EGON –ACTIVE BACKSCATTER RADIO

U. Bilstrup[1], P.A. Wiberg[1], E. Nilsson[1,2], B. Svensson[1], and H. Pettersson[2]

1. Centre for Research on Embedded Systems
2. Laboratory for Mathematics, Physics and Electrical Engineeirng

School of Information Systems, Computer and Electrical Engineering,
Halmstad University, SE-301 18 Halmstad, Sweden

A new low power radio architecture based on a bi-stable regenerative transceiver with backscatter functionality is investigated. A characteristic feature of the new technology is its ability to support communication with thousands of units in very short time period; further that each of these units consumes very little energy. This opens up vast application opportunities in the field of cooperating embedded systems. The goal of the project is to develop a radio design that, after further product development, enables the fabrication of Radio Frequency Identification (RFID) units with a battery lifetime of up to eight years and a price level in the same range as passive RFID tags. Such RFID tags may in combination with nanosensors form low power and low cost sensor networks.

1. Background and Motivation

Today the radio technology has been miniaturized to a level where a transceiver can be realized in the size of a couple of square millimeters. This small form factor has led to new application areas such as: Road User Charging (RUC), Real-Time Location Services (RTLS), and Internet of things. Typical characteristics for these wireless applications are: short range (less than 100 m), short response time, low power consumption, and low data rate. If these requirements are paired with low price, current radio technology is inadequate. This challenge leads into a part of the design space of radio transceivers that traditionally has not been considered. Two radio technologies commonly mentioned for these application areas are passive and active radio frequency identification (RFID). A passive RFID system provides very low cost per tag, but such a system has an extremely limited operational range (a maximum range of a couple of meters). On the other hand active RFID systems are often based on common short range transceivers like IEEE 802.11 or ZigBee, where the tags are expensive and have rather high power consumption (10-100 mA when operating). The short operational range of passive RFID systems, and the high cost and high power consumption of active RFID systems more or less has disqualified both active and passive RFID technologies for these application areas. This has lead to an open field for new innovations in the area of radio technology.

2. Problem

The fact that the transmit output power is very limited for short-range radio transceivers, less than 100mW (typically in the range of 1mW to 10 mW), implies that it is not the emitted output power of the transmitter that dominates the power consumption. Instead the short range transceiver's power consumption is dominated by the radio electronics like: local oscillator, mixer and IF amplifiers and baseband signal processing. These parts of the transceiver are often common or similar building blocks for the receiver chain and the transmitter chain. This implies that the power consumption is similar for the reception and the transmission operations of a short range transceiver.

All commonly available short range transceivers have relatively high power consumption during operation (independent of if it is in receive or transmit mode). This makes it very hard to build a system where devices need to be accessible in short time. As an example, consider a RUC system where a reader must be able to identify a passing vehicle within one second. This response time requirement implies that the device on the vehicle must be in active (receiving) mode for several milliseconds, at least once every second – all the time! One can clearly see that there exists a fundamental trade-off between the response time and the power consumption of such a device. In fact the only realistic way to achieve both short response time and low power consumption is to minimize the power consumption of the transceiver in receiving mode. For cost reasons, in addition it is necessary to consider much simpler radio architectures than those commonly used for wireless short range transceivers today.

3. Approach

A new low power radio architecture and operation method is proposed; it is based on a bi-stable oscillator which has been applied in a feedback amplifier circuit. The two states of the bi-stable oscillator have been defined as receiving and oscillating. In receiving mode the oscillator circuit is biased in such a way that it is just below the threshold to start oscillating, i.e., the circuit is stable. A small incoming RF signal, on the right frequency, brings the oscillator to oscillating mode, the biasing of the oscillator is moved in such a way that the circuit starts oscillating. The bi-stability is based on the non-linear characteristics of the transistor. The new radio architecture is a reincarnation of Armstrong's super regenerative receiver, with the major difference that this circuit is only brought to oscillation by the presence of an external RF signal via the antenna. Figure 1 displays the basic architecture of the radio. It is based on an LC-tank with controllable resonance frequency (here indicated by the presence of a varactor diode), and feedback amplifier represented as a negative resistance. The negative resistance compensates for the resistive losses that are present in the LC-tank. This enables a control of the Q value (the selectivity) of the circuit. Interesting to notice is that the Q value (selectivity) and sensitivity increase for the circuit, the closer to the tipping point for oscillation that the circuit is biased. The first is true since when, G_L=-G_A, the Q value goes towards infinity. The latter is true, since the closer to the tipping point that the oscillator circuit is biased, the less RF energy (via the antenna) is necessary to bring the circuit into oscillation.

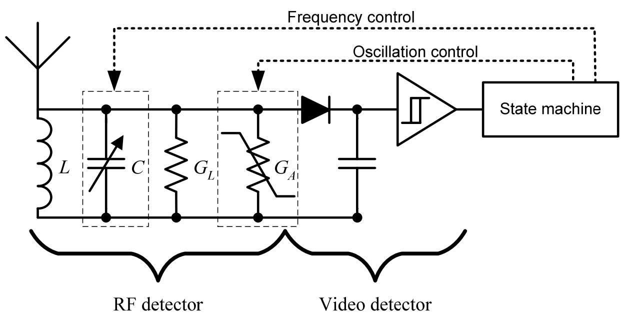

Figure 1: Principle of the new radio architecture.

The active backscatter provides a bidirectional information exchange channel between the reader and the entire set of tags. When the reader is emitting RF energy at certain frequencies, it brings all tags in range (tuned to these specific frequencies) to start oscillate. By defining an alphabet of symbols and assigning these symbols different frequencies the start of an oscillation is the symbol detection mechanism used at the tag, i.e., a form of course frequency shift keying. Further, by letting the tags oscillate for a longer time period than the time when the RF signal is emitted from the reader, it is possible to receive information from the set of tags − so called active backscatter. A tag will start emitting an RF signal at the tuned frequency as soon as it starts to oscillate, since the oscillator is non-shielded from the antenna.

By mapping each tag's individual address to a sequence of symbols, each tag is represented by a unique sequence of symbols. By further expanding the number of necessary symbols by two it is possible to feedback information to the reader during the arbitration sequence.

4. Sensor networks

A new class of sensitive low-power nanosensors is considered for integration with this radio technology. The sensor material is based on carbon nanotubes (CNT) designed to be selectively sensitive to predetermined target molecules down to extremely low concentrations. The sensor material, necessary low-power processing electronics and the novel patented type of radio frequency (RF) transceiver will form compact, cheap and power efficient wireless sensors for primarily medical, but also for safety applications.

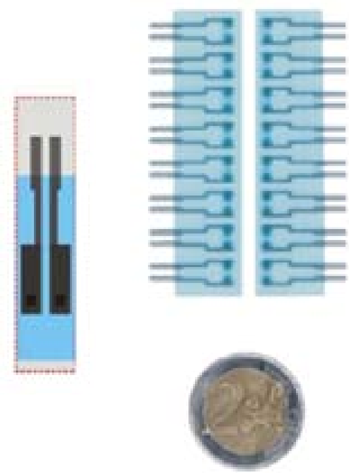

Figure 2: CNT sensors.

The basic sensor mechanism is that the electronic properties of CNTs depend sensitively on the surface of the tubes. If foreign molecules attach to the tubes, physical parameters e.g. electrical potential of the CNT changes drastically. Recently, Crespo et al [1,2] showed that CNTs can act as efficient ion-to-electron sensors for potentiometric analysis. The basic sensor design that we intend to integrate on the chip is a potentiometric sensing device.

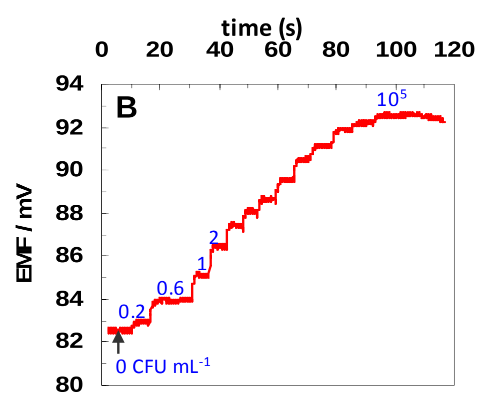

Figure 3: Selective detection of Salmonella Typhi.

This sensor contains two electrodes: one electrode with CNTs and one reference electrode made of e.g. Ag/AgCl. A picture of one sensing device with the two electrodes is shown in the left Figure 2. A potential difference (= voltage) between the two electrodes can be measured when a target substance is attached to the CNT electrode. The magnitude of the voltage is related to the concentration of the target substance which forms the detector signal. An important issue is that the CNTs must be modified to be selectively sensitive to detect a specific target substance. This modification process is called functionalization, and in this process a specific receptor is permanently attached to the CNTs which only interact with the target substance by means of molecular recognition processes. A unique functionalization is thus needed for each specific target substance. For instance the selective detection of Salmonella Typhi in water using a potentiometric sensor based on functionalized CNTs is shown in Figure 3..

Figure 2 displays, right, a matrix of 16 sensing devices together with a 2 Euro coin for comparison. The sensors are fabricated on e.g. a plastic substrate using a simple screen-printing technique in four steps: a) printing of a conducting paste that will form the CNT electrode after baking, b) deposition of the CNTs for instance by airbrushing of by drop deposition, c) printing of the paste (e.g. Ag/AgCl) that will form the reference electrode of the sensor after baking, and d) printing of the top insulating layer and subsequent baking. The CNTs are then ready to be functionalized with the receptor molecule (depending on the chemistry involved in the functionalization process this step might take place before printing of the insulating layer).

5. Status

EGON is an applied research project, in which the approach is to go from idea, via verification, to implementation of a full demonstrator. The present project status is that fundamental verification of the behavior of the bi-stable circuit has been conducted by simulation and implementation. For example, a first chip has been manufactured, see Figure 4, to compare the simulation tools and simulation models' result with a real implementation in a commonly used CMOS process. Furthermore, several discrete circuit designs are under evaluation.

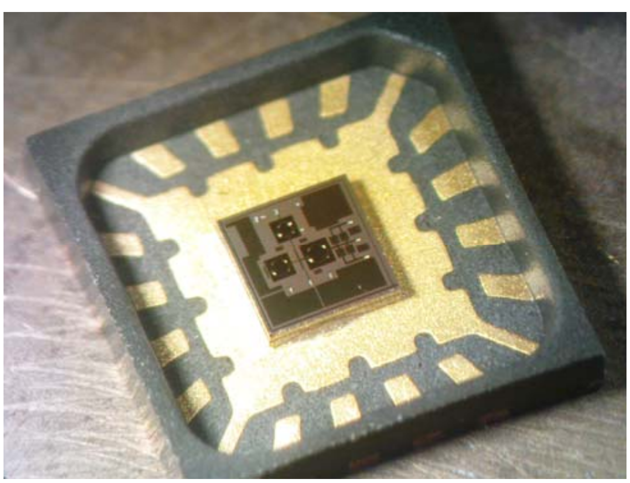

Figure 4: First test chip, an amplifier for the oscillator circuit.

PARTNERS AND STATUS

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Project leaders: Bertil Svensson and Per-Arne Wiberg.

[1] G.A. Crespo, S. Macho, F.X. Rius, Analytical Chemistry 80, 1316-1322 (2008).
[2] G.A. Crespo, S. Macho, J. Bobacka, F.X. Rius, Analytical Chemistry 81, 676-681 (2009).