Internet of Things spans a broad field of applications, RFicient® has a wide variety of potential deployment scenarios. The energy-saving electronics solution is the key to ultra-low power connectivity for IoT devices with long-term use case scenarios, that are either battery based or even aim for energy autonomous operation. Accordingly, RFicient® offers utility across a vast array of applications including building automation, intelligent lighting, electronic labels, remote maintenance, remote control, wireless sensor networks and many more.

IoT spans a broad field of applications – so does RFicient®

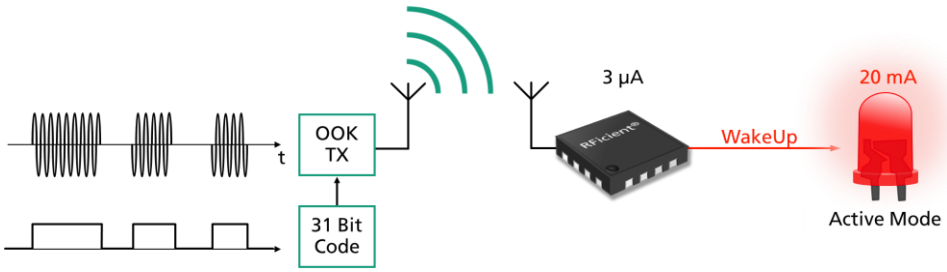
The vision of unleashing the full potential of IoT could be turned into reality by integrating RFicient® in full-featured IoT microcontrollers in addition to a main transceiver based on industry standards such as Bluetooth® Low Energy, Wi-Fi® or ZigBee®. This will reduce power consumption dramatically, allowing several years of operation instead of the current standard of several days if low latencies below 10 ms are mandatory. To be precise, RFicient® based operation of an IoT microcontroller enhances battery lifetime by a factor of 300.



RFicient® enables IoT connectivity via battery operation above 10 years

2 What is RFicient®?

RFicient® is a so-called integrated wake-up receiver that monitors the wireless channel continuously and scans the channel for predefined wake-up sequences. As soon as it receives a wake-up sequence, a digital control signal is generated to activate a particular power-consuming application. In addition to the pure wake-up functionality, an ultra-low power data receiver operation mode with variable data rates is possible. As the receiver current consumption dominates the time of operation, we developed button-cell driven integrated receivers with an extremely low power consumption below 10 µW and very fast response times below 10 ms. A major benefit of RFicient® is the constant current consumption due to its independence of any radio traffic or the presence of transmitted wake-up sequences. As an additional valuable benefit, the receiver sensitivity remains at -80 dBm constant regardless of the data rate or the selected power mode. Thus, a radio range of up to 100 m can be reached.

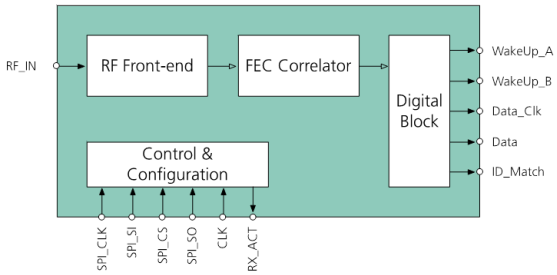


RFicient® generic wake-up procedure

The implemented wake-up receiver operates autonomously without a microcontroller. It comprises an RF front-end and a dedicated logic on chip for digital processing, control and configuration. An RF front-end receives and demodulates an OOK modulated RF-signal with a Fraunhofer IIS patented level processing. An FEC correlator scans the received data for two independent wake-up events, WakeUp_A and WakeUp_B. Based on these codes, data reception and a selective wake-up is implemented. The RFicient® IP is already silicon proven for the license-free frequency bands 433 MHz, 868 MHz and 2.4 GHz.

Highlights at a glance

- Supply current: < 3 µA @ 1.8 V (1 kbit/s)
- Response time: < 30 ms (1 kbit/s)
- Sensitivity: -80 dBm
- Frequency bands: 433 MHz, 868 MHz, 2.4 GHz
- Permanent accessibility
- Operation without microcontroller
- Detection of two independent wake-up events
- FEC coded data reception
- Selective wake-up with 16 bit ID
- Silicon proven 130 nm CMOS-IP



IP-level block diagram RFicient®

As given in the table below, with RFicient® wake-up latencies between 1 ms and 121 ms are attained for current consumption values between 1.5 µA and 48.5 µA. The response time relates to the data rate and current consumption. When operating in the standard configuration at a data rate of 1 kbit/s, the energy consumption is reduced to a mere 2.6 µA at 1.8 V with a response time of only 30 ms. In this mode, a CR2032 button cell can drive RFicient® continuously for seven and a half years.

Current consumption	Data rate	Wake-up pattern duration	Max. operating time CR2032
1.5 µA	256 bit/s	121 ms	11.5 years
2.6 µA	1024 bit/s	30 ms	7.5 years
7.1 µA	4096 bit/s	8 ms	3.5 years
48.5 µA	32.8 kbit/s	1 ms	0.5 years

Current consumption for various operation modes

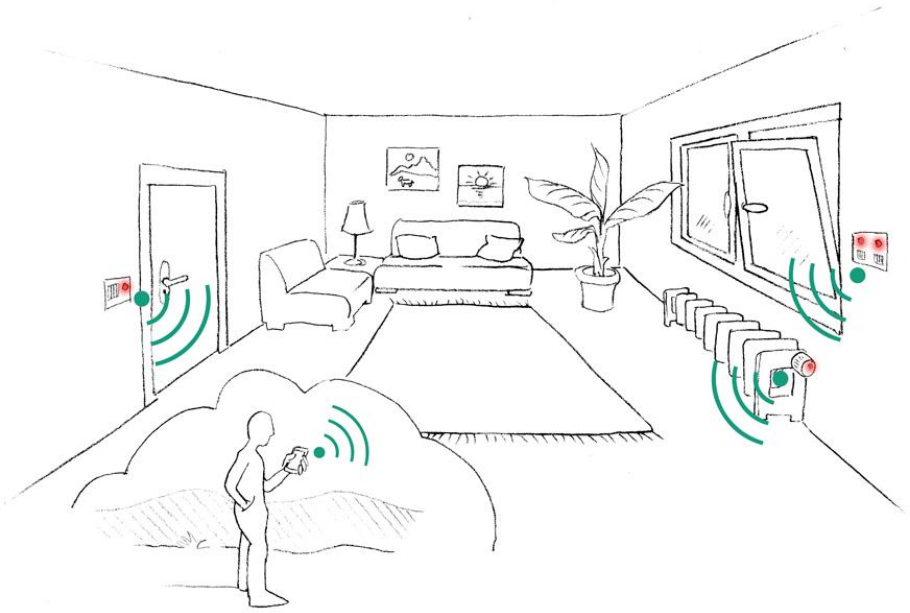
3 IoT use case scenarios with RFicient®

Continuous monitoring of a wireless channel is required for applications where the exact instant of an incoming radio message is unknown to the receiver. Having received a radio request, a quick reply is expected. With RFicient® devices go to sleep when not in use but wake up immediately to deliver services as needed. This facilitates real-time operation scenarios and thus enables many IoT applications relying on long-term battery operation and fast response times.

Pick-by-Light scenario with RFicient®

Wireless Pick-by-Light – Increasing performance in order picking

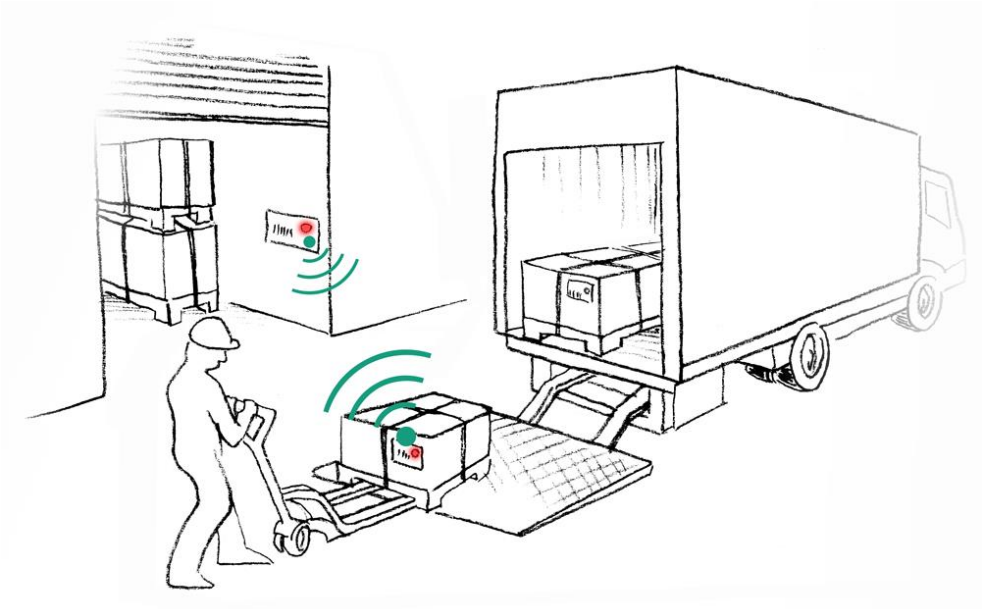
The usage of fully automated systems in the order picking process in intralogistics and industry comes along with high investment and is usually very inflexible. Therefore, purely manual solutions remain the most common type in practice. Nevertheless, a new manual order picking system is necessary to reduce process times and error rates. The so-called pick-by-light method provides an assistance system for manual order picking. In this system, each shelving bay is equipped with a small display board and the flashing of a lamp indicates the searched shelf. Since the installation of wired display boards is complicated and expensive in a high number of compartments and long shelves, radio based sensors are mandatory for this purpose. With RFicient®, such a wireless method of light guided picking is easily installed achieving an extremely long operating life. Furthermore, the miniaturized wireless RFicient® tag electronics can be attached to each packing unit in contrast to the immovable shelving bay. If the picker activates a certain tag via i.e. a handheld device, RFicient® immediately initiates the flashing of a lamp and accordingly signals the picking position. This visual identification of the storage location reduces dead-times and prevents errors.



Building Automation scenario with RFicient®

Wireless Building Automation – Satisfying building and occupants' needs

Automation systems operate buildings more efficiently and economically compared to non-controlled buildings. In such smart buildings, different sensors and actuators continuously monitor windows, doors, the heating and ventilation. Secure, energy efficient and long maintenance free operation of such systems is essential. This is exemplified by windows equipped with sensors that detect whether a window is closed or not, which gives an important control variable for keeping a building's climate within a specific range. A central home server with gateway functionality receives the periodically sensed values and manages as commissioning tool the demand of e.g. heating or ventilation. To this end, hardwired sensors are difficult to install and deploy. Thus, wireless sensors modules with a smart power supply concept are mandatory for this purpose. Sensor modules with built-in RFicient® technology provide both and even more: a wireless solution with an ultra-low power design and real-time capability, which enables measurements immediately on request. To return to the previous example, since the server is able to send requests to the sensor modules, the user can check on the road whether his windows at home are closed, providing a security feature at the same time. Integrating RFicient® in building automation systems results in maintenance free operation of 5 to 10 years. Furthermore, this wireless solution is easy to install or retrofit.



Geo-fencing scenario with RFicient®

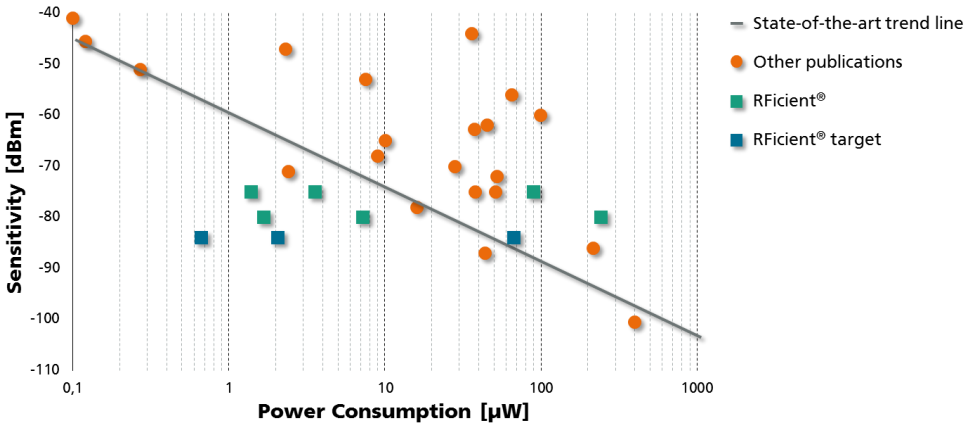
Wireless Geo-fencing – Keeping an eye on incoming goods

Goods receipts process a great number of entering pallets every day. Each package has to be read into the system individually, which is extremely time consuming for pallets with large quantities of packages. To keep an overview and to make sure that especially valuable items do not get lost, geo-fencing is the adequate solution. A so-called geo-fenced area in e.g. warehouses is a predefined zone, in which the attendance of mobile objects is registered. To this end, beacons are placed at certain gates defining geo-fences and a set of boundaries. They periodically broadcast telegrams that consist of a wake-up sequence and the respective position ID. Mobile objects such as forklifts, automated guided vehicles, the packages on the pallets or valuable assets contain an ultra-low power wireless tag module with an RFicient® receiver and a transmitter. When entering or exiting a geo-fence, the object's tag listens to the signal of the beacons. As every beacon message contains the position ID, the signal provides the object with its whereabouts. This activity could trigger a sequence of predefined actions, e.g. a notification or alert if a predefined security rule is violated. The advantage here is the fast reaction time of the RFicient® receiver technology of 30 ms. Special events can be detected quickly and additional radio telegrams can be transmitted immediately. In the case of an alarm, the position ID can be readout, for example, from the objects in fence proximity. Besides the whereabouts, the object's tag provides its ownership, mission and function, which creates the information base for optimizing industrial production and intralogistics processes. If each object logs the current location, even tracking is automatically generated.

4 Current ultra-low power receiver landscape

Integrated wake-up receivers for ultra-high frequency bands can be described with four key features: power consumption, sensitivity, radio frequency and data rate. Within the state-of-the-art, three major receiver architectures are used for the most part: the RF envelope detector, the superheterodyne receiver and the superregenerative receiver. Due to its simplicity, RF envelope detectors are quite popular and achieve sensitivities of -75 dBm at a power consumption of 51 µW. Applying SAW filters and 64-bit long analogue correlators, a lower power consumption of 2.4 µW at -71 dBm was reported for an 868 MHz receiver with 9 kbit/s data rate. For 2.4 GHz a receiver with -65 dBm at 10 µW power consumption was reported. Superheterodyne implementations with uncertain intermediate frequency leave out a PLL synthesizer, but calibrate the local oscillator. An RF band filter such as SAW or BAW filter is mandatory to achieve sensitivities of -72 dBm at 52 µW power consumption. Sub-sampling techniques have been added and led to lower power consumptions of 28 µW. Superregenerative approaches may reach better sensitivities of e.g. -86 dBm, but need 215 µW of power.

The ultra-low power receiver technology at Fraunhofer IIS already defines the current state-of-the-art: Among other sub-10 µW receivers, RFicient® shows the best-reported sensitivity, -80 dBm at about 2 µW to be precise.



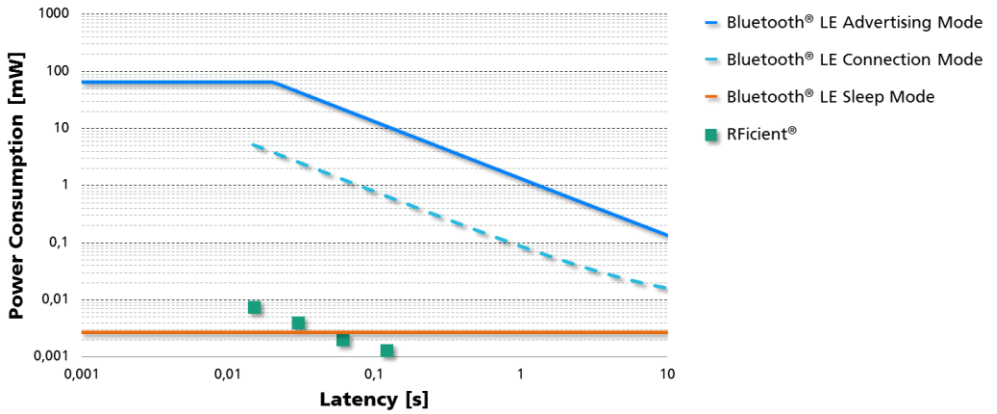
In comparison with other ultra-low power receivers, our performance is outstanding

Bluetooth® Low Energy and RFicient®: Complementary or Competitive?

Bluetooth® Low Energy (LE) is known as an easy to implement, low-cost wireless solution that requires very little power. Nevertheless, wake-up receivers offer clear advantages for many wireless systems with regard to simultaneously providing very low power consumption, low latency and a large number of nodes. Applications based on Bluetooth® LE show clear disadvantages in the three areas mentioned. Especially if only small-sized data packets have to be exchanged at unforeseeable times, as it is typical within the IoT, wake-up based approaches are clearly beneficial.

While the power consumption of RFicient® remains constant, Bluetooth® LE distinguishes between three different modes: sleep, connection and advertising. For example, in sleep mode, a commercial IC that offers a Bluetooth® LE interface consumes 2.7 µW. If a latency of 15 ms is assumed, the active power consumption of the Bluetooth® LE IC is 66 mW. In contrast, the power consumption of RFicient® is merely 7.4 µW, regardless of any mode.

In future, some wireless applications can be implemented purely RFicient®-based without Bluetooth® LE components. However, the use as an add-on receiver for the expansion of full-featured IoT microcontroller is of interest for many existing system solutions. This way, all the advantages of the involved wireless systems can be combined constructively.



Performance Comparison: RFicient® versus Bluetooth® Low Energy

5 Summary

Due to the Internet of Things, there is a strongly growing amount of connected mobile devices and wireless connectivity gains in importance. However, wireless battery-powered IoT applications make sense only if the batteries do not have to be replaced or recharged regularly. For this purpose, we propose an innovative wake-up receiver: RFicient® is extremely power efficient, inexpensive, and does not require battery replacement for multiple years. The innovative approach allows the scalability of current consumption versus data rate at a constant sensitivity, meeting both short reaction time and ultra-low power consumption requirements. Various use case scenarios exemplify the benefits of RFicient®-based solutions for wireless applications. Our current RFicient® technology provides a better sensitivity than conventional receivers at significantly lower power consumption below 10 µW and a faster reaction time. Purely RFicient®-based applications as well as concepts with existing wireless standards in a complementary way are possible.