

Radio sensors powered by ambient energy: From strange ideas to mass market products

Only 10 years ago the idea of reliably operating a multitude of different radio sensors solely with ambient energy seemed unreal. The right kind of topic for inventors dreaming of the perpetuum mobile...These days, however, if one enters the term "energy harvesting" into an internet search engine, one gains about half a million hits. No doubt, the subject has become more than simply another topic of conversation. Surprisingly, however, only very few products exist on the market that hold potential for high unit numbers in mass applications. The article outlines significant technical challenges and their solutions on the way to producing energy autarkic radio sensors in large scale, using select products of EnOcean as examples. In so doing, it becomes clear that innovative technical concepts oftentimes force one to "reinvent" all parts of a system, thus further accelerating technological progress.

Dr. Wolfgang Heller, Product Line Manager, and Frank Schmidt, CTO

Ambient Energy?

Devices operated with environmental energy are not new. Apart from the commonly known procedures in which wind and water are used to obtain energy, a less well known, but technically highly interesting product bears a mention: the Atmos produced by the Swiss company Jaeger-LeCoultre since 1936.

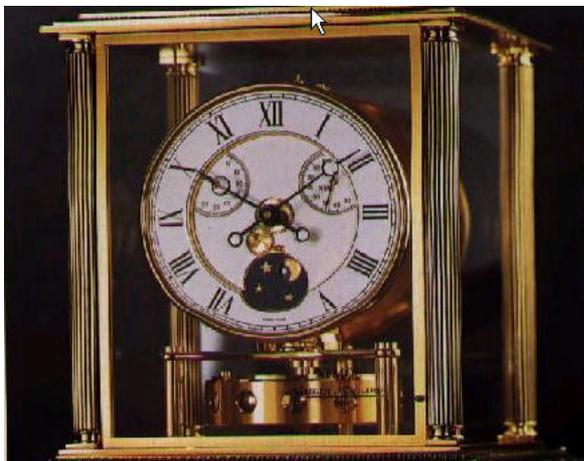


Fig. 1: Atmos, a clock operated by temperature fluctuation

This clock has an expansion chamber filled with ethyl chloride, which expands or contracts during temperature fluctuations, thus winding up a mainspring. Even a temperature change of only one degree Celsius will provide the spring with sufficient energy for two days of operation. To be able to efficiently utilise the low amounts of energy, the clock's engineers took new approaches.

Thus the frequency of the torsion vibrating mass was reduced to two oscillations per minute, while particularly low friction oil-free bearings were developed. All parts are permanently in equilibrium so that no force is exerted contrary to gravity.

RADIO SENSORS POWERED BY AMBIENT ENERGY: FROM STRANGE IDEAS TO MASS MARKET PRODUCTS

The innovative concept for the supply of the clock's energy from the fluctuation of ambient temperature could not be applied directly to the existing technology – a characteristic of innovative technologies, which we are also facing with the energy autarkic radio sensors.

Such fascinating, technically sophisticated products do not, however, automatically prove the mass marketability of the technology used, despite their innovative nature. Taking into consideration construction size, cost and reliability, a systematic evaluation of the potential of different ambient energy converters is therefore a significant first step in the assessment of technical feasibility in view of the market.

The most interesting ambient energy sources for wireless sensors are:

- Linear motion, e.g. a button push
- Solar power
- Vibrations, e.g. vibrating machine parts
- Temperature gradient, e.g. a hot machine and cold environment

EnOcean has recently presented a demonstrator of a wireless sensor, which is driven by temperature differentials. A core component of this development is a discrete DC/DC converter, which is able to start up at voltages of about 100mV which is about an order of magnitude lower than existing solutions on the market. This makes it possible to make use of the small voltages, which are provided by standard Peltier elements when used as energy harvester. With a temperature gradient of 3 Kelvin between the two sides of the Peltier element, the system – which consists of a Peltier element, an EnOcean STM 100 module and the DC/DC converter – starts up and transmits the sensor values every second. The demonstrator provides an integrated temperature sensor and also measures the supply voltage. A third analog input and 4 digital inputs are available for user specific applications.

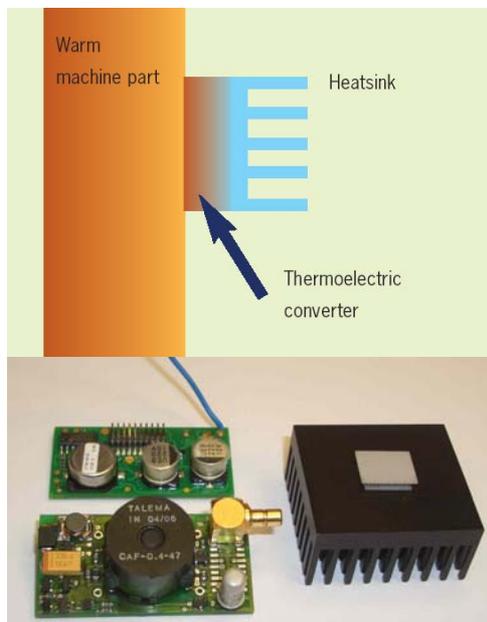


Fig. 2: Demonstrator of a wireless sensor Powered by temperature differentials

RADIO SENSORS POWERED BY AMBIENT ENERGY:
FROM STRANGE IDEAS TO MASS MARKET PRODUCTS

Requirements towards radio technology and energy management

1. Energy storage and energy management

A comparison of the average energy available with the energy requirements of radio systems, which can achieve the ranges (several tens of meters in buildings, even through a few walls) necessary for many products, rapidly shows that the continuous operation of radio transmitters or receivers is not feasible. However, generally this does not present a limitation, as many sensor systems are only to transmit relatively small volumes of data in relatively large intervals (compared to transmission time).

The energy storage technology strongly influences the system performance. The most important requirements are:

- High number of charge-discharge cycles
- Simple charging process which does not consume a lot of energy itself
- High energy density to keep size small
- Low leakage for bridging long intervals without energy supply

	NiMH	Li+	Ultracap
Discharge cycles	-	-	++
Simple charging	-	-	+
Energy density	+	+	0
Leakage	0	+	-

The table shows strengths and weaknesses of available storage technologies.

Ultracapacitors have turned out to be the best solution for most applications as the number of charge-discharge cycles is usually the most important requirement because it is directly related to the lifetime of the product.

The greatest energy savings can be achieved by processing all procedures within the shortest possible time. While the efficiency of e.g. high-frequency modules can only be increased minimally and with great effort, a major share of energy can be saved by executing all operations extremely rapidly.

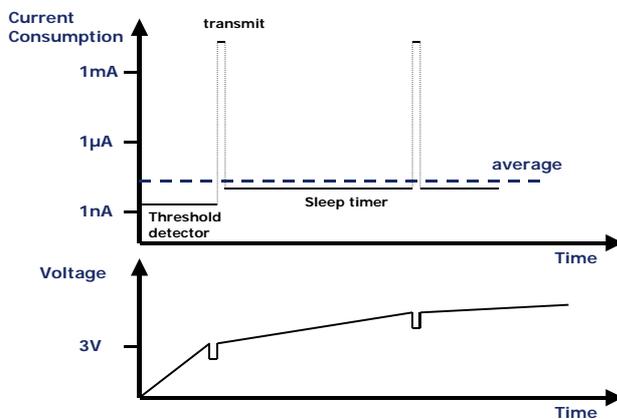


Fig. 3: Voltage and current as a function of time during start up.

RADIO SENSORS POWERED BY AMBIENT ENERGY: FROM STRANGE IDEAS TO MASS MARKET PRODUCTS

While several circuit blocks can be switched virtually completely power-free, others must be operated permanently. Among these are, in particular, threshold switches, which activate electronics and timers that trigger periodic activities such as the reading of sensors, when a specific voltage or sensor signal occurs. These circuit blocks rapidly dominate the entire energy requirements and must therefore undergo particularly aggressive optimization. The timers of the sensor modules STM 100 or STM 250 developed by EnOcean, which require only approx. 20 nA electricity, are a good example.

The timer, which is realized in analogue technology, completely switches off all components during the sleeping phases. This extreme optimization enables a “power reserve” of up to one week, even in complete darkness, solely through the reservoir capacitor located on the circuit board. Similar to radio transmission, the following also applies to the sensor functions: rapid activation and subsequent switching off of the sensor saves energy. This approach is particularly effective in respect of measuring parameters that change slowly, as long duty cycles can be achieved. As shown in the figure it is possible to achieve an average current consumption, which is only slightly above the current consumption of the continuously running blocks.

If, however, highly dynamic processes shall be analyzed it is worth preprocessing the data in the sensor and to reduce the data to be transmitted. In the best-case scenario, no measurement data is transmitted but solely the status, decisions or warnings. The sensor module STM 100, for example, only transmits measurements if a change against the last measurement transmitted is determined – after all, transmission requires more power than measuring.

2. Frequency selection

The radio frequency which is applied also strongly influences the system performance. The signal attenuation strongly depends on the frequency as shown

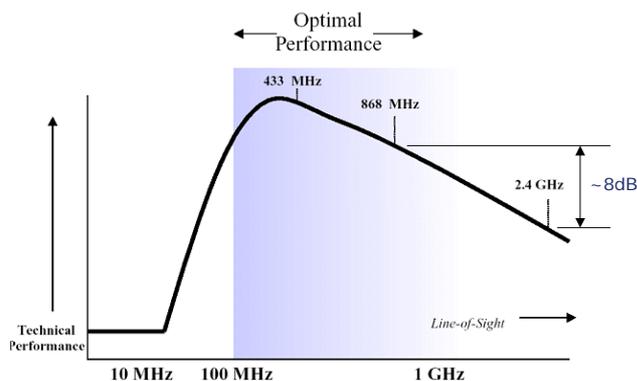


Fig. 4: Performance at different frequencies.

in figure 4. There is a difference of about 8dB performance between 2.4 GHz, which is widely used due to the ability for worldwide operation, and 868MHz, which is used by EnOcean for applications in Europe. If the same transmit power is applied this results in more than doubled reach for 868MHz. This means that at 2.4 GHz 4 times more nodes are needed to achieve area coverage which in turn means much higher component and installation cost.

With a reduced number of nodes also the traffic between the nodes is reduced. This makes it easier to keep the network management simple. For most applications a complex mesh routing mechanism is not needed – simple repeating is sufficient.

RADIO SENSORS POWERED BY AMBIENT ENERGY:
FROM STRANGE IDEAS TO MASS MARKET PRODUCTS

Wireless sensor networks

In wireless sensor networks based on EnOcean technology energy autarkic radio sensors are connected to line powered repeaters and end nodes. For residential homes usually an approach with up to two repeater levels is sufficient. This "Smart Repeating" concept keeps the installation "plug & play", complex system configuration is not needed.

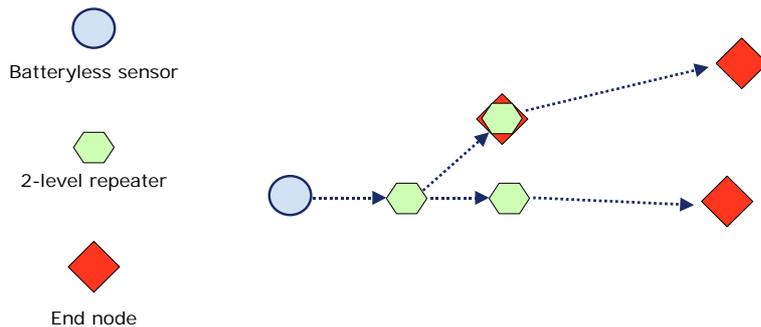


Fig. 5: EnOcean Smart Repeating concept

For larger buildings where 2-level repeating is not sufficient EnOcean is developing a mesh routing concept, which is adapted to the requirements of energy autarkic sensor nodes. Typical routing concepts are based on a bidirectional communication between all components. This is not possible due to the energy budget of the ambient driven devices. The routing concept is also optimized for simple installation. Hardware tools will not be required, the network is self-organizing.

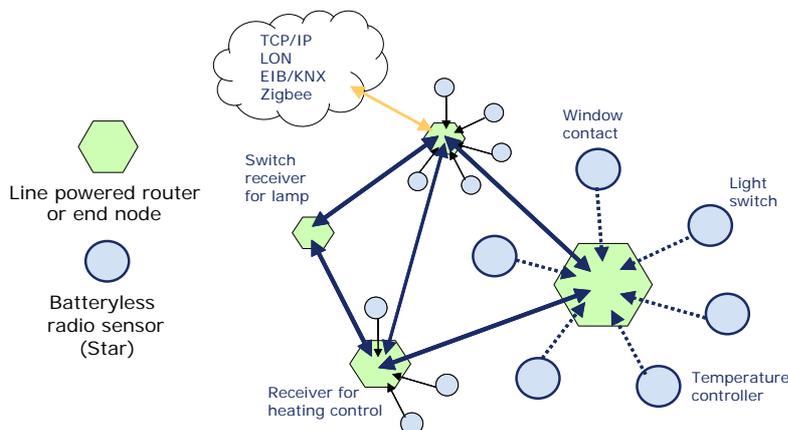


Fig. 6: Mesh Routing concept

Outlook

The EnOcean products available today have largely been developed as discrete solutions as no highly integrated components are available on the market, which feature all principal characteristics required. It is for this reason that the development of an ASIC commenced at the end of 2005, which unites all specific requirements of energy autarkic radio sensor modules in a single-chip solution. On the basis of this component a considerable reduction of size and cost will be possible in parallel with an improvement of performance and flexibility.

RADIO SENSORS POWERED BY AMBIENT ENERGY:
FROM STRANGE IDEAS TO MASS MARKET PRODUCTS

Currently a construction kit is being developed for energy converters and energy stores, which enables the collation of optimum modules for an application. In so doing, the range of usefully available energy amounts shall be made available with as few variants of the individual energy converters and energy stores as possible.