Fully Integrated, Low-power FM-UWB Transceiver for Short-range, High-density Wireless Sensor Networks

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The FM-UWB radio presented in this report was developed within the WiseSkin project. The target is to provide ultra-low power wireless connectivity between the nodes inside of an artificial skin developed for use with prosthetic limbs and haptic applications. The radio exploits the short distance between the nodes; trading receiver sensitivity for very low-power consumption. At the same time, it provides for sub-carrier FDMA; enabling up to four nodes to transmit simultaneously in the same RF band; effectively reducing network latency.

The WiseSkin project aims at the restoration of a natural sense of touch to people using prosthetic limbs. This is achieved by embedding a large number of sensor nodes (with pressure sensors) into an artificial skin. Pressure data from sensors is conveyed to the central unit, which uses this information to drive the actuators (vibrating electromotors) used for stimulation of the amputee's residual limb, enabling sensory feedback and control of the prosthesis. In order to improve the adaptability and robustness of the communication protocol as well as the scalability, flexibility and manufacturability of the sensor skin, wireless communication is used between sensor nodes. The short distance between nodes (e.g., a few cm), enables us to trade receiver sensitivity for power consumption.

A simplified block diagram of the transceiver is shown in Figure 1. The large Frequency Modulation Ultra-Wide Band (FM-UWB) signal bandwidth of 500 MHz relaxes constraints on both transmit and receive oscillators, enabling the use of free-running ring oscillators for carrier generation. These are periodically calibrated using an on-chip Successive Approximation (SAR) Frequency Lock Loop (FLL) to compensate for drift due to temperature variations. The transmitter uses direct digital synthesis to produce the triangular sub-carrier that controls the VCO and subsequently generates the FM-UWB signal. The transmitter consumes 583 μW from a 1 V supply, while radiating a -11.4 dBm FM-UWB signal. The power amplifier with a fully integrated matching network, achieves an average efficiency of 18%.

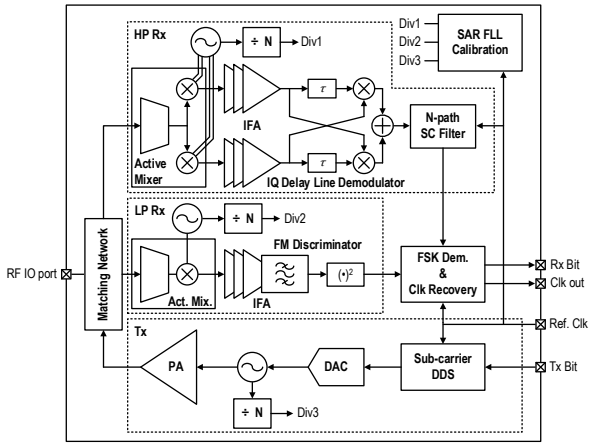

Figure 1: FM-UWB transceiver block diagram.

Two receivers have been implemented providing different modes of operation in terms of power consumption, sensitivity and number of channels. The "high-power" (HP) receiver consumes 550 μW, and allows up to 4 nodes to transmit at once in the same RF band. This is achieved using different sub-channels [1] (SC-FDMA). For a single user, the sensitivity is around -68 dBm. The sensitivity degrades slightly with the increasing number of users and/or their power (Figure 2).

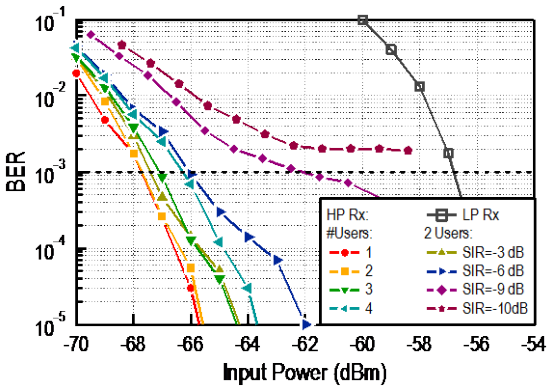

Figure 2: BER curves for the two receivers.

The integrated FSK demodulator and clock recovery circuit enable correct operation at a reference clock offset of up to 8000 ppm. With the state-of-the-art on-chip RC oscillators providing roughly 2100 ppm variation over the operating temperature range, the integrated transceiver demonstrates the feasibility to completely remove of all of the off-chip components; reducing the size and cost of sensor nodes.

Another property of the selected receiver architecture is its robustness to out of band narrow-band (NB) interferers. Both the HP and LP receivers can still demodulate data with a 3 dBm NB interferer present at 2.4 GHz (58 dB stronger signal for the LP and 66 dB stronger signal for the HP receiver). This NB signal could be used to power the sensor node (assuming rectifier efficiency >50%); enabling a fully wireless solution, offering enhanced robustness to the sensor skin [2].

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[1] V. Kopta, *et al.*, "An approximate zero IF FM-UWB receiver for high density wireless sensor networks", IEEE TMTT Transactions on Microwave Theory and Techniques, 65 (207) 374.

[2] V. Kopta, *et al.*, "System and method for remote powering at least one sensor or actuator from a RF power source", US and EU Patent Application (2016).