A pulsed UWB receiver SoC for insect motion control

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11.3 A Pulsed UWB Receiver SoC for Insect Motion
Control

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For decades, scientists and engineers have been fascinated by cybernetic organisms, or cyborgs, that fuse artificial and natural systems. Cyborgs enable harnessing biological systems that have been honed by evolutionary forces over millennia to achieve astounding feats. Male moths can detect a single pheromone molecule, a sensitivity of roughly 10^{10} grams. Thus, cyborgs can perform tasks at scales and efficiencies that would ordinarily seem incomprehensible. Semiconductor technology is central to realizing this vision offering powerful processing and communication capabilities, as well as low weight, small size, and deterministic control. An emerging cyborg application is moth flight control, where electronics and MEMS devices are placed on and within a moth to control flight direction. To receive commands on the moth, a lightweight, low power and low volume RX is required. This paper presents a pulsed ultrawideband (UWB) RX SoC designed for the stringent weight, volume and power constraints of the cyborg moth system.

A high-level drawing of the cyborg moth system is presented in Fig. 11.3.1. Commands are sent from a basestation and received wirelessly on a Manduca sexta hawkmoth. A unidirectional wireless link is employed to reduce power consumption of the moth electronics. A tungsten 4-electrode stimulator is implanted in an adult moth to stimulate nervous tissue in the abdominal nerve cord, thereby causing abdominal movement, which has been shown to alter flight direction [1]. A 35μAh, 0.2g Zinc-Air hearing aid battery supplies energy to the system at 1.3V, and is regulated to 1V and 2.5V by an LDO and a dc-dc boost converter. As the carrying capacity of a moth is limited to approximately 0.8g [2], a highly integrated UWB RX SoC is required. Pulsed UWB wireless signaling is employed as UWB radios can achieve highly integrated, energy efficient operation in nanometer CMOS processes.

A block diagram of the RX architecture and packet structure is shown in Fig. 11.3.2. The non-coherent, energy detection RX receives UWB pulses in one of three 500 MHz channels at 3.5, 4.0 and 4.5 GHz. The RX achieves near compliance with 802.15.4a at low power of 2.5mW at 1.3V. A table of results is shown in Fig. 11.3.6. A die micrograph is shown in Fig. 11.3.7.

The RX SoC was fabricated in a 90nm CMOS process. The RX operates at a 16Mb/s instantaneous data rate and achieves a sensitivity of -76dBm at 10^{-3} BER, corresponding to a duty cycled sensitivity of -98dBm at 100kb/s. The RX SoC instantaneous power scales from 8-to-22.7mW while demodulating data, yielding 0.5-to-1.4nJ/b. In the cyborg moth system, the duty cycled RX looks for a packet of data every millisecond, requiring an overall average system power of 2.5mW at 1.3V. A table of results is shown in Fig. 11.3.6. A die micrograph is shown in Fig. 11.3.7.

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References:
Figure 11.3.1: Cyborg moth motion control system.

Figure 11.3.2: Block diagram of pulsed UWB RX SoC and packet structure.

Figure 11.3.3: Inverter-based, 6-stage RF front end. Any of the 5 stages following the LNA can be disabled to reduce power consumption.

Figure 11.3.4: Integrator/ADC block diagram and DC-input DNL/INL.

Figure 11.3.5: Photo of tethered moth before and during stimulus, showing abdominal deflection, with stimulus measured results below.

Figure 11.3.6: Table of measured results.
Figure 11.3.7: Die micrograph of pulsed UWB RX SoC.