A 53μW Super-Regenerative Receiver for 2.4GHz Wake-up Application

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I. Introduction

In Wireless Sensor Networks (WSN), individual nodes are powered off most of the time, staying in sleep mode, and powered on in a short time to communicate, staying in active mode, in order to minimize the power consumption to extend the life time of the nodes, which is normally powered by a single battery or through energy harvesting. Typically, the receiver for data communication in each node periodically wakes up to monitor the channel for potential incoming signal. Alternatively, a second receiver, named wake-up receiver, could be used to monitor the channel and active the main circuits when necessary. The wake-up receiver should consume much less power than the main receiver and typically less than 100μW [1]. A few works have been done on the wakeup receiver design in GHz range applications [2][3] by employing high performance passive device, FBAR, which will increase sensor nodes' cost significantly.

In this paper, a super-regenerative receiver with a modified quenching method, which adopts cycling control scheme, is proposed for low cost wake-up application. The super-regenerative receiver front-end is designed in 0.18μm CMOS technology.

II. Operating principles

Basically, a super-regenerative receiver detects input signal through start-up time difference of oscillation [4]. The start-up time is defined as the time required for oscillation building up to maximum amplitude after oscillator is turned on. For an LC oscillator, it can be given as

$$\tau_{start-up} = \tau \ln \frac{V_{osc}}{A}$$

where τ is the time constant of LC tank, V_{osc} is the oscillation amplitude, and A is an initial amplitude of an excited signal across the tank, which determines the start-up time of a given oscillator.

Figure 1 shows the proposed super-regenerative receiver front-end, including an isolation amplifier, an oscillator and an envelope detector. The isolation amplifier as an interface between antenna and oscillator, provides input matching, injects input signal into the tank, and prevents feed through from oscillator to antenna. Oscillator periodically oscillates to detect signal through start-up time differences. Envelope detector detects the oscillation envelope for further process in baseband. Comparing to the conventional super-regenerative receiver [5], whose quench signal turns on-off oscillator only, all blocks in our proposed super-regenerative receiver are turned on-off

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by a quench signal with a small duty cycle ratio. Consequently, the power consumption is reduced dramatically.

III. Circuit design

A. Isolation amplifier and oscillator

Isolation amplifier (ISA) and oscillator (OSC) use the same load as shown in Figure 2. The isolation amplifier is fully differential to provide good power supply rejection and is designed based on Power Constrained Simultaneously Noise and Input Matching Technology (PCSNIM) [6] for its input matching to maximum power delivery and cascaded topology is used to optimize its reverse isolation. The ISA provides input matching of -23dB at 2.4GHz with a current consumption of 105 μA when it is powered.

The oscillator is based on a differential Colpitts oscillator [7]. It provides larger oscillation amplitude under the same bias current compared to LC cross-coupled oscillator. For a low power oscillator, the quality factor Q of the inductor is critical since it determines the overall Q of the tank. Bond-wire inductors are used as L1 and L2 to offer a compromise between Q and integrity. A switch M7 is connected across the tank to turn off the oscillation quickly when the power goes down. The oscillator oscillates at 2.4GHz. Its peak differential amplitude is 110mV with bias current of 205 μA. When quenched by a 100 kHz 10% duty cycle signal, it dissipates 184.5 μA on average in oscillation period. The maximum radiated power to antenna is -68.8dBm.

Power on-off control is implemented through turning on-off current source, M5 and M6. When the power control signal goes high, the gates of current sources are connected to bias voltage. An additional capacitor is placed at the gate of M5 to get a slow rising bias to make sure the bias of isolation amplifier arrives at steady state earlier than that of the oscillator. Additionally, the slow rising of oscillator bias helps to improve the sensitivity [4]. When the power control signal goes low, the gates of the current sources are grounded quickly and the isolation amplifier and oscillator are powered down.

B. Envelope detector

The envelope detector (ENV) is designed based on [8], shown in Figure 3. The transistors M1-M4 work in weak inversion region to provide deep nonlinearity. The output of the circuit provides a voltage proportional to the rectified envelope of the input signal. V_{inp} and V_{inn} are DC coupled to outputs of oscillator. The oscillation envelope is held by capacitor C1. A replica pair is used to provide pseudo-differential output. Power on-off control is implemented the same as that of isolation amplifier. When the detector is powered on, it dissipates only 2.1 μA.

IV. Simulation results

The super-regenerative receiver front-end is designed in 0.18μm CMOS, dissipating around 292μA current during power-on period. The simulated leakage current is 240pA during power-off period. Its performance is summarized in Table 1.

The simulated start-up time of oscillation is around 1µS when there is no input signal. By referring to it, a start-up time difference is calculated when there is input signal. The difference is larger as a higher power input signal is received. Figure 4 shows the corresponding time differences as input signal power changes. From the simulation results, we expects to detect input signal with power larger than -75dBm.

Figure 5 illustrates the receiver operation when a 100kbps OOK signal with power of -75dBm and carrier frequency of 2.4GHz is received. The receiver is quenched by a 100 kHz signal with 10% duty cycle.

V. Conclusion

We present a super-regenerative receiver in 0.18µm CMOS technology. A new quench method is proposed to reduce the power consumption of a super-regenerative receiver. Compared with conventional quenching method, the power consumption is saved during oscillation off period. By extending the off-period, the average power is dramatically reduced without degrading its sensitivity, which is suitable as part of wakeup receiver front-end. The simulation results shows that the designed super-regenerative receiver, quenched by a 10% duty cycle signal, dissipates an average power of 56µW for 100kbps data rate, an energy efficiency of 0.56nJ/bit.

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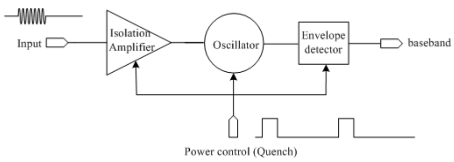

Figure 1 Proposed super-regenerative receiver front-end block diagram

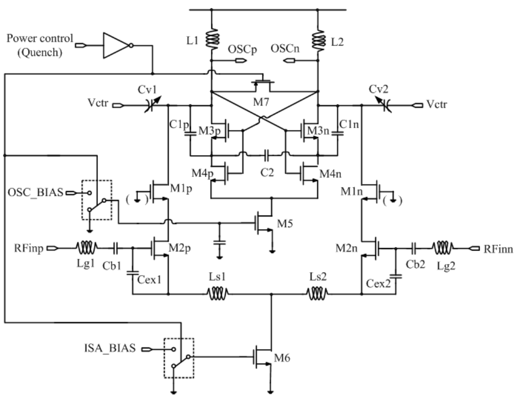

Figure 2 Isolation amplifier and oscillator

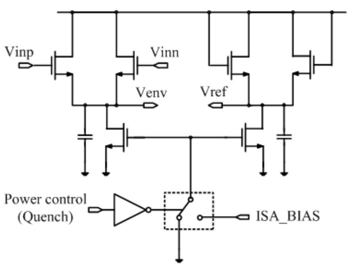

Figure 3 Envelope detector

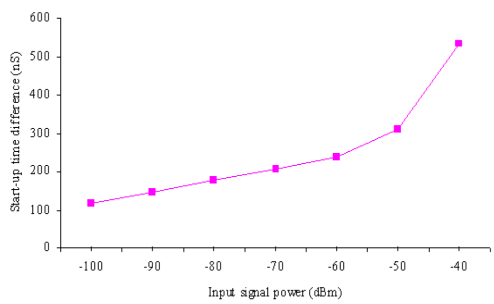

Figure 4 Start-up time differences between the start-up time when there is no input signal and the start-up time when oscillator is excited by an input signal of varying power

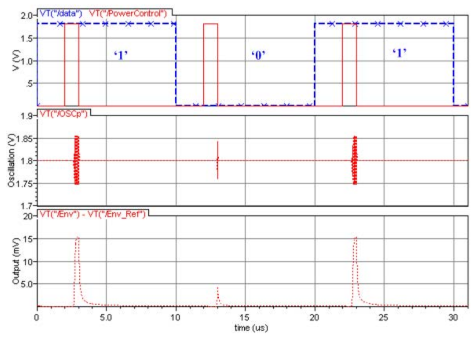

Figure 5 Operation of the propsed super-regenerative reciever

Table 1 Performance Summary

Technology	0.18µm CMOS
Supply	1.8V
Frequency	2.4GHz
Quench signal	100kHz, 10% duty cycle
Data rate	100kbps
Sensitivity	-75dBm
Aveage power consumption	53µW
Energy efficiency	0.53nJ/bit