Research and Implementation of Passive Wireless Communication System Based on Ambient Backscatter

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Abstract. The ambient backscatter technique has attracted a lot of attention in passive communication systems. This device achieves wireless communication through radio frequency signals in backscattering Environment. In this paper, we focused on how to improve energy collection efficiency, communication rate and communication distance of passive wireless communication system. An ultralow power multi-antenna decoding algorithm and 5-stage charge pump booster rectifier circuit were proposed. The environment electromagnetic wave energy collection module, passive transmitter and passive receiver were designed. The experimental results show that communication rate of the passive wireless communication system can reach 50kbps and communication distance can reach 6 feet.

1. Introduction
Passive wireless communication system utilizes the radio frequency signal in the environment as the only source of power [1], such as television signal or WIFI signal. Ambient backscatter technology refers to the equipment through backscattering ambient RF signals, RF signal as a carrier to achieve wireless communication [2-3]. Passive wireless communication system can eliminate the need for wires and batteries, and can communicate anytime and anywhere [4].

![Figure 1 The basic principle of ambient backscatter communication](image)

The basic principle of ambient backscatter communication is as shown in Figure 1. Sender A and receiver B are two passive devices, the TV tower is the external signal source and energy source [5].
Assuming that A need to send a packet to B, the sender module A controls the antenna switch according to the data packet to be transmitted, and thus changing the matching degree and reflection characteristics of the antenna, the antenna of the transmitting module A can switch between the two states of reflection and absorption [6]. When the data sent by A is 1, the switch is turned on and the electromagnetic energy radiated from the TV tower to A antenna is mostly scattered back to B; When the data sent by A is 0, the switch is closed and electromagnetic energy radiated to A is absorbed, thus electromagnetic energy of the antenna scattered back to B is reduced accordingly. The data sent by A is loaded into the amplitude of the RF carrier in the environment, which is similar to 2ASK modulation [7].

In this paper, we have developed environment electromagnetic energy collecting module to supply transmission module and receiving module, and designed transmitter and receiver module with low power consumption device. And then, for testing system performance, a passive wireless communication test system based on ambient backscatter is developed.

2. Design of Environmental Electromagnetic Wave Energy Collection Module

In passive wireless communication system, the environmental electromagnetic wave energy collection module converts electromagnetic energy into electrical energy, which can be applied through a specific circuit. At the same time, this module converts radio frequency alternating current (AC) signal into direct current (DC) signal, and completes the charging of energy storage capacitor [8]. The environmental electromagnetic wave signal used in this paper is 2.45GHZ WIFI signal.

The environmental electromagnetic wave energy collection module consists of antenna, impedance matching with filter network, boost rectifier circuit, energy storage unit and load unit, as shown in figure 2. Through manual testing and optimization of sucker antenna impedance in the center frequency of 2.45GHz, using network analyzer E5071C to carry on load impedance test, test results show that load impedance at the center frequency for 2.45GHz is 40.717 9.2362j. Thus, load impedance can be equivalent to a series of capacitors and a resistor.

5-stage charge pump boost rectifier circuit is used to design environment electromagnetic wave energy collection module. The diode should have characteristics of low threshold voltage, short reverse recovery time and good RF characteristics [9]. After a long time of comparative analysis, the final decision is to use Schottky diode SMS7630-075, and storage capacitor is F750G228MRC, and voltage monitor is NCP583.

Experimental results show that when input power is -14.5dBm, energy conversion efficiency is 21%, and when input power is 0dBm, energy conversion efficiency is 51%.

3. Passive transmitter design

According to the principle of ambient backscatter data transmission, the block diagram of passive transmitter designed in this paper is shown in Fig.3.

(1) Antenna design.

In passive wireless communication systems, data transmission and energy transmission are accomplished by passive transmitters and passive receiver antennas. The important parameters of the antenna include input impedance, Voltage Standing Wave Ratio (VSWR), polarization mode and antenna gain [10]. The antenna is 2.45GHz sucker rod antenna. We test VSWR and return loss S11 of sucker rod antenna with network analyzer E5071C, and optimize them manually. The optimized VSWR is 1.08, and the optimized S11 is -39 Db.
Figure 2: Environmental electromagnetic wave energy collection module circuit schematic

(2) RF switch selection and testing.
Passive transmitter transmits data by controlling radio frequency switch, thus changing impedance matching with degree of the antenna. We select SKY13392 as radio frequency switch. After testing and analyzing, we can obtain superior RF performance when insertion loss is -3dBm and isolation loss is -25dBm.

(3) Passive transmitter testing.

MCU uses 16-bit mixed-signal microcontrollers MSP430G2553[11]. To generate PWM wave from 1KHz, 2KHz, 3KHz, 4KHz, 5KHz, 10KHz, 50KHz, 100KHz and 1MHz by MSP430G2553 internal 16-bit timer A and B, each frequency waveform duration is 30S, which makes it easy observe the maximum communication rate of passive wireless communication systems. AV1442 RF signal generator is used to output 2.45 GHz carrier signals with different power, and horn antenna ANT1 is used as environmental radiation antenna. Passive transmitter controls RF switch through MSP430, which makes switch back and forth when on and off, thus changing the impedance of ANT2. Receiving antenna ANT3 and ANT4 are connected to AV4036B spectrum analyzer to observe the power of ambient backscattering signal. Test schematic and field diagrams is shown in Fig. 4.

Figure 3: Diagram of passive transmitter

Figure 4: Passive transmitter test
Test results show that in passive wireless communication system, ambient backscatter signal produced by passive transmitter is about 0.7 dBm. Thus, ambient backscatter signal can be decoded by receiving module.

4. Passive receiver design

![Passive receiver diagram](image)

Figure 5 diagram of passive receiver

Passive receiver hardware circuit design is based on ultralow power multiantenna decoding algorithm\[12\]. We optimize the antenna, impedance matching, passive transmitter and ultra-low power hardware circuit design. All operations are implemented using analog circuits, which can reduce the power consumption of the order of magnitude. And passive receiver is mainly composed of antenna, impedance matching circuit, Uma algorithm module, energy collection module and MSP430 processor, as shown in figure 5.

Passive receiver circuit schematic diagram is shown in figure 6. Impedance matching parameters is same as transmitter part, the envelope demodulation used by the non-coherent envelope detector, RF detector diodes selected zero bias Schottky diode HSMS2860, R = 100K, C = 15pf. The operational amplifier uses TSV6390, and comparator selects NCS2200.

![Passive receiver circuit](image)

Figure 6 Schematic diagram of the passive receiver circuit

5. System testing

In this section, we test the relationship between communication rate, communication distance and bit error rate. First we build passive wireless communication system test platform, as shown in figure 7. The distance between passive receiver antennas is fixed at 1/2 wavelength of carrier signal, and the distance from horn antenna to passive environment backscatter equipment is fixed at 1.2 m. Horn antenna provides energy for the whole passive wireless communication system and the radio frequency signals in the environment. Communication distance represents the distance from passive transmitter to passive receiver, communication rate is the rate of the passive transmitter toggle switch, i.e., 1KHz, 2KHz, 3KHz, 4KHz, 5KHz, 10KHz, 50KHz, 100KHz and 1MHz in the launch program. When testing communication speed and communication distance, two ambient RF energy levels are selected as -30dbm and -10dbm, and communication speed is selected by 10kbps, 50kbps and 100kbps. In each environment RF energy levels and different communication rates and communication distance to do multiple experiments, each location sends 10000 bits.

Test results are shown in figure 8. We choose literature [3] to compare with this paper. The black curve represents the test result of 10 Kbps communication rate in reference [3]. The red curve, green
curve, and blue curve represent the Uma communication rates of 10 kbps, 50 kbps, and 100 kbps, respectively. We can see from figure 10:

The bit error rate increases as communication rate and communication distance increases. The main reason is that: the greater the communication distance is, the higher communication rate led to the ambient backscatter signal attenuation in the transmission process more greater, so that the signal-to-noise ratio of ambient backscattering signal received by passive receiver antenna is very low, and can not decode the ambient backscatter signal.

Figure 7 Passive wireless communication system test platform

2) As the energy of RF signal in environment decreases, the bit error rate increases. The reason is that: RF signal energy in environment is low, thus transmitter backscattered to receiver of ambient backscatter signal energy is very low, and receiver antenna to receive ambient backscatter signal to noise ratio is very low. So the signal-to-noise ratio of ambient backscatter signal received by receiver antenna is low.

3) Compared with the reference[3], the system we designed greatly improves communication rate and distance speed. When the bit error rate is less than $10^{-3}$, Uma maximum communication rate can reach 50kbps, and communication distance can reach 6 feet. Even when ambient RF energy level is relatively low, Uma can reach 10kbps and 1 meter communication distance. When ambient RF energy level is high, Uma can achieve maximum 100kbps communication speed and 6-foot communication distance. The reason why passive wireless communication system is greatly improved in communication speed and communication distance is that: this paper has been fully optimized in all aspects of ambient backscatter signal decoding, impedance matching, antenna design and hardware circuit design.

Figure 8-1 Environmental RF energy is -10 dbm

Figure 8-2 Environmental RF energy is -30 dbm

6. Conclusion
In order to improve energy collection efficiency, communication rate and communication distance of passive wireless communication system, this paper has carried on the comprehensive optimization in
the aspects of ambient backscatter signal decoding, impedance matching, antenna design and hardware circuit design. Firstly, a 5-stage RF-DC charge pump boost rectifier circuit is designed and tested, and the energy collection efficiency is up to 51%. Then based on the principle of ambient backscatter technology data transfer, TI's MSP430G2553 is used as the control chip to design the passive transmitter. Finally, a passive wireless communication system test platform is built, and communication rate and communication distance are tested. The results show that: the system by designed in this paper can improve communication rate from 1kbps to 50kbps, communication distance from 2.5 feet to 6 feet.

Acknowledgment
This work was supported by National Natural Science Foundation of China (NSFC)( 61663001), and partially supported by the Project(JXNE2018-08).

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