Low power wireless ultra-wide band transmission of bio signals

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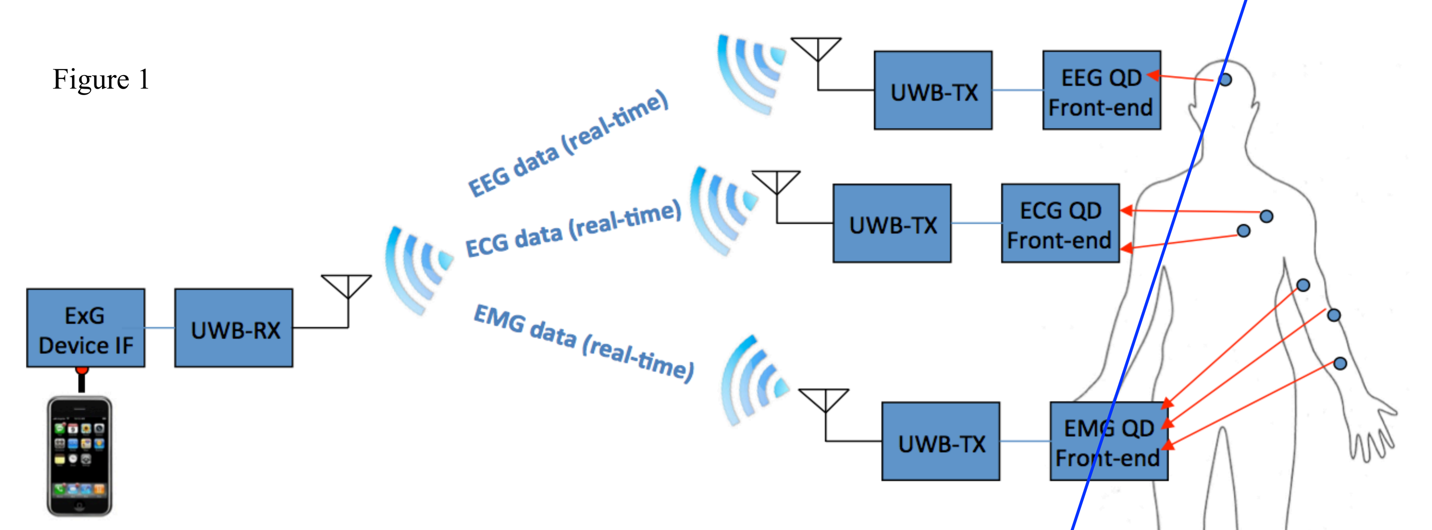
A brief description of the project

The paper shows the design of microelectronic circuits composed of an oscillator, a modulator, a transmitter and an integrated antenna. Prototype chips were recently fabricated and tested exploiting commercial 130 and 180 nm CMOS technologies. Preliminary results are summarized along with some measurements of the prototypes' behaviour. A digital Synchronized On-Off Keying (S-OOK) was implemented to exploit a Ultra-Wide-Band transmission. In this way, each transmitted bit is coded with a S-OOK protocol (see later).
Wireless transmission capabilities have been also evaluated. The chips fit a large variety of applications like spot radiation monitoring, punctual measurements of radiation in High-Energy Physics experiments or, since they have been characterized as low-power components, readout systems for medical applications.

The main objective of this proposal is to design a system for transmission and reception of signals and biological parameters through dedicated radio circuits using a purely digital approach (asynchronous events). Each source of biomedical parameters will be translated into temporal events that can be transmitted and received without further processing. The system, in fact, thanks to its intrinsic use of events, allows controlling in an extremely efficient release of energy for the transmission of information, and therefore exploit an approach completely on-demand to minimize the consumption of power. The events are generated occurrence of particular patterns in the input signal (and then it is extracted the information content of the signal of interest) and efficiently (with respect to energy consumption, complexity, integration and flexibility) synthesized via a digital system asynchronously. The information is transmitted only when required, allowing for a longer battery life than traditional wireless processes. From the technological point of view it will be exploited the wireless transmission techniques that employs the Impulse Radio Ultra-Wide-Band, localized around 3-5 GHz, for transmitting and receiving signals by very reduced temporal pulses, resulting in very wide spectral occupation. As a consequence of that, we gain limited power consumption at the transmitter side.
This wireless system can find various applications in the field of medicine, allowing accurate measurements of various biological parameters detected from time to time by a single receiver (collector). The latter will have the task of reworking the received signals to identify the correct sequence and the source of information. Figure 1 graphically shows the idea. The device must have reduced final dimensions to be integrated on a single microchip, which, after having amplified and processed the information of external sensors, must be able to transmit it at distances of the order of meters, possibly using an integrated antenna. The miniaturization of the system to use more sensors, perfectly compatible with low-consumption electronics, can meet the needs of medical applications such as the remote control of biological parameters or the construction of robotic equipment (exoskeletons). The proposed mechanism will be developed in a prototype phase to discrete components in order to validate an initial feasibility study, and will then be integrated microchip in a final stage.

Figure 1



Transmitter and receiver of bio signals via Ultra Wideband apparatus

We have been able to mount a prototype data acquisition chain composed of a commercial amplifier for instrumentation (INA114), which we use to interface and read out the bio signals. The Figure 2 shows how this amplifier is mounted in the readout chain, used to read out a cardiac signal, and how it is interfaced with the following voltage controlled oscillator (VCO) circuit, showed in Figure 4. The VCO is used to digitize the information and to interface with a wireless transmitter. The Figure 3 shows the digitized signal (green waveform), which changes in frequency depending on the amplitude of the VIN signal (blue waveform).

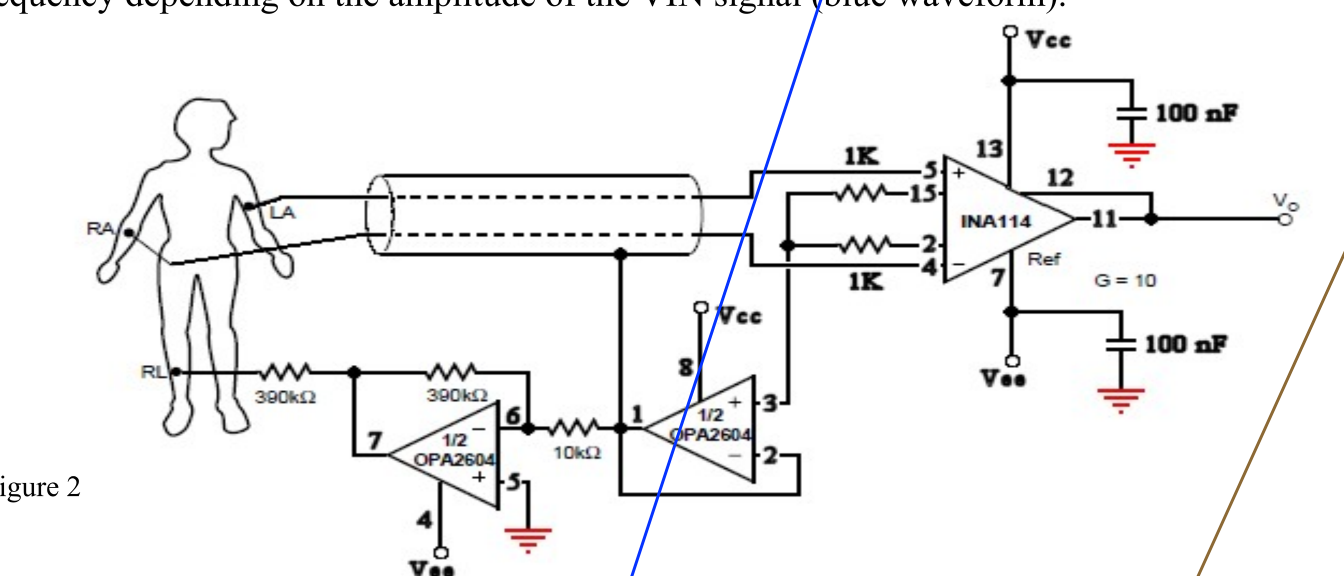


Figure 2

The VCO is part of a Sigma-Delta modulator (as it is like a serial 1-bit converter) that converts a given analogic continuous signal to a digital series of pulses, which are read as a variable-frequency square wave. After that, the S-OOK modulation takes place and, on every rising edge of the VCO output, a series of RF burst are generated (See later).

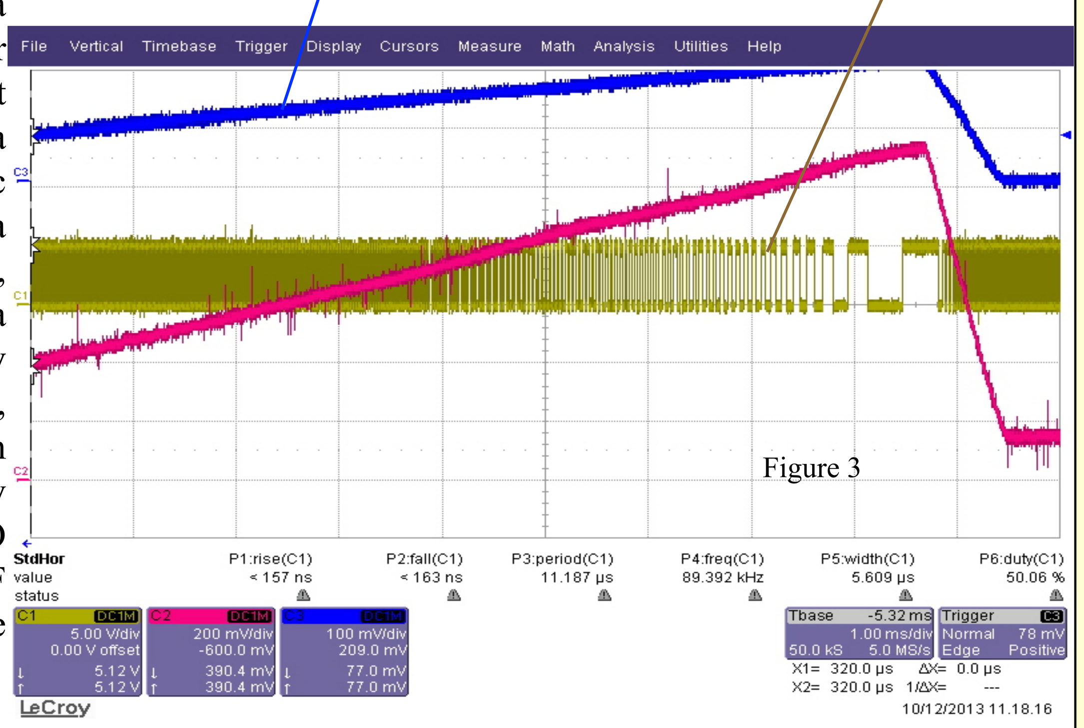


Figure 3

The Sigma-Delta architecture

It is here described the design of a Sigma-Delta-like modulator to interface with the analogic output voltage level of a generic sensor. The aim is to be able to read out the sensor output level and convert this voltage variation into a frequency shift over a free-running oscillator. Figure 4 shows the basic blocks that implement the modulator:
- a Sloper which acts as an integrator since it integrates a voltage level, being successively reset by the output signal of the adjacent comparator;
- a Comparator which compares the output level of the sensor with a predefined reference level;
- a Toggle which reads out the output saw-tooth signal of the comparator and generates a more stable square waveform with a frequency range of the order of hundreds of kHz. For this purpose a digital frequency divider was also used (FFs);
- an Enable_Trasmitter which creates a about 200 ns monostable signal to enable the following Ring_Oscillator;
- a Ring_Oscillator that oscillates at 3.5 GHz, if enabled. It drives the Trasmitter for the final antenna coupling;
- one Trasmitter able to drive, at 3.5 GHz, a 50 Ω antenna.

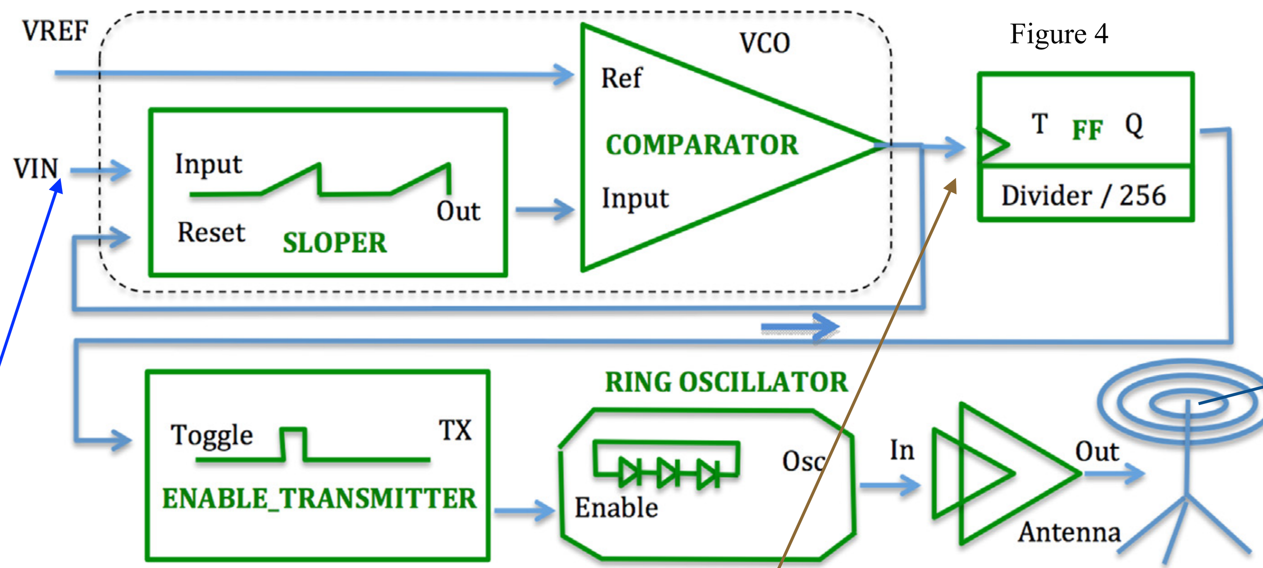


Figure 4

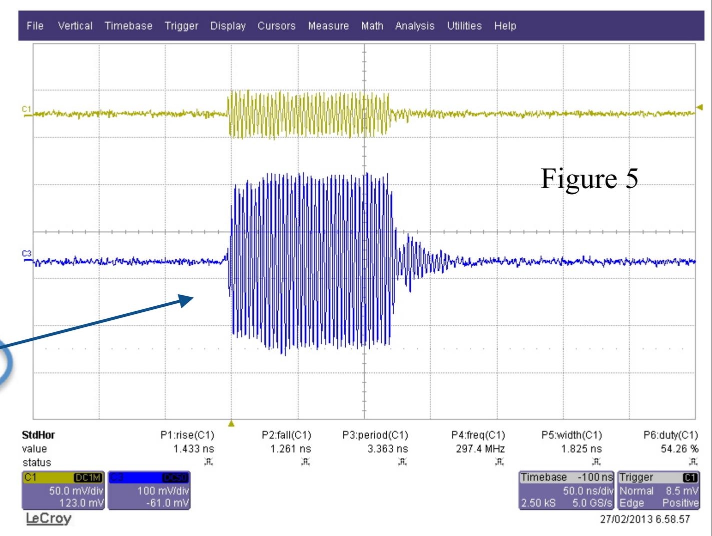


Figure 5

The circuit refers to an input "VIN" voltage from the sensor whose range may vary, in this contest, from 0 to 3 volts. Nonetheless, the measurements presented here were partially carried out using the Ring_Oscillator at 350 MHz other than at 3.5 GHz. Figure 6 shows a simulated frequency variation of the VCO versus the "VIN" voltage.

It is apparent in the Figure 6 that as "VIN" varies from 0 to 3V the Toggle circuit produces a square wave with almost decreasing frequency from about 85 to 50 kHz.
Figure 7 shows the detected power vs distance, showing that we are able to detect the waveform in a one-meter-range.
The Figure 8 shows the UWB spectrum of the transmitted signal. The received and amplified RF waves are visible in the Figure 5, aside the block-scheme. The peak in Figure 8 is centered at 350 MHz, as expected.
The Figure 9 shows the S-OOK modulation protocol, described below.

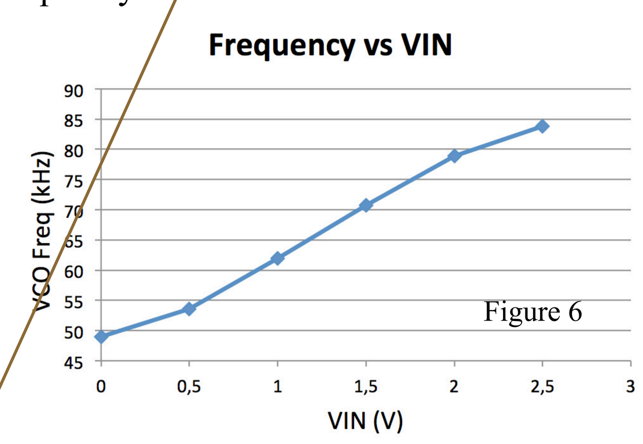


Figure 6

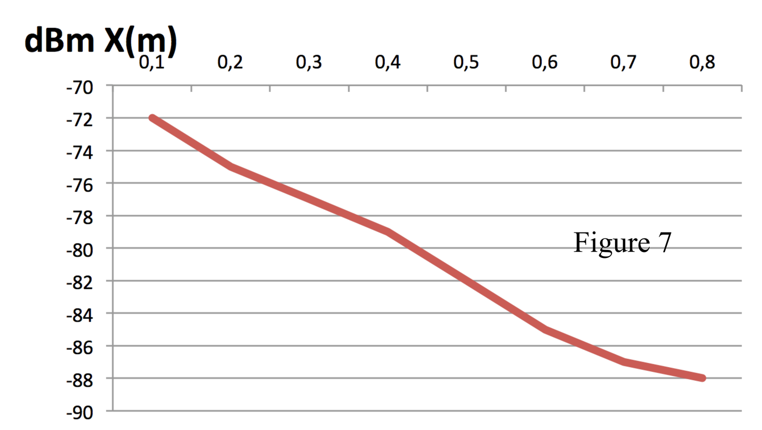


Figure 7

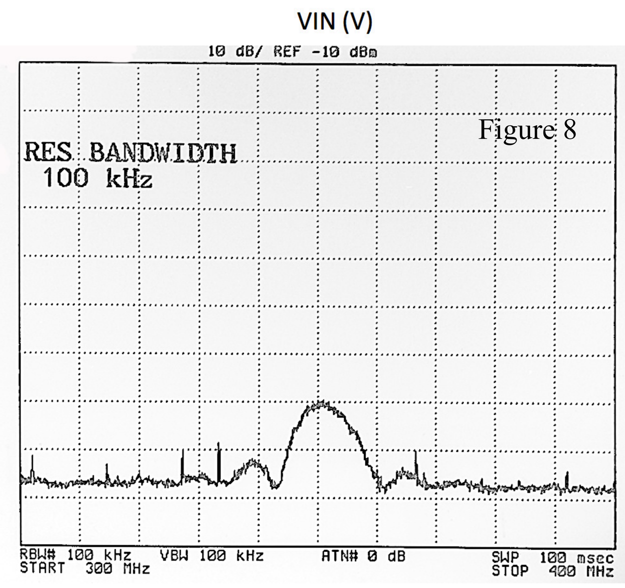


Figure 8

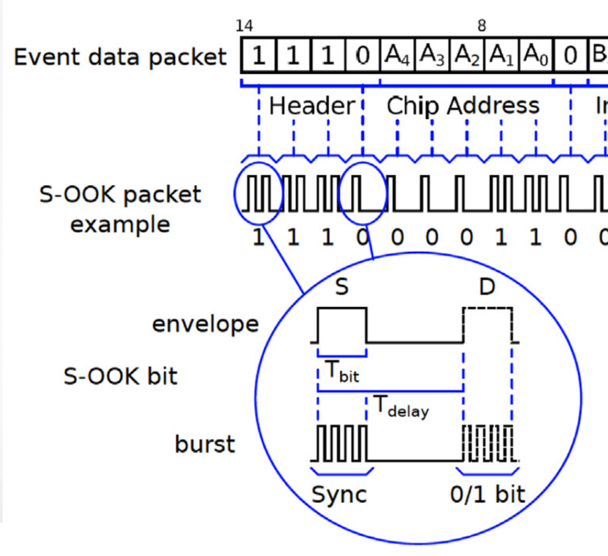


Figure 9

The digital modulation

The transmission tests were carried out exploiting a specific digital modulation, namely Synchronized On/Off Keying (S-OOK) digital modulation. Moreover, for these tests the carrier was used nominally at 3.5 GHz. The S-OOK modulation is devoted to "translate" bit transmission requests into transmission trigger events for the following UWB transmitter. Standard OOK maps each 1 into an impulse trigger, and each 0 into a "space" that is a no impulse trigger, or just a delay. S-OOK adds a synchronizing impulse "S" before the data bit "D", thus allowing the receiver to know whenever a data bit is being effectively transmitted and hence not requiring to recover any timing information regarding the data stream. Despite using a synchronizing impulse, this solution allows to design a fully asynchronous event-based receiver, more robust with respect to undesired delays due to the transmission channel. Here we have used an external S-OOK modulator together with the on-chip transmitter. Indeed, this S-OOK modulation was easily implemented in one prototype ASIC. In more detail, any digital series of 0s and1s, i.e. the modulation sequence of bits, enables or disables the RF transmitter. Hence, the effective transmitted bits were formed by a series of RF bursts centered at a carrier frequency of 3.5 GHz. VREF input in fact, has the capability to enable the entire circuit when set at a 1 digital level and disabling the transmission if set to 0 logic level. The above Figure 9 shows a sequence of 14 bits, each of which composed of a set, or envelop, of RF pulses that include a header and an address code. In this example the S-OOK modulation carries the information to transmit, via the packet frequency: the higher the 14-bit packet repetition time, the lower the original analog signal level. Thus, a variation of the input signal of the sensor causes a variation on the frequency of the14-bit packets. The address and coding bits are here meant only to a multi channel parallel transmission. Eventually, the T-bit and T-delay in the Figure 9 can be adjusted depending on the signal input bandwidth. By following this approach any information can be transmitted, consuming very low power from the transmitter side.
The Figure 10 below show the received S-OOK bursts, along with the superimposed amplitude of the reconstructed bits.

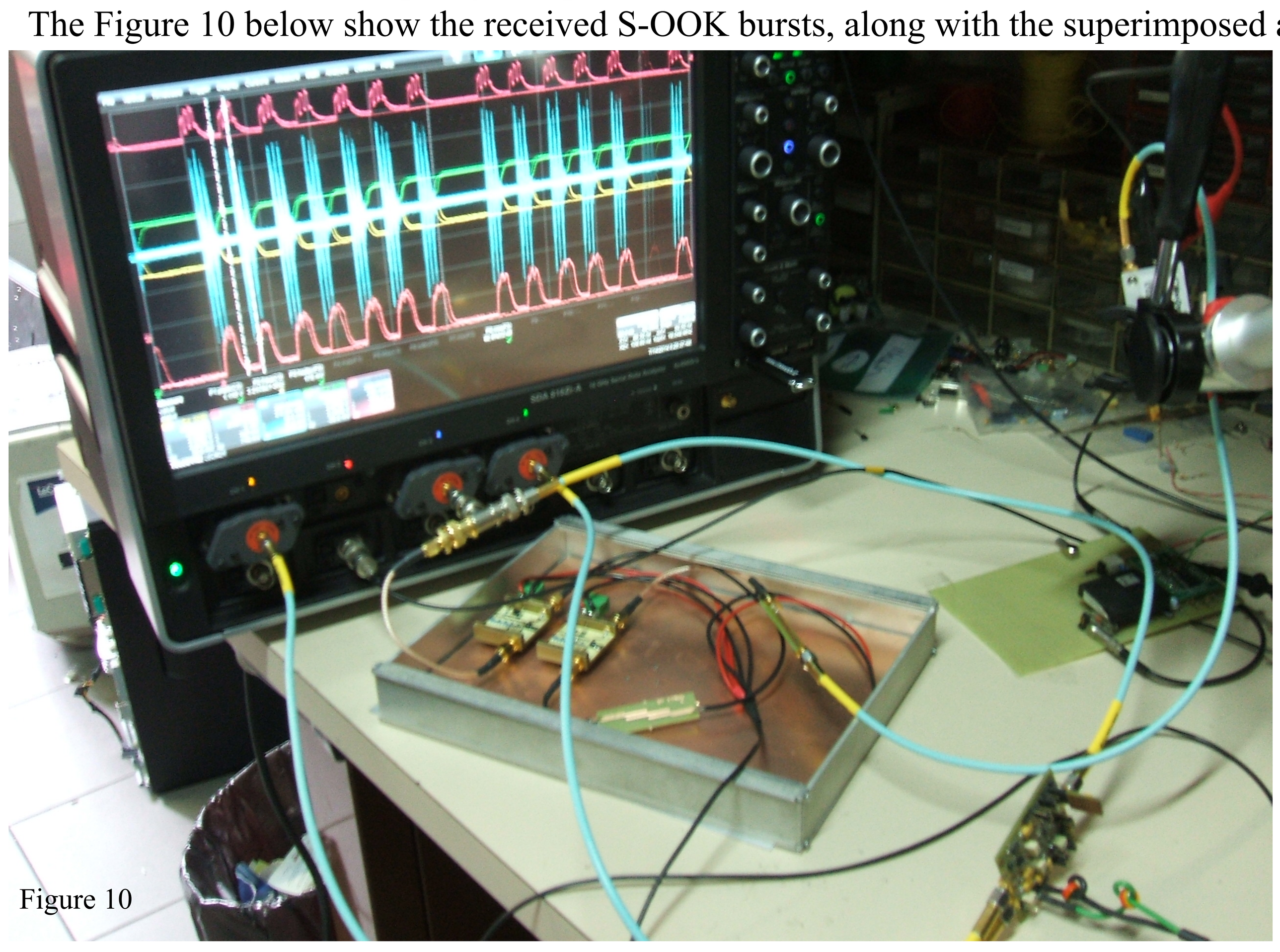


Figure 10

Conclusion

The proposed approach using standard CMOS process suggests the use of this technology for monolithic implementations of generic sensors along with microelectronic readout circuits. In addition, the prototype that we have described allows an Ultra-Wide-Band, low-power digital modulation. The range of transmission via the integrated antenna is of the order of 1 m and the total power consumption was measured as low as a few hundreds of μW. Future improvements of the microelectronic design are oriented to include an additional on-chip remote powering system, using state-of-the-art deep submicron architectures. In this way the chip will be able to work without any in-system battery and this also fits medical applications.