R-less and C-less Self-sampled ASK Demodulator for Lower ISM Band Applications

Chi-Chun Huang, *Student member, IEEE,* Chih-Lin Chen, and Chua-Chin Wang, *Senior member, IEEE*
Department of Electrical Engineering
National Sun Yat-Sen University
Kaohsiung, Taiwan 80424
Email: ccwang@ee.nsysu.edu.tw

***Abstract*—An ASK demodulator with a high bandwidth for lower ISM band frequencies is presented. A total of 15 MOS transistors are used in the proposed design without using any passive element. It is very compact to be integrated in an SOC (system-on-chip) for wireless communication biomedical applications, particularly in biomedical implant. The proposed design with a low area cost and low power consumption is easily to be integrated in other mobile medical devices. The self-sampled loop with a MOS equivalent capacitor compensation mechanism enlarges the bandwidth, which is more than enough to be adopted in any application using lower ISM bands.**

Keywords- ASK demodulator, ISM band, self-sampled, wireless communication

I. INTRODUCTION

Recently, implantable biomedical devices become a popular research topic, particularly applications of electrical stimulations. The stimulation implants have been developed to diagnose or cure the patients' diseases, e.g., bladder stimulation for urine control [1], neuron electrical micro-stimulation to alleviate paralysis and atrophy [2], and cortical neural prosthesis for deep brain stimulation which has been deemed as one of the promising solutions for the disabilities of Parkinson's disease [3].

Two of the most important issues of biomedical implants are patient's safety and comfort. To avoid the rick of infection on the wound caused by wired connections, the wireless connection has been widely adopted in many implants. The implants can be powered and commanded by a pair of coils (external and internal) using a transcutaneous magnetic coupling method to ensure the safety. The amplitude shift keying (ASK) modulation is particularly suitable for the coil coupling method in biomedical implants because of its simplicity [4]-[11]. Moreover, thanks to the recent development of SOC technology, the size of the implants is drastically shrunk.

Traditionally, ASK demodulators in implanted devices, [4], [5], [6], contained a large capacitor, which can either be a discrete component on a PCB (printed circuit board) or occupy a huge area on the SOC chip. Consequently, an extra discrete component increases the size of the implants and causes the patient's comfort drastically. On the other hand, the area cost becomes very expansive if advanced processes are used for the SOC realization for the implants. Obviously, the large capacitor becomes unaffordable for the ASK demodulator in the SOC chip. Then, the ASK demodulator in [7] without using any capacitor has been proposed to save the area as well as the cost. Later, the design in [11] got rid of another passive element, resistor, to save more area on silicon. However, the ASK demodulator in [11] needed a unit gain buffer, which works as a rectifier and increases redundant power consumption. Besides, the bandwidth of all of the prior ASK demodulators is too low to be employed for many ISM bands, including 6.78 MHz, 13.56 MHz, 27.120 MHz and 40.68 MHz. All of these public bands are widely utilized in industrial, scientific and medical applications. The ASK demodulator bandwidth should cover as many bands as possible such that it could be employed in a variety of wireless applications.

Therefore, we propose a novel ASK demodulator without using any passive element. By decoupling the parasitic capacitor, the bandwidth of the proposed ASK demodulator is over 300 MHz, which is more than enough for almost all kinds of biomedical SOC implants.

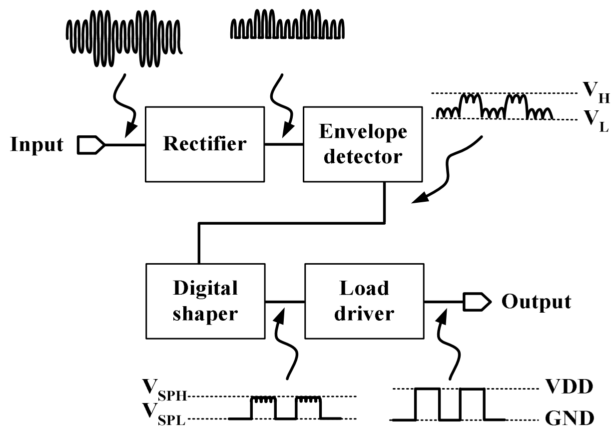

Figure 1. Architecture of the proposed ASK demodulator

This research was partially supported by National Science Council under grant NSC 96-2923-E-110-001 and NSC 96-2628-E-110-019. Moreover, this research was partially supported by National Health Research Institutes under grant NHRI-EX97-9732EI.

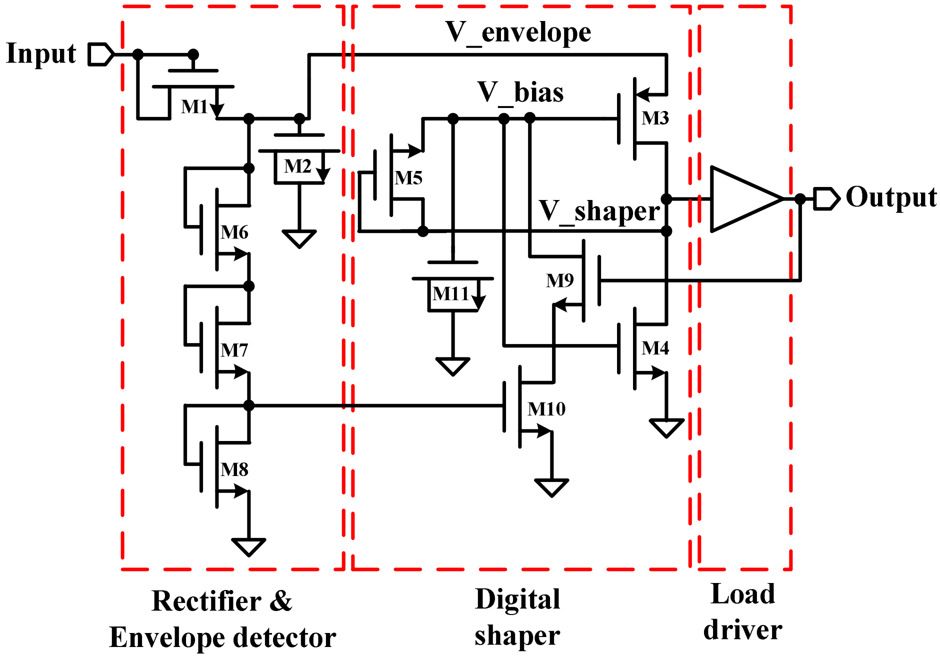

Figure 2. Schematic of the proposed ASK demodulator

II. THE ASK DIMODULATOR DESIGN

The proposed ASK demodulator is composed of 4 sub-circuits, as shown in Fig. 1, including a rectifier, an envelope detector, a digital shaper, and a load driver. Because of the limited input range, the amplitude of the ASK signal delivered from the coil of implants must be reduced by a voltage divider (not shown). Then, the rectifier converts the received ASK signal into a half wave. The envelope detector picks up the envelope of the half wave. The digital shaper is the most important part, which recovers the digital data from the envelope. At last, the load driver provides a large driving current to pull the output from rail to rail. Fig. 2 shows the entire circuit of proposed design. Since the load driver is composed of two inverters, there are totally 15 transistors in the proposed ASK demodulator without any passive element.

A. Rectifier and Envelope detector

Referring to Fig. 2, the diode connected transistor (M1) and the current path (M6~M8) work as a rectifier to reject the negative voltage of the ASK signal. M2 serves as a peak detector to pick up the envelope voltage of the half wave from the rectifier, i.e. V_envelope. The mark (high voltage) level of V_envelope (V_H) is generated when the high level of the ASK signal is received, and vise versa for the space (low voltage) level.

B. Digital shaper

The digital shaper converts the envelope signal generated by M2 into a digital signal such that the following load driver can provide a rail-to-rail logic output accordingly. The operation of the digital shaper is described as follows.

(1) In the initial state, V_bias is 0 V and M3 is turned on. If there is any positive voltage on the source of M3, the V_bias would be biased on a certain voltage via M3 and the diode connected M5.

(2) When V_envelope = V_H, the V_bias will turn on M3. The voltage on V_shaper is $V_{SPH.}$

(3) When V_envelope = V_L , M3 would be cut off and the V_shaper would then drop to another level, called V_{SPL}.

- **AC analysis:** According to the above description, **t**he V_bias is the critical gate drive for M3 to slice the logic level of the envelope signal. Hence, it is important to keep the V_bias stable. M11 is as a S-D-shorted capacitor, C_{M11}, to resist the high frequency noise from the ripple of V_envelope. Referring to Fig. 3(a), The parasitic capacitance Cgs3 between the gate and source of M3 is much smaller than C_{M11}. In other worlds, Z_{M11} is far smaller than Z_{gs3} at high frequency. Therefore, the equivalent circuit shown in Fig. 3(b) gives the equation of the noise on V_bias from V_envelope as follows:

$$N\_bias = \frac{N\_envelope \times Z_{M11}}{Z_{M11} + Z_{gs3}}$$

where the *N_envelope* is the high frequency noise coupled in the V_envelope, and *N_bias* is the noise on V_bias. By the same analogy, the M11 can resist the

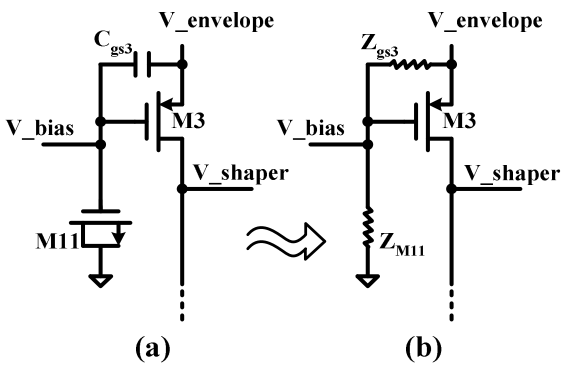

Figure 3. High frequency equivalent circuit

high frequency noise from V_shaper as well. In other words, the V_bias is decoupled from V_envelope at high frequency bands.

- **Self-sampled loop:** If there is no DC path from V_bias to ground, the redundant charge from the noise of V_envelope would be accumulated on V_bias to increase the bias voltage. Then, the slicing function of the digital shaper will be contaminated because of the wrong gate drive voltage of M3. Therefore, M10 works as an active load to provide a DC path with M9. When the V_envelope is high, M9 will be turned on to discharge the redundant charge on V_bias. On the other hand, when the V_envelope is low, V_shaper will be 0 V and cut off M5. Since there is no charging path to V_bias, M9 is also cut off to stabilize V_bias.

C. *load driver*

The output signal of digital shaper is digital pulses with noise ripple. What even worse is that it is not a rail-to-rail logic. Therefore, a load driver is required to generate a perfect digital signal and boost the driving current. The load driver is composed of two inverters whose switch points have been tuned to match the output signal of the digital shaper.

III. SIMULATION AND IMPLEMENTATON

TSMC (Taiwan Semiconductor Manufacturing Company) 0.35µm 2P4M CMOS process is adopted to carry out the proposed ASK demodulator design. Referring to the layout shown in Fig. 4, the chip area is 101 µm x 32 µm. According to post-layout simulations shown in Fig. 5, the proposed design can perfectly demodulate the ASK signal in different data rates. Fig. 6 shows each minimum threshold for ASK high level voltage in every PVT (process, voltage, and temperature) corner. For the sake of robustness, the ASK low level has been selected to be 2.5 V. Meanwhile, referring to Fig. 6, the worst threshold of ASK high level is 2.8 V. Therefore, basing on the threshold (2.5 V, 2.8V), the maximum carrier frequency and maximum data rate are 300 MHz and 1 Mbps. The specification of the proposed ASK demodulator is shown in table I. The comparison of the proposed design with other prior designs is shown in Table II. The bandwidth of the proposed design is the best while the layout area is relatively small.

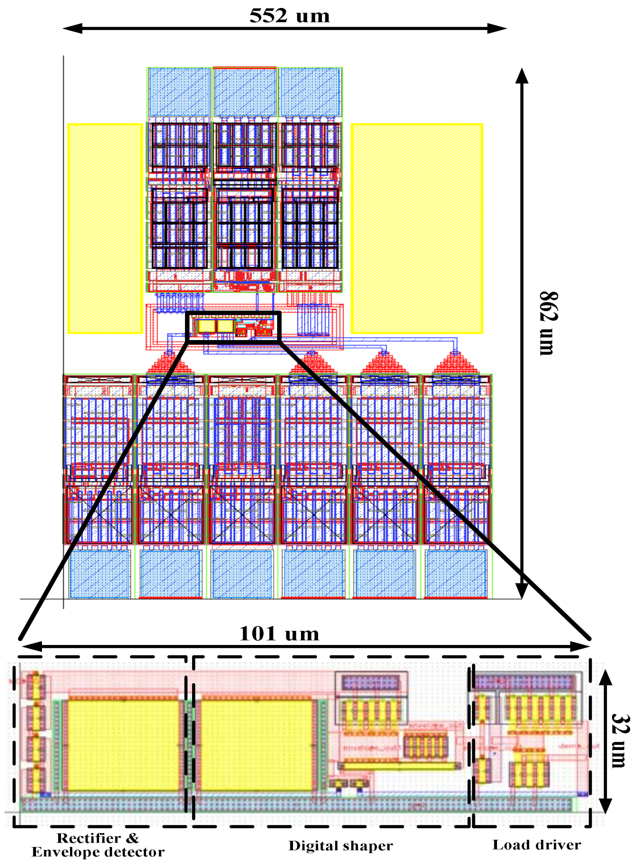

Figure 4. Layout of proposed design

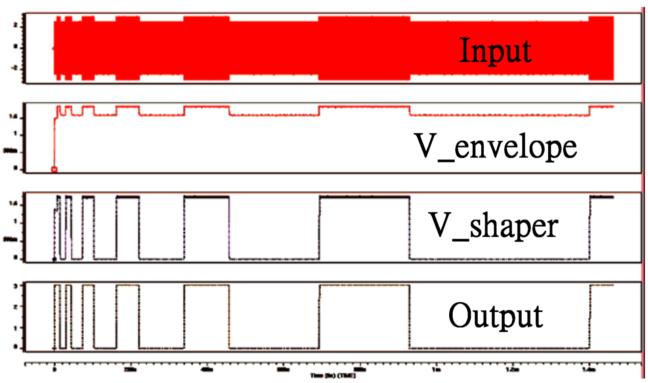

Figure 5. Post-layout simulation result

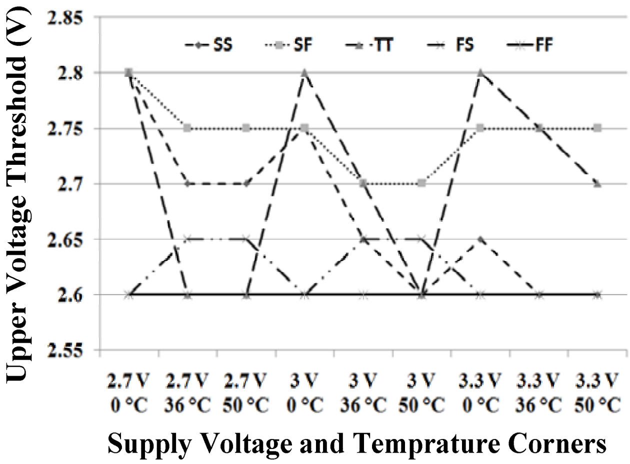

Figure 6. Upper voltage threshold at 45 different corners

IV. CONCLUSION

We have proposed a novel ASK demodulator. Without any passive element, a total of 15 MOS transistors are used in the proposed design. The 300 MHz bandwidth of carrier frequency is far more than enough to be used in a variety of low ISM band applications. The proposed design is very compact for wireless biomedical implants as well as other portable wireless communication systems.

ACKNOWLEDGMENT

The authors would like to express their deepest gratefulness to CIC (Chip Implementation Center) of NAPL (National Applied Research Laboratories), Taiwan, for their thoughtful chip fabrication service. The authors also like to thank ``Aim for Top University Plan" project of NSYSU and MOE (grant no. 96C031001), Taiwan, for partially supporting this investigation.

TABLE I. SPECIFICATION OF THE PROPOSED ASK DEMODULATOR

Power supply voltage	3 V
Input ASK low level	< 2.5 V
Input ASK High level	> 2.8 V
Output logic low level	0 V
Output logic high level	3 V
Max. carrier frequency	300 MHz
Max. data rate	1 Mbps
Power consumption	0.58 mW @ FF, 3.3 V, 50 °C

TABLE II. COMPARISON WITH PRIOR ASK DEMODULATORS

	[10]	[7]	[11]	[12]	[13]	Ours
Year	2000	2004	2007	2007	2008	2008
Process (μm)	0.5	0.35	0.35	0.35	0.18	0.35
Passive element	8 C	1 R	0	0	0	0
Gate count	>26	17	12	>19	32	15
Carrier Freq. (MHz)	1-15	2	2	10	2	300
Data rate (Kbps)	200	10	20	2000	1000	1000
Power (mW)	0.06	23.9	1.01	0.084	0.336	0.58
Core area (μm^2)	220 K	12700	3025	N/A	468.3	3300

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