# The Research and Realization of Wireless Energy Consumption Detector Based on the Internet of Things

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***ABSTRACT:*** *Intelligent power consumption detection device is an important part in Smart Home system, which can intelligent identification , positioning , tracking, monitoring and management the household electrical parameters, enabling users to keep abreast of household electricity consumption. This paper is mainly about the design of a Wireless Energy Consumption Detector (WECD) based on the Internet of Things, combine with the IEEE802.15.4E wireless protocol. The whole system includes hardware and software parts, the choice of MCU chip, RF chip and power measurement chip for WECD, the design of each module circuit based on the chip working principle, the paper also make a key analysis of device driver module, wireless data forwarding module and wireless data showing module of indoor terminal. After a series of rigorous testing, the result indicates a high reliability and accuracy of the WECD.*

**Categories and Subject Descriptors**
**C.2.1 [Network Architecture and Design]**; Wireless communication: **C.2.2 Network Protocols**

**General Terms:** Wireless Communication,Wireless energy, Hardware and software

**Keywords:** Wireless Energy Consumption Detector, Smart Home, IEEE802.15.4E

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## 1. Introduction

The Internet of Things is another huge innovation after the Internet technology [1] , it is a network composed of RFID, infrared sensors, GPS, laser scanners and other sensor devices, according to the agreed protocol, which can connected and communicate with the internet , so as to realize intelligent identification , location, tracking, monitoring and management of things. The combination of energy consumption monitoring technology and the Internet of Things technology can detect range from family unit narrowed to a single electrical appliances, it also can provide users with more details of the electrical energy consumption and achieve energy conservation, these remarkable features not only bring economic benefits, but also create a broader space for the development of Things in the Smart Home.[2] [3] At present, the energy consum-ption detector in the domestic market owns high accuracy, but generally the function is single, and expensive, bulky, and there is no uniform standard interface for the sensor, neither a network adapter interface module[4] [5], that makes it is difficult to dock with the other company’s network interface module. it is not only inconvenience to users, but also make the electric energy measurement difficult to realize the network of distributed measurement.

The subject of wireless power consumption detector in this paper is to help to build a Smart Home wireless energy monitoring system to accomplish the following goals: Home appliances, can be real-time display, power electricity statistics, timing control, and electricity excessive promptsÿ Real-time power, electricity, switch status, device model and other data package could be send to the multifunction home gateway through the IEEE802.15.4E protocol [6], Provide data support for energy management in the Smart Home applications [7], It is also available for the local terminal and mobile terminal to monitoring household appliances energy consumption information and status.

## 2. WECD overall design

Based on requirement analysis of WECD, considering low cost, low power, accuracy and reliability, we decide the scheme design. Figure 1 shows the scheme design of WECD. Use energy metering IC and voltage and current acquisition circuit send electric energy pulse signal to the main processor chip to account. Send the energy consumption data to the radio chip to retransmit. Power management circuits get and transfer the power from 220VAC directly, then supply power for the each section of circuit.

According to GB / T 17215.211-2006 ≪AC measuring devices General requirements, tests and test conditions≫ "*and GB/T*-17215-2002 ≪*Alternating-current static meters for active energy — Classes* 1 *and* 2≫ there are eight points to be considered in the design of WECD:

**(1) Data types:** Electrical instantaneous active power and cumulative power can be real-time acquisition and processing;

**(2) Power Requirements:** 220VAC - / +10% (50HZ);

**(3) Load capacity:** Large household appliances are generally not more than 4000W, in the case of access to electricity, the maximum load current of not less than 20A;

**(4) Communication features:** Support for wireless data transceiver, power supply control, reserved for the serial interface, for the upgrade;

**(5) The data accuracy:** Not less than the national standard level 2;

**(6) The equipment energy consumption:** no more than national standards provisions of 2.5W;

**(7) Operating Temperature:** -5 °C ~ 45 °C;

**(8) Structural characteristics:** Electrical outlets for our standard plug, internal plug terminals use high quality phosphor bronze, good elasticity, no oxidation, no deformation; the shell requires the use of the imported fire retardant materials with excellent electrical insulation.

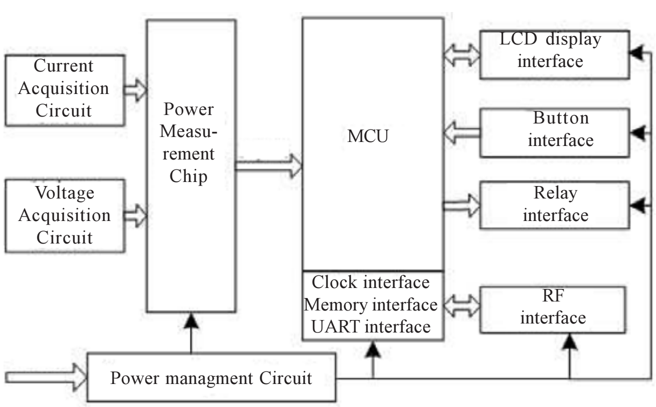


Figure 1. WECD Scheme Design

## 3. WECD Hardware Design

In this paper, it chooses ATmega64 as the chip with the clock frequency of 16MHz, and the CC2430 [8] as its transceiver chip, the integrated peripheral circuits in CC2430 can simplify the hardware circuit and its high reliability can meet the needs of home environment for networking applications at the same time, and also support IEEE802.15.4E protocol stack migration. The select of the measurement chip is a key part in the WECD, its performance will directly affect the accuracy of information of energy consumption, thus the design chooses ADE7755 [9] which is one of the low-power, high-performance ADE77XX chips serial in ADI's. This chip can make power measurement kernel with on-chip flash drive, LCD, real time clock and intelligent battery management circuit, and allow the electric energy meter to keep time, detection of temperature changes, read LCD data and other important functions of the system. And the select of the ADE7755 measurement chip will greatly simplify system design, improve the accuracy of measurement for its high precision, high-performance, flexible output, low power, low cost, which makes it to be the most commonly used program to single-phase energy meter.

The overall hardware design for WECD was shown in Figure 2. Peripherals equipped with voltage and current acquisition circuit, LCD display circuits, power management circuits, keyboard scanning circuit, and switch control circuit. Measurement chip ADE7755 with a different range of voltage and current sensor connected directly to simplify the interface design and improve accuracy and stability of the power measurement. Since its output pulse signal, the CPU via the interrupt pin can be easily and accurately the cumulative power. When there is a load, the instantaneous power signal CF output pulse signal to the microcontroller ATmega64, through the count of CF, can get cumulative power, and then ATmega64 use internal power algorithm to count the internal timer to set the integration time of CF , and then divided by the integration time to get the instantaneous active power and electricity and other data according to a set tariff, ATmega64 electrical value of the instantaneous active power, the cumulative electricity consumption, electricity and other digital information sent to the CC2430 via the serial port, CC2430 wireless routing of data through the wireless router to send to the Smart Home gateways, wireless acquisition in order to achieve low-level electrical energy consumption information. The following will descript several important circuits.

### 3.1 The Detection Circuit in Energy Consumption

The Detection Circuit in Energy Consumption is the key part of the WECD hardware design, for the precision and stability of the detector is related to the accuracy of Electricity meter. Figure 3 shows the SCH of energy consumption detection circuit, it is composed ofmeasuring voltages circuit, current detecting circuit and peripheral circuit of ADE7755. First load current pass by shunt. Then load current pass by the filter circuitconverting into proper

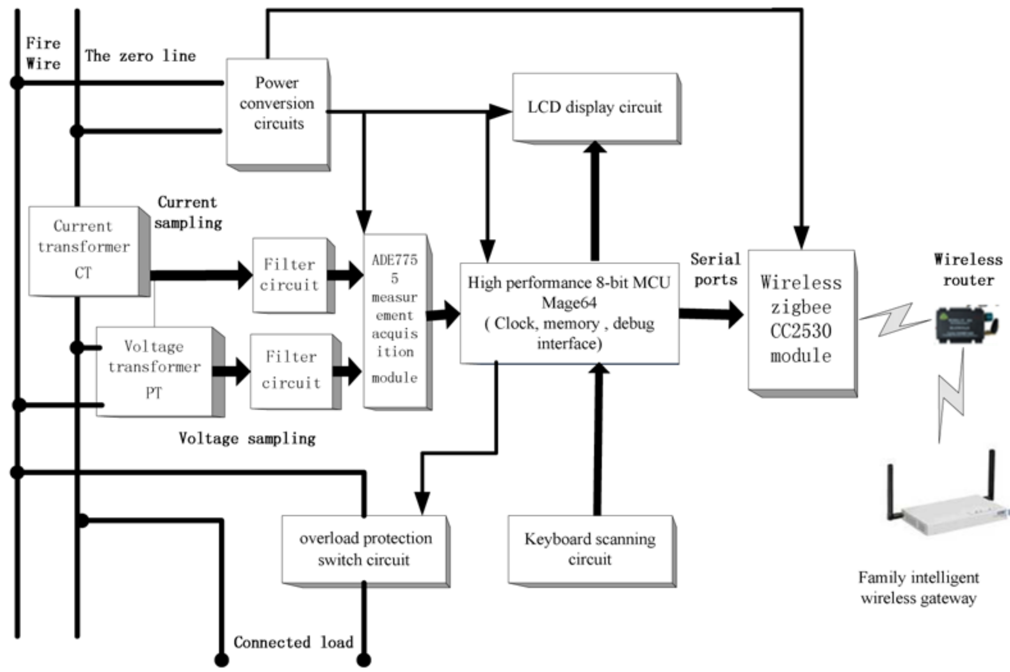


Figure 2. The Overall Hardware Design for WECD

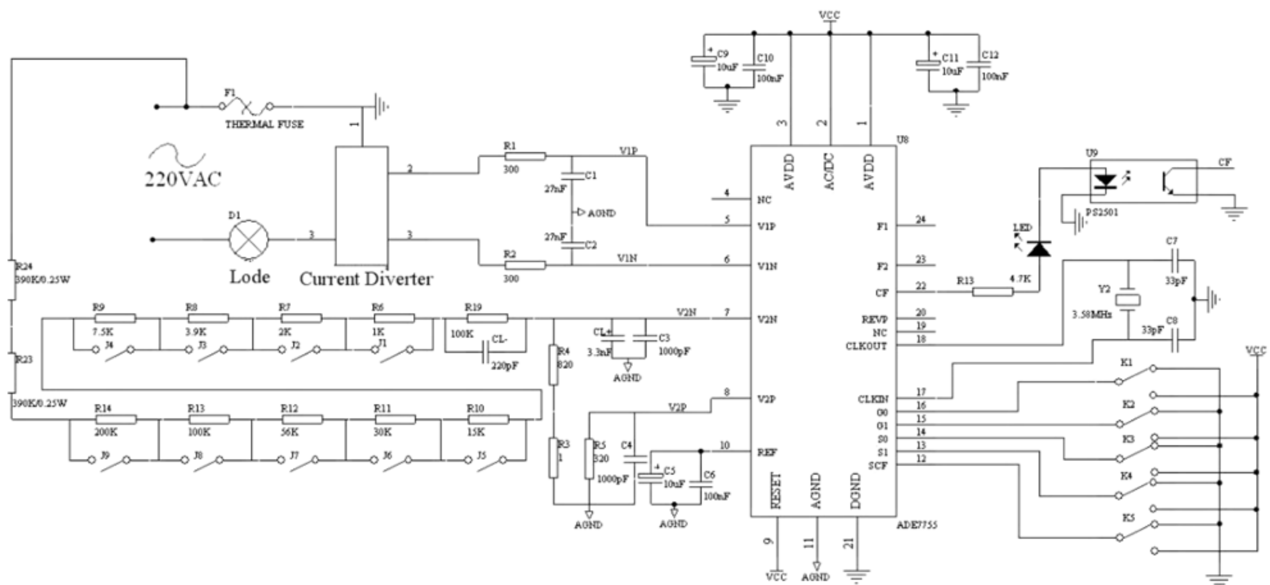


Figure 3. The SCH of Energy Consumption Detection Circuit

voltage signal. And send voltage signalto current channel of ADE7755 (V1P port and V1N port). After 220V phase voltage reduce by calibrationattenuationnetwork, voltage signal is sent to the voltage channel of ADE7755 (V2P port and V2N port). Both of them convertinto instantaneousactive power and output from CF port in the high frequency pulse form. Then send external interrupt signal input port of ATmage64. Main control chip deal CF pulse with quantities calculation and count operation. Obtain instantaneousactive power and cumulativeelectricity values.

F1 is a shunt, R1 and R2 are sampling resistances. C1 and C2 are sampling capacitor and select27nF and 33nFgenerally. They supply sampling voltage signal for current sampling channel. Sampling voltage is decided by resistance of shunt and current that flow over it. Current sampling channel use completelydifferential input.V1P is positive input port. V1N is negative input port. Based on technical index of ADE7755, Current sampling channel's differential peak voltage should be less than 470mV. Current sampling channel has a PGA. Its gain is decided by G1 and G0 of ADE7755.

Table 1 shows gain selection of current channel. When using shunt sampling, G1 and G0 use high level. Gain selection is 16. Peak voltage that flows over the shunt is $\pm$ 30mV. Common electric appliances'power consumption is between 100W and 4000W. Therefore hardware design of current accord with specification5 (20) A. we chose manganin shunt that resistance is 500μΩ. Because this shunt make sampling voltage 10mV less than half values of peak voltage when shunt's current is the maximum current 20A.

| G1 | G0 | Gain | Maximum differential signal |
|---|---|---|---|
| 0 | 0 | 1 | ±470mV |
| 0 | 1 | 2 | ±235mV |
| 1 | 0 | 8 | ±60mV |
| 1 | 1 | 16 | ±30mV |

Table 1. Gain selection of ADE7755 current channel

The voltage input channel of ADE7755 (V2N, V2P) is difference channel, Pin V2N is connected to the resistance points of the resistance points voltage circuit, V2P is connected to GND. The sampled signal of the voltage input channel is get from attenuation line voltage, and R6 to R14 is calibration attenuation network, we can get the sampled signal needed by jointing J1 to J9 to adjust sampled signal. The voltage samples values of this energy consumption detector is 174.2mV when its fundamental current is 5A. The testing scope of the attenuation calibration network is 30% at least for allowing the shunt tolerance and 8% reference source error, according to the parameter in the Figure 3, the adjustable scope is 169.8mV~250mV that meets the requirements. The -3dB frequency in this attenuation network is decided by R4 and C3, as well as R19, R23 and R24, the value of these three resistances is greater than R4 even the jumper caps are all connected. In order to ensure the phase matching of the two channels and eliminate ill effects from phase detuning, the R4 and C3 selected should mate R1 and C1 of the current sampling channel.

### 3.2 The Circuit of The Wireless Data Transceiver

The CC2430 is based on wireless SOC design, which the interior has been integrated a lot of the necessary circuitry, therefore use less external to realize the functions of send and receive circuit signals, CC2430 peripheral circuit schematic shown in Figure 4, Y2 32MHz crystal, with a 32 MHz quartz resonator and two capacitors (C3 and C4), a 32 MHz crystal oscillator circuit; Y1 32.768kHz crystal oscillator with a 32.768 kHz quartz resonator and two capacitors (C1 and C2) constitute a 32.768 kHz crystal oscillator circuit. C5 is 5.6pF, the non-balanced transformer circuit in the circuit by the capacitor C5 and inductor L1, L2, L3, and a PCB microwave transmission line, the entire structure can meet the RF input / output matching resistor (50 Ω) requirements. In addition the voltage feet and feet are added to the filter capacitor to provide the stability of the chip work.

## 4. WECD Software Design

In the design of low-level drivers program in theWECD, the key part is the energy acquisition module and wireless data transceiver module. Figure 5 is the software flow chart

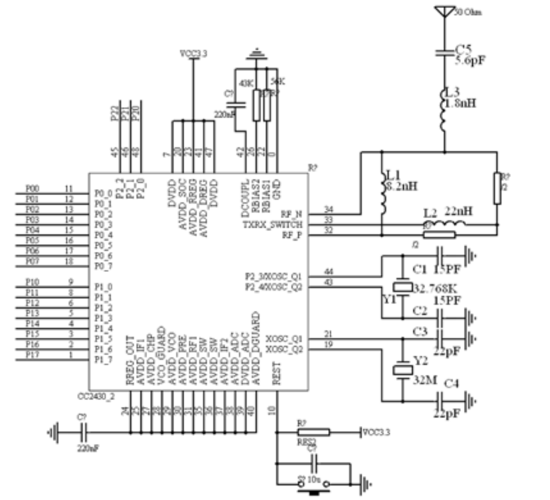


Figure 4. The SCH of CC2430peripheral circuit

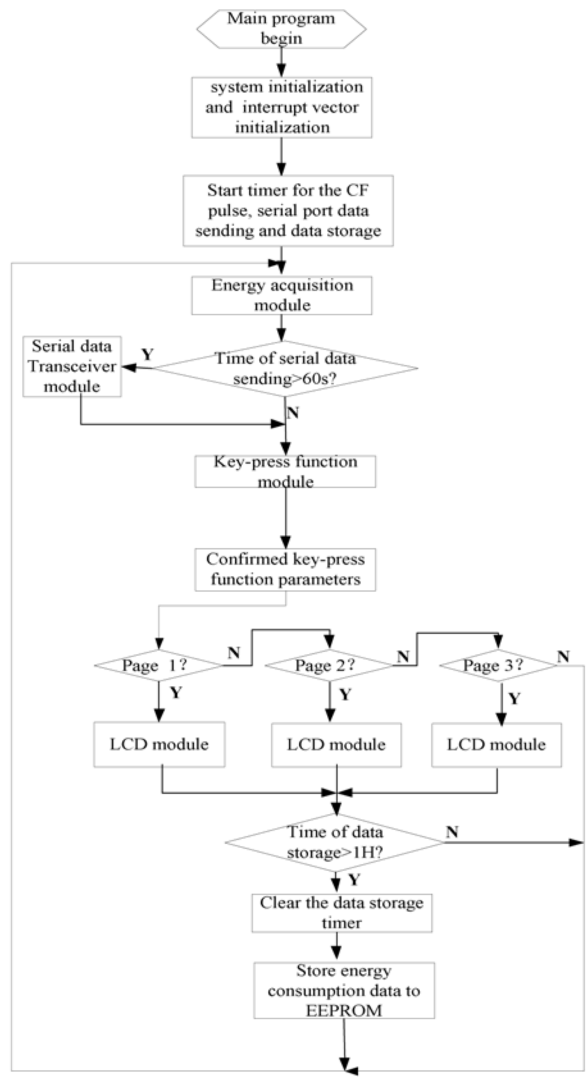


Figure 5. Software flow chart

of wireless energy consumption detector. First is the systeminitializes of the interrupt vector, ADE7755, enabling port, timer and counter to make sure system's interrupt response and function timing process. Main program uses polling method to detect CF pulse and get the energy consumption data. Main program base on button function's flag bit judging the page number. Then main program send data to the LCD module to display. In addition, system timed uses the serial data transceiver module to send energy consumption data to the data forwarding module of CC2430.And system timed stores energy consumption data in the EEPROM of MCU to avoid data loss. In the interrupt response, serial data transceiver module will execute the operation of response port when the module receives data from CC2430.

## 5. Systemverification and test

Figure 6 is the product photo of WECD. The WECD has been tested on the confirmatory test [10]. Problems need to be analyzed and processed to realize system's good operation.

Figure 6. Wireless energy consumption detector

### 5.1 Electromagnetic Compatibility Test

Based on electromagnetic compatibility test requirement of 7.5 clause in GB/T 17215.211-2006, The WECD is tested on immunity of radiofrequency electromagnetic fields and verify its reliability [11]. Figure 7 is the radiofrequencyinterference level 3 vertical polarization test curves.

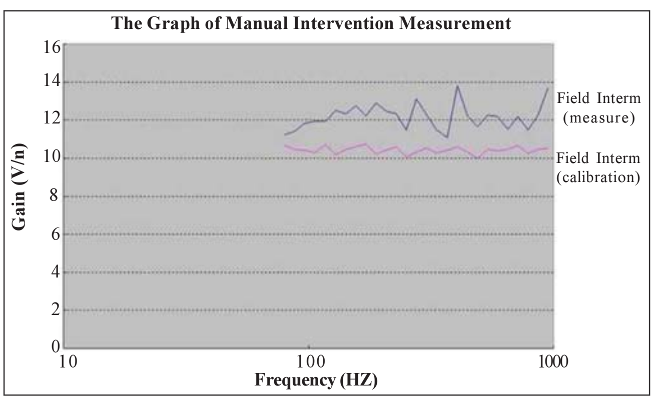


Figure 7. Radio frequency interference level 3 vertical polarization test curves

From the Figure 7, we can know that the WECD can work normally whether practical field of power amplifier is bigger than 10V/m in the test. Therefor the WECD contents therequirement of design and application in the test.

### 5.2 Accuracy Test

Use WF-D01A as standard meter. Its qualification accords with GB/T1725.321-2008. The accuracy precision is grade 1. Current range is from 1.5A~120A. Reference voltage is 220VAC/50Hz [12]. The WECD regards as detected meter. Based on 3.5 clause in JJG596-1999, The WECD should belong to mounted electric energy meter. In the circuit design, we chose ADE7755 as current channel's shunt. Figure out that reference currentIb(Imax) is 5(20)A. Based on the test's clause, mounted electric energy meterload current can be 0.5Ib, Ib, Imax.Owing to lack of power frequency, chose electric cookerthat load current is 2.3A as load. Use master meter method counting relative error to test accuracy. Table 2 shows the result of relative error test.

From Table 4.1 relative power error of WECD is recorded 50 times and its relative electric quantityerrors recorded 40 times per 24hours when the load current is 0.5Ib.Take out maximum error and minimum error. Determine the range of wireless energy consumption detector's relative power error is from 0.11% to 0.17%. Andthe range of wireless energy consumption detector's relative electric quantityerror is from 0.08% to 0.16%.

Based on 2 clause in JJG596-1999, ranges of level 0.5,level 1 and level 2 mounted meter are ± 0.1%, ± 0.2% and ± 0.3%respectivelywhen accuracy levelof standard meter is level 0.1 and power factor is 1.Because accuracy levelof standard meter is level 1, amplify relative error 10 times. Wireless energy consumption detector's accuracy level is level 2 under a rough estimation. For improving accuracy test, we use third-party testing. Testing unit tool is three-phasemultifunctional electric energy meter. The accuracy level of this meter is level 0.05.Relative power error is national level 2. Relative electric quantityerror is national level 2.

| Gain Type | Power error（50 times） | | Charge error（4 times / 24 hours） | |
|---|---|---|---|---|
| | The Max error | The Min error | The Max error | The Min error |
| Electric cooker ($I_r$≈0.5Ib) | Measured value 532.0W proof test value 531.1W relative error 0.17% | Measured value 531.2W proof test value 530.6W relative error 0.11% | Measured value 12.1kw/h proof test value 12.09kw/h relative error 0.16% | Measured value 12.2 kw/h proof test value 12.18kw/h relative error 0.08% |
| Relative error range | 0.11%~0.17% | | 0.08%~0.16% | |

Table 2. The result of relative error test

### 5.3 The Test of Communication Distance

In the condition of WECD with antenna, it sends energy consumption data every minute, and the sniffer gets those packets, after one hour, it gets the test results of wireless communication distance, Figure 8 shows The test schemes of communication distanceand Table 3 shows

The comparison of packet get rate of communication distance.

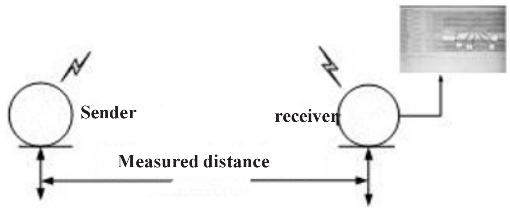


Figure 8. The test schemes of communication distance

From the Table 3, Along with the growth of the communication distance, the reasons of low packet get rate are electromagnetic interference, air humidity, obstacles, multipath loss, the gain and the height settled of the antenna in the test environment and so on, and the communication protocol can also affectthe communication distance.

| Antenna gain | Packet get rate (25meter long) | Packet get rate (50meter long) | Packet get rate (75meter long) | Packet get rate (100meterlong) |
|---|---|---|---|---|
| Antenna(3db) | 91.7% | 83.3% | 68.3% | 48.3% |

Table 3. The comparison of packet get rate of communication distance

### 5.4 The RF Penetrability Test

Figure 9 shows the test schemes of RF penetrability, By timing one hour, it measures the packet get rate when there is no wall or there are two walls or three walls between the device and the router, and the width of each wall is 20cm, and Table 4 shows the result of the comparison of packet get rate of penetrability test.

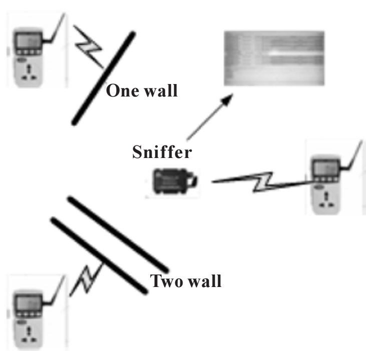


Figure 9. The test schemes of RF penetrability

| Obstacle | Packet/per(hour) | Packet get rate |
|---|---|---|
| No wall | 58/60 | 96.7% |
| One wall | 54/60 | 90% |
| Two walls | 49 /60 | 81.7% |

Table 4. The comparison of packet get rate of penetrability test

From the RF penetrating test structure in the Table 4.3, the RF penetrating of device is nice when the device near to the router, because in the Household environment, the electromagnetic interference is weak, as the paper uses the high reliability of the wireless network protocol IEEE 802.15.4E, it helps to reduce the packet loss rate.

## 6. Summary

In the Smart Home system, this paper researches on the appliances power acquisition theory, combined with IEEE802.15.4E network protocol, it designs the hardware and software of the wireless energy consumption detector, and this detector is used to collect and deliver the appliances power consumption information, users can get those information or control those appliances by various terminal devices. After a long period of testing, the function and the performance of the WECD is nice, but for energy consumption data acquisition accuracy and wireless transmission and data applications, from the long-term development perspective of the Internet of Things, it needs to be improved in energy consumption data acquisition accuracy, data types, accurate measurement error information, etc.

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**Author Biography**

**Wei Fu** was born in Lu Zhou city in Sichuan province in October 1981. She has received her control theory and control engineering master degree in Chongqing University of Posts and Telecommunication in China in June 2008, and received her electro-engineering bachelor degree in Sichuan Normal University in China in June 2005.

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Teacher Fu had owned the second in the Chongqing Science and Technology Progress Award in 2009 for the key technology and application of EAP in the field control network.

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She is now a postgraduate student in Chongqing University of Posts and Telecommunication, and she majors in the control theory and control engineering. She has a paper namedResearch on 6LoWPAN Family Wireless Medical Sensor Network and Monitoring Sensor Node accepted by Process Automation Instrumentation in 2012, and this paper will be published this year, and she now mainly researches in the Smart Home of the Internet of Things.

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