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Wireless ultra-wide-band transmission prototype ASICs for low-power space and radiation applications

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ABSTRACT

The paper describes the design and the fabrication of a microelectronic circuit composed of a sensor, an oscillator, a modulator, a transmitter and an antenna. The chip embeds a custom radiation sensor, provided by the silicon foundry that has fabricated the prototypes, but in principle the entire system can read a general sensor, as long as a proper interface circuit is used. The natural application for this circuit is radiation monitoring but the low-power budget extends the applications to space where wireless readout circuits can be applied to any type of sensors, even if not radiation sensitive devices.

1. Introduction

The chip is designed to asynchronously trigger an Ultra-Wide Band (UWB) transmitter with a repetition frequency dependent on the sensor voltage level. In more detail, for a main medical application, a 403 MHz band has been chosen because at this frequency the human body shows the least attenuation of radio waves. An integrated antenna was also implemented into this prototype for testing purposes only, since frequencies of hundreds of MHz would require much larger antennas. The chip was fabricated using the TowerJazz semiconductor CMOS commercial 180 nm technology, by extending the principles of other designs, constructions and measurements performed on similar circuits recently tested at the “Istituto Italiano di Tecnologia”, Center for Space Human Robotics in Turin, Italy. The tests confirmed the feasibility of the proposed approach via event-driven asynchronous transmission, Ultra-Low Power and Ultra-Wide-Band [1–3]. The entire layout area is about 1 mm^2 but the sensitive cell only is $30 \times 30\ \mu m^2$. The sensor device was separately tested using previous samples fabricated using the same technology and a sensitivity of 1 mV/rad was estimated within an absorbed dose range up to 10 krad. The circuit is powered with 3.3 V and the total power consumption is very low, i.e. about 165 μW, making it also upgradable with a remote power system. The paper shows also some preliminary measurements on the transmitted power versus distance, as a validation of the feasibility of such a low-power wireless transmission circuit.

2. The readout architecture

A Sigma–Delta-like modulator was used as a readout circuit to interface with the analog output voltage level of the sensitive cell (sensor). The sensor output voltage is then converted to a frequency shift of a free running Voltage Controlled Oscillator (VCO).

Fig. 1 shows the basic blocks of the Sigma–Delta modulator:

– a VCO, which is composed of an integrator – here named Sloper – and a Comparator. The Sloper integrates the quasi-constant voltage of the sensor's output and creates a ramp. This saw-tooth signal starts from the sensor's output value and reaches an external reference voltage REF, here set at 2 V. When the Sloper reaches the REF level the Comparator triggers a reset signal that restarts the Sloper. The Sloper then integrates again, starting from the sensor's signal level. As a consequence of the Sloper and Comparator functions, the VCO frequency depends on the sensor voltage, and this frequency is the transmitted information. In fact, the higher the sensor's output level the sooner the Sloper reaches the REF voltage and the higher the VCO frequency;
– a Toggle circuit which reads out the VCO output saw-tooth signal and generates a more stable square wave. This wave is

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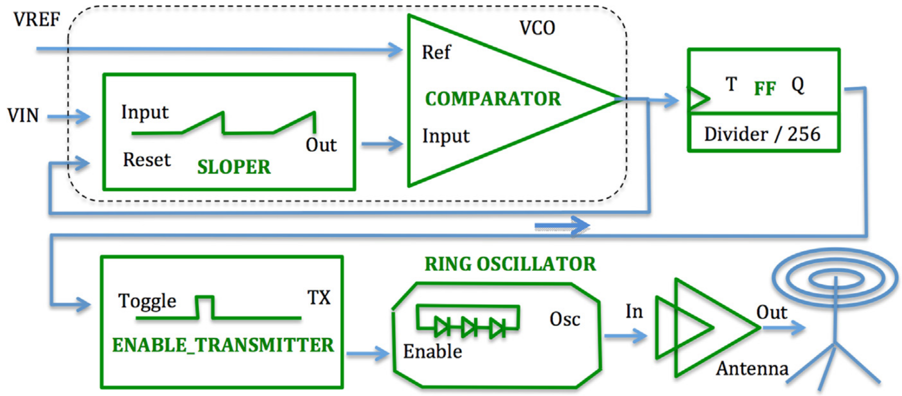

Fig. 1. Block diagram of the Sigma–Delta modulator used as a readout circuit.

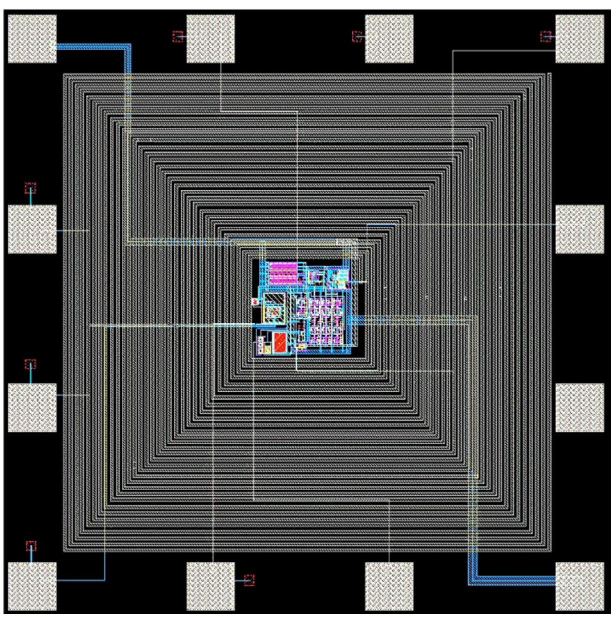

Fig. 2. Layout of the full prototype with an integrated antenna distributed in a spiral outside the inner circuit area towards the pads.

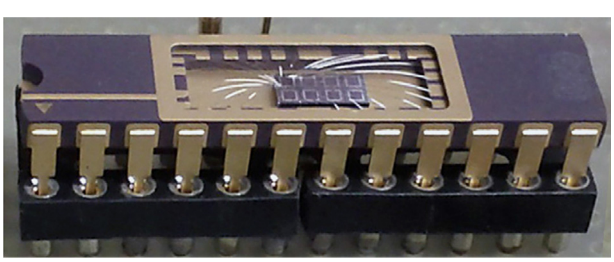

Fig. 3. Picture of the fabricated prototype.

furthermore reduced – via flip-flop in series – to a desired frequency of the order of hundreds of kHz;

- an Enable_Transmitter circuit which creates a 200 ns wide monostable signal to enable the high-frequency Ring_Oscillator;
- a Ring_Oscillator that oscillates at about 400 MHz, when enabled. The oscillator drives the Transmitter that interfaces with the antenna;
- a 400 MHz Transmitter capable to drive a load composed of a 10 pF capacitor and a 50 Ω resistor in parallel.

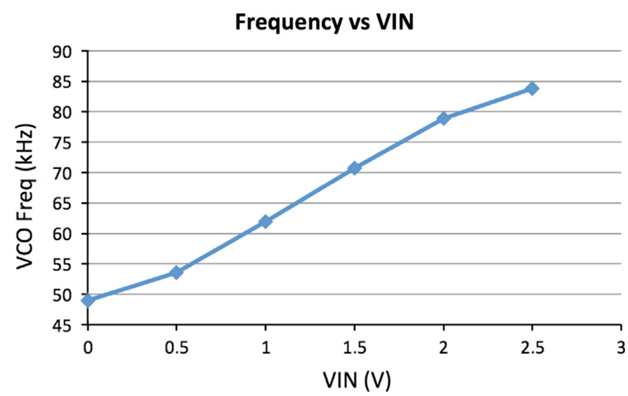

Fig. 4. Dependence of the output frequency VCO on VIN, the input voltage at the modulator input, as measure on the first prototype of the chip.

Fig. 2 shows the entire layout of the chip that is 1 mm^2, pads included. The active part inside is about 200×200 μm^2 and the sensitive cell only is 30×30 μm^2. There is also a visible antenna, for transmission tests, distributed in a spiral outside the inner circuit area towards the pads. This chips was one of a set of prototypes recently fabricated and, particularly, we wanted to study different antenna shapes. Here we present a case with a spiral-shaped antenna. Fig. 3 shows the chip bonded on a DIL-package for laboratory tests.

3. Ultra-wide band wireless measurements

Fig. 4 shows a plot of preliminary tests of the readout circuit. The input varies – VIN Sloper input in Fig. 1 – from 0 V to 2.5 V and the VCO circuit increases the output frequency quite linearly from 50 kHz to 85 kHz. Tests on the entire circuit connected to off-chip antennas are still ongoing since a fine tune of the parasitic components must be performed to enhance the transmission.

A set of measurements was done to evaluate the received UWB signal power, by varying the distance of a spectrum analyzer, which was used as a receiver. A 10 dB/div monitor was set with a 100 kHz input filter to clean the integrated input signal. Fig. 5a shows that the Ring_Oscillator, which generates the UWB waves, works at a lower frequency than expected, i.e. 350 MHz instead of 400 MHz. This discrepancy can be interpreted in terms of parasitic parameters of the oscillator, which were not entirely under control during the design. Nevertheless, despite the foreseen inefficiency of the antenna due to its very small geometry with respect to the wavelength, the

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