A RF TRANSCEIVER FOR WIRELESS MONITORING SYSTEMS OF THE VERTEBRAL COLUMN BEHAVIOUR

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Abstract: This paper presents a radio-frequency (RF) transceiver designed, using a standard 0.18 μm CMOS process, for operation in the 2.4 GHz ISM band. The receiver has a sensivity of -64 dBm and consumes 3.5 mW from a 1.5 V supply. The RF transmitter delivers an output power of +11 dBm (15 mW) with a power consumption of 45 mW. These features make the RF transceiver suitable to be integrated in microsystems, where the low-power is a major requirement. The application of these microsystems is to monitoring the influence of heavy loads, in the behaviour of the vertebral column.

1 INTRODUCTION

The human posture has been an object of studies in biomechanics, once some deviations of structural and functional positions induce an unbalanced body. These deviations usually, affects the vertebral column and are caused by physical efforts, bad postures in work, deficiency in sustentation muscles, infections and congenital causes. The main pathologies of vertebral column caused by the referred deviations, are the scoliosis and lordosis. Sometimes these pathologies appears in children when they carry the heavy backpacks on the backs, in this case, it's very important monitoring the influence of loads (backpack weight) in vertebral column behavior. Figure 1 shows an adolescent female with scoliosis in the vertebral column. Her rib proeminence is most obvious upon her bending forward. The radiograph demonstrates a right thoracic scoliosis. The study of influence of backpack weighs on the vertebral column of children is an important issue, that has been worked by many researchers for years (Palastranga *et al*, 2002). The application cited in this work uses the following approach: applying indirect information, using the electrical potential generated by the muscles, when they contract and when they are rest. The technique which could measure this electrical potential is the electromyography (EMG). Based on the results of EMG, combined with the movements of the body, measured by the accelerometers, it is possible to know by numerical simulation, the displacement occurred on the insertions points between the muscles and the vertebral column (Pato *et at*, 2007). Using these values of displacements in a finite element code, like ANSYS, it is possible to compute the value of stress field in the vertebral column, especially it is possible to observe where are the points more affected and the respective stress value.
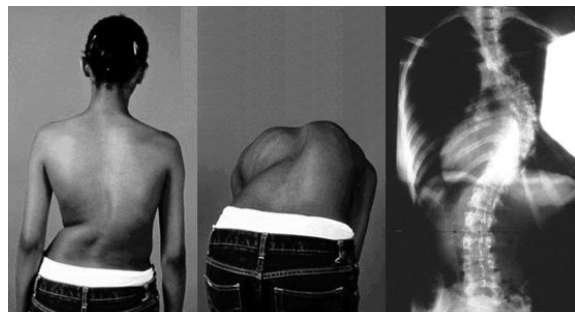

Figure 1: An adolescent female with scoliosis.

The radio-frequency (RF) transceiver proposed in this paper, was designed using a standard 0.18 μm CMOS process. This process allows to have the power supply of 1.5 V. The proposed low-power/low-voltage transceiver, is intended for use in wireless sensor networks, more specifically, for the monitoring the influence of heavy loads, in the behavior of the vertebral column.
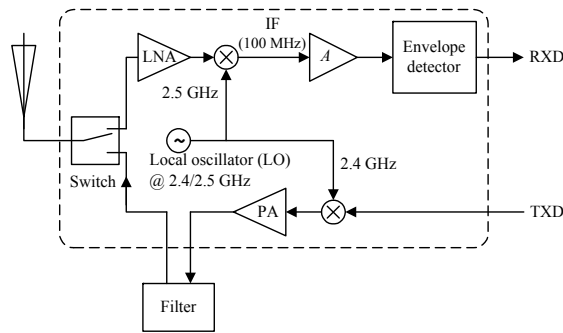
Figure 2: The block schematic of the RF transceiver.

2 TRANSCEIVER'S DESIGN

The transceiver has a receiver, a transmitter, an antenna-switch and a phase-locked loop (PLL) as frequency synthesiser. The Figure 2 shows the architecture of the proposed transceiver, where the reception is made by means of direct demodulation, using the technique of heterodyne detection. The final demodulation step is made with the use of a envelope detector, applied for an intermediate frequency of 100 MHz.

The quality requirement for the proposed RF transceiver is a transmission with a bit error probability less than 10^{-6} (one error for each one million bits transmitted) with a sensitivity of -64 dBm, in a transmitted power of +11 dBm using Amplitude Shift Keying (ASK) modulation (Carlson *et al*, 2002). All of these specifications are useful to make this transceiver suitable for short range applications (e.g., between fifty five and sixty meters - #55 / #60 meters), and obviously, to the target biomedical application, which will be further explained in the section 4.

2.1 Receiver

The Figure 3 shows the receiver's front-end schematic. This circuit has a low-noise amplifier (LNA) that provides a 50 Ω input impedance, using a tuned load to provide high selectivity. The amplified RF signal is directly converted to an intermediate frequency (IF) with a mixer, followed by a low-pass filtering and a post-amplifier. The final downconversion to the base-band is made with envelope detection.

The low-noise amplifier (LNA) is the first gain stage in the receiver path. In a LNA, the signal must be amplified as much as possible, keeping the signal-to-noise ratio (SNR) as low as possible. This is achieved with the best noise figure (NF). The

LNA is an inductively degenerated common source amplifier. The cascoding transistor M_2 is used to increase the gain, to better isolate the output from input and to reduce the effect of M_1's C_{gs} (Yao *et al*, 2007). The LNA enters in the sleeping mode, when the current in the polarization stage is switched off. The same principle applies to the all subsystems.
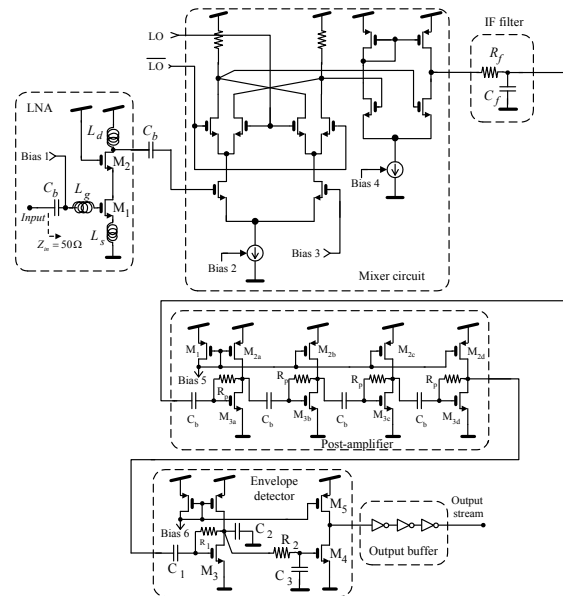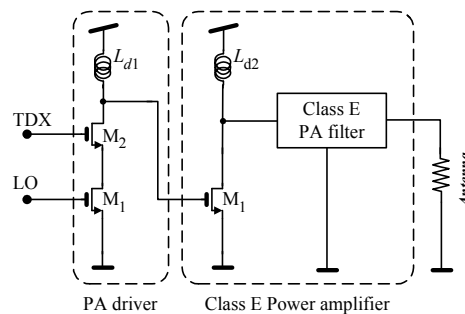

Figure 3: The schematic of the receiver.

Figure 4: The schematic of the transmitter.

The downconversion to the IF uses a four-quadrant multiplier Gilbert cell as a mixer. This mixer performs well with local signals (LO) at 2.5 GHz and a square shape. The main advantage is the possibility to use ring-oscillators, rather than tuned *LC*, thus, a big on-chip area saving is possible to be achieved, without a severe degradation in the phase-noise. Moreover, this don't poses special cares, because the down-conversion from IF to the base-base, is made by way of an envelope detection, whose input signal comes from the output of a low-

pass filter detector. The IF frequency is produced from the 2.4 GHz RF and from the 2.5 GHz local frequency. A minimum IF level at the envelope detector defines the receiver's sensitivity. This envelope detector is of active type, e.g., it provides gain, compared with the conventional topology using a simple clamping circuit. Thus, the sensitivity of the receiver is bigger, compared when a passive detector is used.

2.2 Transmitter

Figure 4 shows the schematic of the transmitter. The upconversion to the pass-band at 2.4 GHz, is made by a cascade circuit, comprising transistors M_1 and M_2. This circuit combines the transmitted bitstream (TXD) with local carrier generated in the frequency synthesizer described further. This circuit produces an AKS digital signal compatible with the usage of a switched power amplifier of class E (Sokal *et al*, 1975). The external filter that follows the power amplifier is a typical class E network, and removes the spectral components around the 2.4-GHz carrier frequency.

2.3 Frequency Synthesiser

The local generation of the frequency synthesiser is a phase-locked loop (PLL) with integer division in the feedback path. The Figure 5 shows the block diagram of the PLL, which has a reference generator circuit with a crystal based oscillator at 20 MHz, followed by a phase-frequency difference circuit (PFD) without dead zone, a current steering charge pump (CP) and a third order passive filter. The passive section output is connected to the VCO, which generates the desired frequencies of 2.4 GHz or 2.5 GHz. These frequencies must be divided by 120 or by 125 and connected to the PFD again, closing the loop. For the TSPC logic, it is required a rail-to-rail input to work properly. At these frequencies, the power consumptions are lowest, when compared with the SCL logic (Pellerano *et al*, 2004). In real PFDs there is an offset around the zero phase difference, and a gain inversion region takes place for phase differences higher than 2π-Δ *rad*. In this gain inversion region, the PFD outputs the wrong control signals increasing the phase and frequency differences between the inputs, and the lock time takes a sudden turn for the worse (Lee *et al*, 2003). The PFD has a linear gain in the range [-π, +π] and a constant gain in the remain interval. This constant gains increases the bandwidth of the PLL, making it faster to lock, compared with

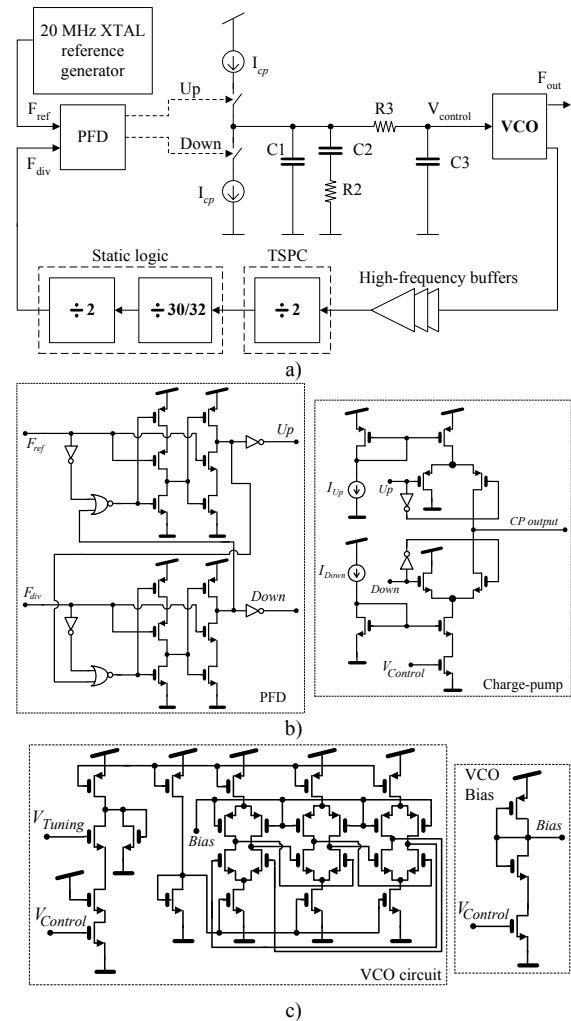those containing other structures (Kim *et al*, 2005).

Figure 5: a) The PLL structure, b) the schematic of the PFD-CP, and c) the schematic of the VCO.

The charge pump (CP) is of current steering type (Chih-Ming *et al*, 2002). This circuit avoids the problems in conventional CPs. In spite of being switched, the currents are routed from the load to an alternative path, and from that path to the load. To finish, the voltage controlled oscillator (VCO) is of ring type, in order to save on-chip area and because the phase and frequency errors are not critical in the used modulation.

3 EXPERIMENTAL RESULTS

For the receiver, simulations shown a sensivity of -64 dBm and a consumption of 3.5 mW from a 1.5 V

supply. The RF transmitter delivers an output power of +11 dBm (15 mW) with a power consumption of 45 mW. The receiver has a total power consumption of 3.5 mW for the receiver (1.5 mW for the LNA, 0.6 mW for the down-conversion mixer and 1.5 mW to the post-amplifier and envelope detector). The transmitter has the power consumptions in the following blocks: 2.7 mW in the driver and 41.5 mW in the power amplifier.
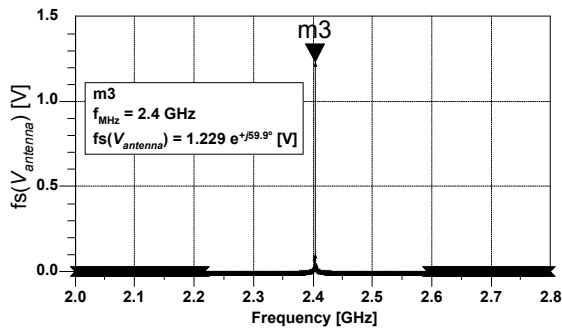

Figure 6: Amplitude spectrum of the amplified signal at the antenna terminals.

The Figure 6 shows the amplitude spectrum of the amplified signal at the terminals of an antenna, with an input impedance of 50 Ω.

4 APPLICATION

The application for microsystems using the transceiver proposed in this paper, is to make wireless acquisition modules, in order to allow the monitoring of heavy loads influence on vertebral column's behaviour. Each module makes the electromyography (EMG), to measure the electric potentials on the iliocostalis and longissimus thoracis muscles, and use a dual-axis accelerometer to get the movements of the body, in order to obtain the complete behaviour of the vertebral column. The acquired information is to be transmitted with the maximum rate of 250 kbps, however, the simulations shown, that the baud-rate can be extended without *jitter* problems, for frequencies up to 10 Mbps. An analog channel with differential input connected to the electrodes, is required to measure the EMG signal, while the remained channel is to measurements of the patient's movements.

The analysis of the EMG signal must be made in the amplitude domain, thus, before proceeding to the ADC conversion, it is required a peak detection of the amplified EMG signal, followed by an integration (Robertson *et al*, 2004). This mandatory process eliminates the fluctuations that characterize the EMG signals.

The measurements of the motion and the positioning of the patient's body is made with the use of a commercial dual-axis accelerometer of MEMS type. This chip connects to a commercial microController by way of an integrated Serial Port Interface (SPI).

The Figure 7 shows the block diagram of a first possible prototype, which contain the sensor interface read-out, the electronics for data acquisition (amplifications and analog-to-digital conversion) a micro-controller, and the proposed RF transceiver. A coin-sized 1.5 V battery will provide the supply and a commercial DC/DC step-up converter makes possible to supply the remaining components of the prototype with different voltage levels. As it can be seen in this Figure, the anti-static (ESD) protections are provided by way of power-rail connected diodes (Ker *et al*, 2005).
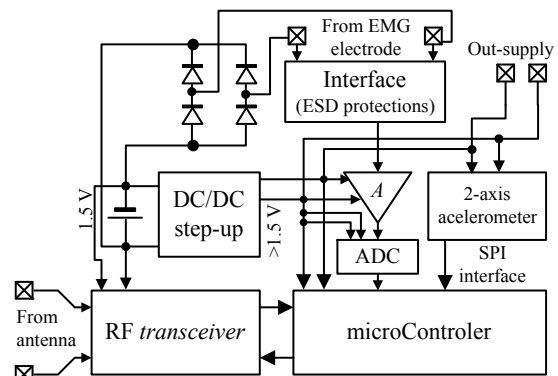

Figure 7: Block diagram of the microsystems for use in wireless modules.

5 CONCLUSIONS

This paper presented a low-power/low-voltage radio-frequency (RF) transceiver at 2.4 GHz, for working with a single 1.5 V coin-sized battery. Simulations shown for this transceiver a consumption of 3.5 mW in the receive mode and 15 mW of transmitted power, with a power consumption of 45 mW in the transmitting mode. These characteristics fulfil the requirements for short-range communications.

The target application for this transceiver is in wireless acquisition modules for monitoring of heavy loads influence on vertebral column's behaviour, in order to understand the influence of

heavy loads as a risk factors in the vertebral column, such as the scoliosis and lordosis. These factors normally associated to appears in children when they carry the heavy backpacks on the backs. Thus, it's of extremely importance to characterise the influence of heavy loads (backpack weight) in the vertebral column behaviour. This solution fits the medical doctors requirements for an easy placement and removal of wireless modules. The main advantage of this solution, is the maintenance of the mobility and lifestyle of patients during the diagnosis.

The possibility to control the receiver and the transmitter subsystems, allowing them to be switched on and off is another advantage of this RF transceiver. This is a specially important topic of design, in applications where power efficient algorithms are mandatory, e.g., in wireless sensors networks (Enz *et al*, 2004).

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