Wireless Ultra-Wide Band Transmission of (Bio)Signals

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***Abstract*—The paper describes the study, design, fabrication and test of microelectronic circuits used to exploit Ultra-Wide-Band (UWB) wireless communication for bio-medical applications. In particular, it is here described a prototype Application Specific Integrated Circuit (ASIC) composed of a modulator, a high-frequency oscillator and a transmitter. Other prototype circuits were recently fabricated and tested exploiting commercial 130nm and 180nm CMOS technologies. Wireless transmitted signals have been detected and measured by a receiver circuit that we have built up using a commercial wide-band amplifier connected to custom designed filters and a digital demodulator. Preliminary results are summarized along with some waveforms of the transmitted and received signals, as a validation of the feasibility of the system. In particular, wireless transmission capabilities of the system have been evaluated within a one-meter of transmission distance. The main aim of this research is to study the possibility to integrate all the described electronic components into a very small, low-powered, microelectronic circuit fully compatible to bio-medical (and in-vivo) applications. Nonetheless, the use of external sensors can spread the variety of applications of the device, as it is basically independent of the physical parameter sensed by the sensor. In addition, this study exploits a Synchronous On-Off Keying (S-OOK) modulation within the UWB transmission: this is a novel type of transmission for such small -1mm^2 - devices, which make them suitable also to in-vivo applications.**

***Index Terms*—UWB, biosignal, wireless, on-off keying**

I. Introduction

The main objective of this work is to design and test a system that might be used for transmission and reception of signals derived from biological parameters through dedicated circuits using a purely digital approach (asynchronous events). Each source of biomedical parameters is read out and its voltage signal is translated into temporal events (bursts) to be transmitted and received without further processing. The system, in fact, allows controlling in an extremely efficient way the release of energy for the transmission of information, and therefore exploit an approach completely on-demand to minimize the consumption of power. The paper describes a design composed of a modulator, a high-frequency oscillator and a transmitter, which has been recently fabricated and tested via some commercial CMOS technologies nodes: from 30 nm [1] to 180 nm [2]. The information is hence transmitted only when required, allowing for a longer battery life than traditional wireless processes [3], [4]. The studies fit a large variety of applications like spot radiation monitoring [5] or, since the circuits under test have been characterized via low-power components, readout circuits for medical applications. From the technological point of view we are exploiting wireless transmission techniques that employ the impulse radio Ultra-Wide-Band, localized around 3 to 5GHz, for transmitting and receiving signals by very reduced temporal pulses, resulting in very wide spectral occupation. And this is why we gain limited power consumption at the transmitter side.

This wireless system can fit various medical applications allowing parallel measurements of biological parameters detected from time to time by a single receiver (collector). For example, the work described in [6] shows studies already investigated using sensors for temperature, sleep and blood pressure signals, acquired via traditional non-wireless electronics. We are working for the replacement of that readout electronic with our wireless system.

The receiver collector has the task of reworking the received signals to identify the correct sequence and the source of information. Fig. 1 graphically shows the conceptual idea. The entire transmitting device must have reduced final dimensions to be eventually integrated on a single microchip, which must be able to transmit the information at distances of the order of a few meters, possibly using an integrated antenna. The miniaturization of the system allows to use sensors working in parallel, is perfectly compatible with low-consumption electronics.

In more detail, if we refer to electromyographic, electrocardiographic or electroencephalographic signals, we need to read out very small voltage amplitudes, of the order of tens of μV, overwhelmed with a much higher (white) noise. For these types of applications the front-end circuit, from the electronic viewpoint, requires a so-

Manuscript received February 4, 2016; revised September 16, 2016.

doi: 10.18178/ijeee.5.2.135-139

called amplifier for instrumentation, here not described, to directly interface with metal-plate sensor's outputs.

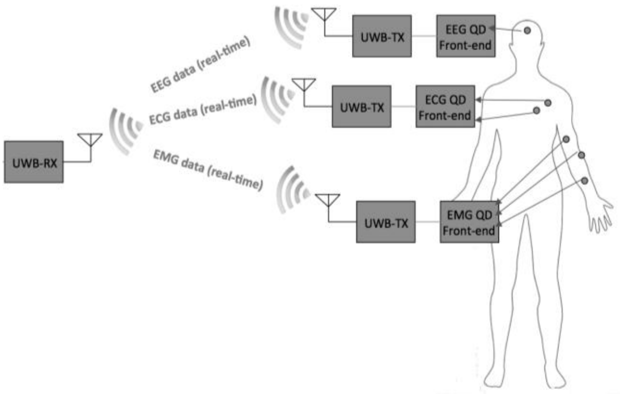

Figure 1. T_x and R_x of bio signals via an ultra-wide-band apparatus.

These are those devices normally used to acquire biological signals to monitor electrocardiograms. To do that, these amplifiers amplify and expand the bio-signals to normal range of amplitudes of the order of 1 V [7].

In this study we do not face the medical or clinical aspects of the system; we only investigate the technical and electronic features of the prototype.

II. Data Acquisition System

We have been able to mount a prototype data acquisition chain by including a commercial amplifier for instrumentation [8], which we use to interface and read out the bio signals. After that the amplified signal feeds a digital modulator, schematically composed of a Voltage Controlled Oscillator (VCO) circuit. The VCO is used to digitize the information by converting the voltage amplitude of the sensor into a variable frequency digital wave (voltage-to-frequency conversion). Then, the digital signal can interface with a wireless transmitter. The Fig. 1 shows the principle of how different and independent sensors can be read out and how the information can be wireless transmitted to a unique receiver. Again, the information is digitally modulated to transmit an UWB protocol, balanced around a carrier of about 3.2 GHz. In addition, the example in the Fig. 1 is designed to read out a variety of signals that range from cardiac Electro CardioGram (ECG), cerebral Electro EncephaloGram (EEG) or ElectroMyoGram (EMG) signals, via Quick Disconnect (QD) techniques. Eventually, the asynchronous transmissions are collected via a unique receiver, the UWB-R_x in the Fig. 1. The flexibility of the proposed system to interface with different types of sensors, along with the very small dimensions of the transmitters, i.e. of the order of 1 mm^2 as shown below, make the system unique in the field especially if connected to radiation sensors that exploit the re-programmability of the floating-gate based devices. For dosimetry or radiation monitoring applications, in fact, the circuit needs an external radiation sensor or via embedded on chip sensors. By contrast, medical applications are those that we are also studying for in-vivo measurements on small animals. In addition, the examples reported in [9], [10], show that the UWB transmission and S-OOK modulation are features particularly suited for low-power, short-range applications.

III. Modulator

The modulator has been fabricated recently, as part of an integrated circuit, using a 130nm CMOS process [11], [12]. The high-frequency carrier was set at 3.2GHz. The goal is to be able to read out the original sensor output level and convert this voltage variation into a frequency shift over a free-running oscillator. Fig. 2 shows the basic blocks that compose the modulator:

- The Sloper, which acts as an integrator since it integrates a voltage level, being successively reset by the output signal of the adjacent Comparator;
- The Comparator, which compares the input signal with a reference level (VREF). The Comparator and the Sloper form the VCO, altogether;
- The toggle (T type FF) which reads out the output saw-tooth signal of the VCO and generates a square-like wave with a frequency range of the order of hundreds of kHz. A divider was also used to reduce the frequency to tens of kHz;
- The Enable_Transmitter, which creates a 120-ns signal to enable the following Ring_Oscillator;
- The Ring_Oscillator, which freely oscillates at 3.2GHz, if enabled. It drives the Transmitter for the final antenna coupling;
- The Transmitter that drives an antenna at 3.2GHz.

The circuit refers to an input "SENSOR VIN" voltage from one sensor, upper ramp. The amplitude in this contest varies in the range of 1 V (i.e. 1V to 2V).

Fig. 3 shows a simulation of the circuit in Fig. 2. As a consequence of a 1 V amplitude variation (decrement) of "VIN" the toggle circuit produces a square wave with a linearly decreasing frequency. This has been measured from about 85 to 50kHz. Fig. 4 shows the received and amplified high-frequency wave is visible. The left side of the figure shows the detected burst at 3.2GHz, created by the Ring_Oscillator. This oscillator, enabled depending on the "VIN" level, creates a burst every rising edge of the VCO output as shown in the right side of Fig. 4. The burst rate, i.e. how many of these are present in a given period, is inversely proportional to the voltage amplitude of the sensor's output.

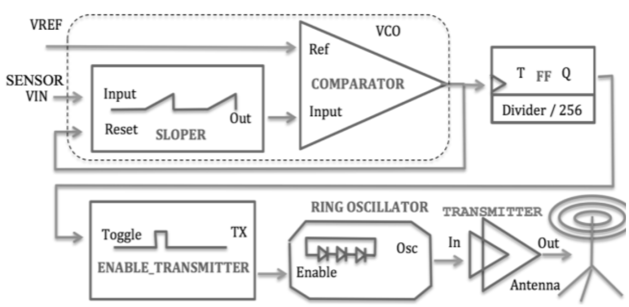

Figure 2. Basic blocks of the modulator circuit.

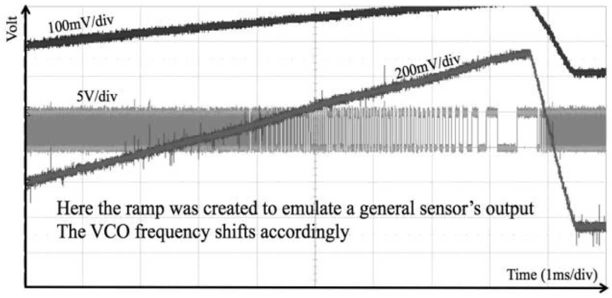

Figure 3. Sensor's signal (top saw-tooth curve), amplified sensor's signal (bottom saw-tooth curve), VCO output frequency (square wave).

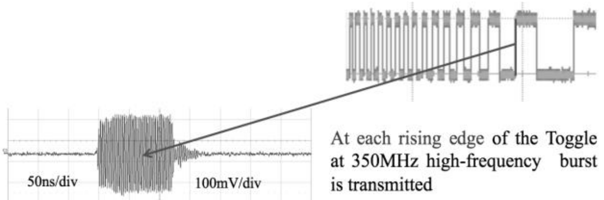

Figure 4. 120-ns wide received burst created by the 3.2GHz ring oscillator.

IV. Digital Protocol

The transmission tests were carried out exploiting a carrier frequency set at 3.2GHz, using a prototype chip designed with the UMC 130nm technology within the IIT@Polito group. Thus, the effective transmitted bits were formed by a series of bursts, always centered at a carrier frequency of 3.2GHz. In more detail, a specific digital modulation called Synchronous On-Off Keying was used to span a set of 15 bits, here not visible in detail, instead of one individual burst. All the previous description of the system remains valid but here, the transmitted information is composed of 15 coded bursts instead of one individual. In this way the different channels of transmission, related to different sensors working in parallel, can be identified as they embed a different digital mask. Fig. 5 partially shows how a set of 3.2GHz bursts was being transmitted. The top waveform is an emulated sensor's output ramp, which slows down the frequency of the modulator square wave (central waveform), which in turn slows down the repetition time of the high frequency bursts (bottom waveform).

All in all, in this example the S-OOK modulation carries the information to transmit, via the packet frequency: the higher the 15-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 the 15-bit packets. The address and coding bits are meant to a multi channel parallel transmission, to reconstruct the origin of each packet. By following this approach the information (modulated signal) can be transmitted, consuming very low power from the transmitter side as, in any case, for most of the time the high-frequency Ring_Oscillator is switched off. In the receiver circuit an accorded antenna receives the bursts, and via a series of band-pass filters reconstructs the envelops of the transmitted modulating wave.

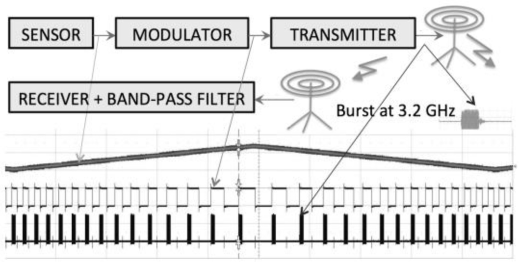

Figure 5. Digital transmission.

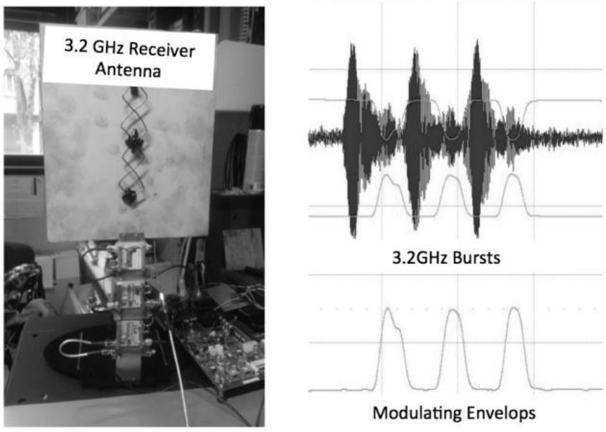

Figure 6. Burst in the receiver, after being amplified and filtered.

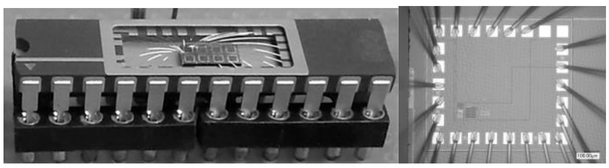

Figure 7. Left: One of the prototypes including 8 flavors of the transmitter chip. Right: one individual 1x1 mm^2 transmitters.

Fig. 4 shows how the high-frequency 3.2GHz waves, within the burst, are filtered out and only the envelopes are revealed despite the carrier. After that, a digital circuit treats this modulating wave as a digital wave made of 0's and 1's and reconstructs the transmitted information via a bit stream. Fig. 7 shows the chip bonded on a DIL-package for laboratory tests. In particular, the prototype was designed in different flavors with different internal electronic geometries.

V. The Ultra Wide Band

Fig. 4 shows one of the time-bursts as typically transmitted signals for this prototype. The correspondent expected spectrum is shown in the Fig. 8. We have carried out many measurements by varying the distance of receiver and the central frequency of the carrier at the transmitter side. In the Fig. 8, a 350 MHz frequency spectrum example of a transmitted UWB signal is shown. Fig. 9 shows an equivalent plot centered at 3.2 GHz and this confirms that the concept is applicable over a wide range of frequencies. During these measurements we have used not only an external antenna (see Fig. 6) at the transmitter side, hence just outside the chip shown in Fig. 7, but also an on-chip antenna prototype, tuned for a central carried over 1GHz. Fig. 10 shows power measurements at the receiver side using on-chip antennas at various distances of the receiver in the range of 10cm to 1m. In these conditions, the total average power was evaluated in about 165μW, which is power consumption fully compatible with wireless, low-power applications. In addition, recent studies and researches in monitoring systems for space applications show interest for extremely low-power circuits - ASICs -.

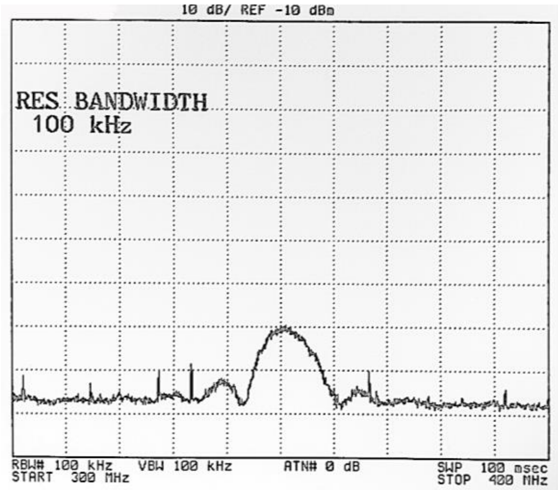

Figure 8. The power spectrum starts at 300MHz and stops at 400MHz. A 350MHz peak is clearly visible.

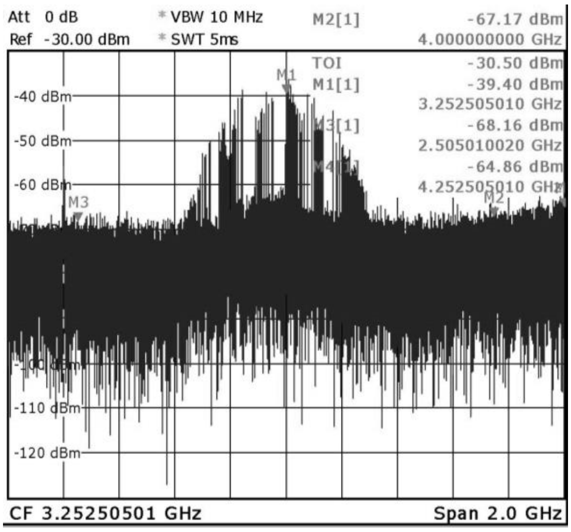

Figure 9. Power spectrum centered at 3.2 GHz.

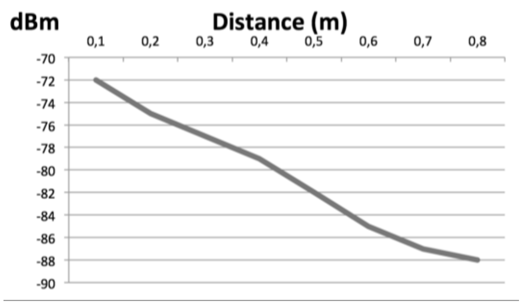

Figure 10. Power distribution (dBm) of the transmitted signal versus distance.

VI. Conclusion

The proposed approach using standard CMOS process suggests the use of this technology for 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 (possibly also via an 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. Electrocardiographic, electromyographic, cerebral electroencephalographic, other biological parameters such as blood temperature or pressure are the main targets for the proposed study. All in all, the UWB carrier frequency used in the electronics can be set upon the applications. For example, for in-vivo measurements, a lower frequency would be considered to have a greater electromagnetic power transmission into the body (mainly water).

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