

# SMART AND SAFETY AC POWER SOCKET FOR AN IOT APPLICATION OF THE SMART HOME

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**Abstract:** *This paper presents a safety power socket system that can be controlled wirelessly and that has been specifically designed to monitor electrical events. Each socket of the system embeds a microcontroller, 2.4 GHz Wifi chip, relays, and current sensor. The main features of the system include the remote control of the power outlet, real-time monitoring of the current consumption, the customization and programming of the power supply time schedule, the automatic interruption of vampire currents, and the prevention of certain types of electrical fires and electrocutions. A prototype with such features has been implemented and tested in a simple home automation network in order to validate its functionalities. The results show that the system reacts fast and avoids overconsumptions and electrocutions, being able to make the next generation of homes safer and smarter.*

**Keywords:** *IoT, Smart socket, safety socket, smart home.*

## 1. Introduction

Smart home is recently rising as one of the best smart IoT application. In the modern homes, the electricity is provided to electrical devices through the last element of the power supply chain, the power sockets, which have been regarded traditionally as a mere junction. In fact, power sockets have not evolved as fast as other everyday devices, although they seem to be one of the best positioned candidates to be improved as smart homes are becoming increasingly popular.

Recently, different functionalities have been added to power sockets, like wireless control or current consumption monitoring, but there are still many others that could make such devices safer and smarter. This paper addresses some of the most common problems that arise when interacting with power sockets and shows a novel approach to two of them: the prevention of electrical fires and the avoidance of electrical shocks.

Regarding electrical fires, they are described as fires that begin because of some type of electrical failure or malfunction. The National Fire Protection Association (NFPA) [1] latest report states that, in 2011, just in the USA, there were 47,700 home electrical fires that resulted in 418 civilian deaths, 1,570 civilian injuries, and \$1.4 billion in direct property damage [2]. In the same report, it is also stated that, of all the electrical fires whose cause could be determined precisely, the vast majority were caused by short-circuits.

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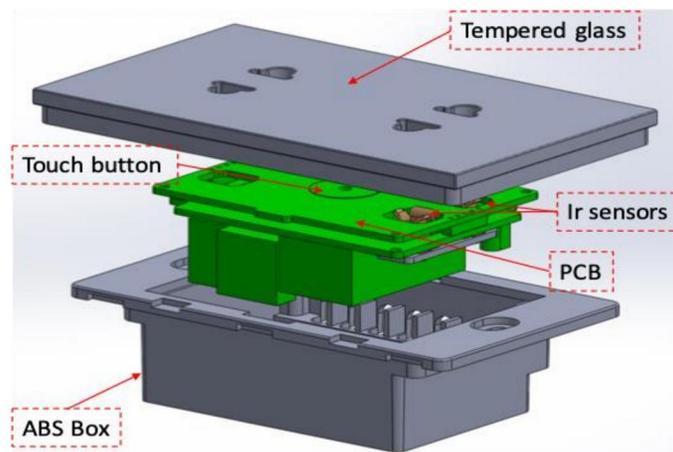
A similar situation occurs with electrical shocks. According to the Electrical Safety Foundation [3], in North America each day nearly 7 children are treated in hospital emergency rooms for electric shock or burn injuries caused by tampering with a wall outlet. In the same region, fires and burns are the third leading cause of unintentional death among children aged 14 and under.

In order to address the two issues previously mentioned, this paper presents a smart power socket system that has the following features. It is able to detect overconsumptions that might lead to overheat in low-current systems and, therefore, to an electrical fire. This device prevents electrocutions, since it only supplies power when it identifies a valid appliance. The smart socket can be controlled remotely using Wifi technology. It is also possible to monitor in real-time and make available to external devices (e.g., PCs connected to the Internet, smartphones, and tablets) current consumption data. The intelligent outlet can disconnect the power supply when a vampire current is detected (a vampire current is a current that arises when an appliance consumes power when it is in stand-by mode or when it claims to be switched off).

## 2. Design of the Socket

### 2.1. The mechanical structure of the socket

The socket is designed including three main parts. First, the tempered glass is used for save, durable and sensitive touching button. It is also very pretty for good design of user interface. Second, this is a core of the smart socket which is PCB circuit with IC and microcontroller mounted on its surface. The program is installed into the microcontroller to perform functions that socket has to possess. The last component is a box to cover and fix the PCB circuit which is made from ABS plastic. The design model of the socket is shown in the Fingure 1.



*Figure 1. The mechanical design of the socket*

### 2.2. Designing the prevention of electrical fires

Electrical fires can occur due to different problems, with the most common ones being power overloads, short-circuits and arcs. In cases, when they happen, the energy released must be smaller than the maximum load capacity of the transmission medium to avoid irreparable damage.



**Figure 2.** Arc causing fire on the socket

In the case of power overloads, the current must remain below the maximum permissible load current of the transmission medium ( $I_z$ ). The following rule is commonly applied in accordance to IEC/EN 60898-1/-2 and IEC/EN 60947-2 by miniature circuit breakers (MCBs) manufacturers to determine when the circuit should be opened in the event of an overload:

$$I_{t=30} \leq 1.45I_z \quad (1)$$

where  $I_{t=30}$  is the monitored current at an ambient temperature of 30°C.

In the case of short-circuits, it is necessary to determine the maximum short-circuit current. If the short-circuit release time is under 100 ms, the next rule is usually followed to prevent the devices from firing and avoid damage [4]:

$$K^2 S^2 \geq I_k^2 t_{cut-off} \quad (2)$$

where  $K$  is coefficient of the material medium (As/mm<sup>2</sup>),  $S$  is cross-sectional area of the conductor of the transmission medium (in mm<sup>2</sup>),  $I_k$  is RMS value of the short-circuit current flowing through the medium (in A), and  $t_{cut-off}$  is release time in seconds of the protection device for the current. Equation (2) indicates that if a high current is maintained during too much time, the conductor through which it flows might be melted and even catch on fire. Such equation in (2) is derived from thermodynamic equations that regulate adiabatic processes and it enables designers to check the suitability of a composite cable used for the c.p.c. (circuit protection conductor, i.e., the earthing conductor and all the equipotential bonding conductors).

The case of arc causing fire can be avoided by preventing the generation of arc. Generally, the arc occurs because the pins of plugs are close to terminals of the socket under high voltage between them as shown in figure 2. The arc cause of emitting arc reveals a mechanism for contacting and transmitting current in the socket without arc. It is the plug's pins mounted in socket's terminals with zero voltage in both sides. To achieve this mechanism, this research proposes a method which is the electricity being supplied to the socket's terminals after 3 second when the plug's pins were plugged in the socket.

### 2.3. Designing the prevention of electrical shocks

Power socket usually includes different safety measures in order to prevent electrical shocks. The most common one is the addition of a third prong (ground) that reduces the risk of electric shock and protects equipment from electrical damage. There are also power

sockets that are encapsulated into a tamper resistant receptacle that prevents the insertion of objects. There are also power sockets (AFCI, Arc Fault Circuit Interrupters) that reduce the risk of electrical shock by interrupting power when arc fault occurs in the circuit. Moreover, there is another kind of sockets (GFCI, Ground Fault Circuit Interrupters) that prevents shocks by shutting off the power when the electricity flowing into the circuit is superior to the one returning (i.e., when there is a leakage). All these traditional solutions work in most situations, especially when the same outlet combines different functionalities (e.g., ground fault protection and tamper resistance), but there are still cases when they fail (e.g., when the ground is not properly set or when a kid is able to tamper the socket).

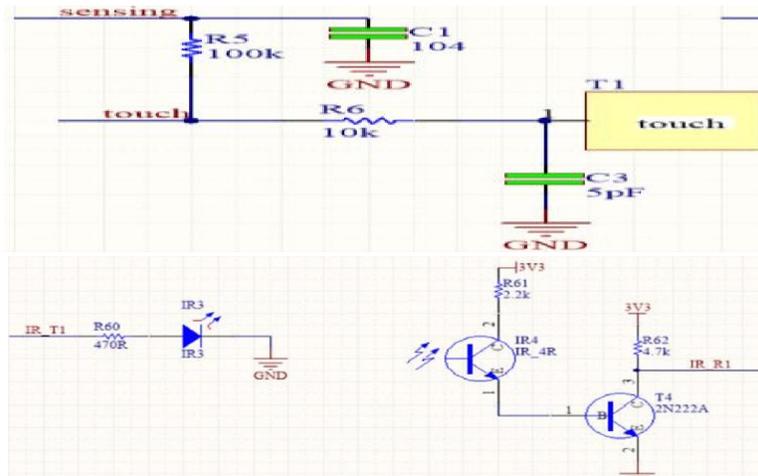


Figure 3. Schematic circuit of touch and infrared sensor

The system proposed in this paper prevents electrical shocks based on the following principle: if there is no appliance connected to the outlet, electricity will not be supplied. In this way, most of the tampering will have no consequences and no electrical shocks should occur. To achieve this goal, it is necessary to identify when an appliance is connected to an outlet. There are different mechanisms that allow for identifying appliances, but most of them rely on mechanical systems, nonautomated systems (e.g., pressing a button to indicate that the appliance is connected), or proprietary technologies. This design uses infrared sensors to detect plug's pins in the socket's terminals for automation mode and using a touch button for nonautomated mode. Figure 3 shows the button and infrared sensors mounted on PCB circuit in the sockets.

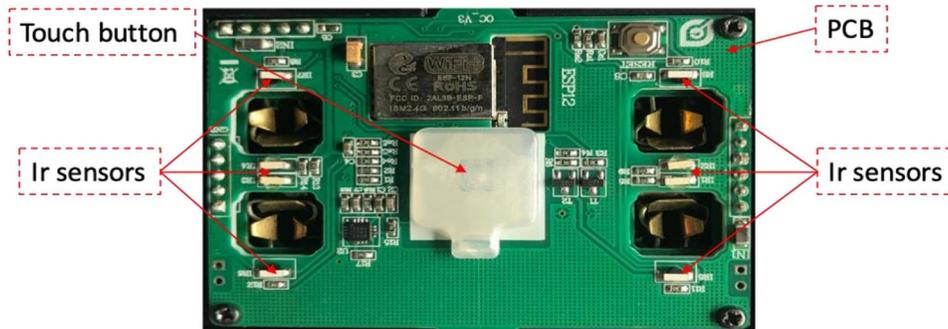


Figure 4. Implementation of touch and infrared sensors

## 2.4. Designing prevention of a vampire current

The vampire current is a significant problem to home energy efficiency. Surprisingly, just a few smart power outlets [5] automate the detection of vampire currents and are able to disconnect appliances after they have been in stand-by for a certain amount of time. If the current exceeds the maximum allowed during  $t_{cut-off}$  (duration to open circuit), the system turns off the power supply to avoid damage and electrical fires. In order to perform this function, we design the socket hardware to measure power consumption of appliances including voltage and current measurement.

### 2.4.1. Background math for measurement

In an AC circuit voltage, current, and power are defined as follows:

$$v(t) = V \cdot \cos(\omega t) \quad (3)$$

$$i(t) = I \cdot \cos(\omega t - \theta) \quad (4)$$

$$p(t) = v(t) \cdot i(t) = V \cdot I \cdot \cos(\omega t) \cdot \cos(\omega t - \theta) \quad (5)$$

When the load is purely resistive, voltage and current are in phase. When the load is either inductive or capacitive, voltage and current are out of phase. Using several trigonometric identities, the power can be expressed as:

$$p(t) = \frac{v \cdot i}{2} \cdot \cos(\theta) \cdot [1 + \cos(2\omega t)] + \frac{v \cdot i}{2} \cdot \sin(\theta) \cdot \sin(2\omega t) \quad (6)$$

The average (real) power, P. Real power is the energy that flows to the load. It is what the electric company bills home users for. It can then be written as:

$$P = V_{rms} \cdot I_{rms} \cdot \cos(\theta) \quad (7)$$

Reactive power, Q, is the energy that flows back and forth in an inductive or capacitive load. On average, no reactive power is consumed. It can be written as:

$$Q = V_{rms} \cdot I_{rms} \cdot \sin(\theta) \quad (8)$$

Together, real power and reactive power form complex power. This is the actual power that the electric company is supplying. It can be written as:

$$S = P + jQ \quad (9)$$

The magnitude of complex power is called apparent power, |S|, in units Volts-Ampere. The power factor, PF, a measure of efficiency. It is defined as:

$$PF = \cos(\theta) = \frac{P}{|S|} \quad (10)$$

### 2.4.2. Voltage measurement

To measure voltage, the general idea is to use a very large voltage divider to divide the 270 V peak-to-peak signal down to level which can be sampled by the ADC. Using a 1001:1 voltage divider (with 1 MΩ and 1 kΩ), 270 V peak-to-peak is divided down to 0.27 V peak-to-peak. A very large resistor (1 MΩ) was used in the divider to limit the current between AC live and neutral. Assuming a 270 V drop, only 0.27 mA flows through the 1 MΩ resistor,

dissipating 0.03 W, well within the power ratings of the resistor. To calculate the line voltage from the voltage divider output, the following equation can be used:

$$V_{line} = 1001 \times V_{divider} \tag{11}$$

2.4.3. Current measurement

To measure current, the general idea is to break the neutral line and insert a very small current-sensing resistor (0.2 Ω). This would create a small voltage difference across the resistor. Since we know the voltage drop and the resistor value, we can mathematically determine the current through the neutral line. Since the resistance is very small, very little power is dissipated through it. We carefully checked the ratings of this and other circuit components for power ratings. The resistor is rated for 3 W. We expected a 2000 W appliance to draw about 10 A. This results in a voltage drop of 0.54 V and a power dissipation of 0.58 W. To calculate the line current from the current-sensing resistor voltage drop, the following equation can be used:

$$I_{line} = \frac{V_{current-sense}}{R_{current-sense}} = \frac{V_{current-sense}}{0.2\Omega} \tag{12}$$

2.4.4. Power calculations

To calculate real power, voltage and current are multiplied during every sample and summed up. After 1000 samples are taken, the power summation is divided by 1000 to get the average power over 1 second. The following equation describes the operation:

$$P = \sum_{i=1}^{1000} \frac{IV}{1000} \tag{13}$$

To calculate apparent power,  $V_{rms}$  and  $I_{rms}$  should be multiplied together every second. Power factor was calculated by dividing average power from apparent power.

**Firmware architecture design**

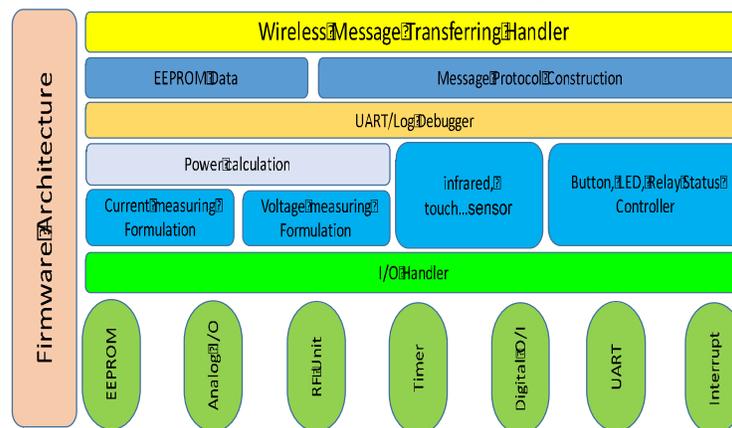


Figure 5. Software architecture

As shown in the figure, the software is designed to handle every signal come in and out from a microcontroller to perform the socket's functions. Physical signals from input and output pin of the microcontroller is processed by a software module called I/O handler. It

encodes raw data then transfer them to a higher processing modules such as: current, voltage formulator, sensing data processor and relay, display controller. Needed data to perform tasks is extracted at these modules and transferred to a wifi processor via the UART protocol.

The used wifi processor, Esp8266 is a low-cost Wi-Fi microchip with full TCP/IP stack and microcontroller capability. It is capable to program the proposed functions of the sockets. The api (Application programming interface) of the sockets function is implemented to be able to control and monitor from a third-party smartphone application such as turning on/off, timing turn on/off, sending consuming power, etc. The socket becomes an IoT device because these apis make it can be controlled and monitored via the internet. Therefore, users can manage their household appliances easily from smartphones.

### 3. Experimental Analysis

#### 3.1. Experiment setup

The block diagram is shown in Figure 6. Our device is placed between the mains line and the device under test. Current measurements occur on the neutral line. The relay is switched on the AC live line. A voltage divider is used to step down the voltage to the correct levels. All signals are optically isolated before reaching the MCU.

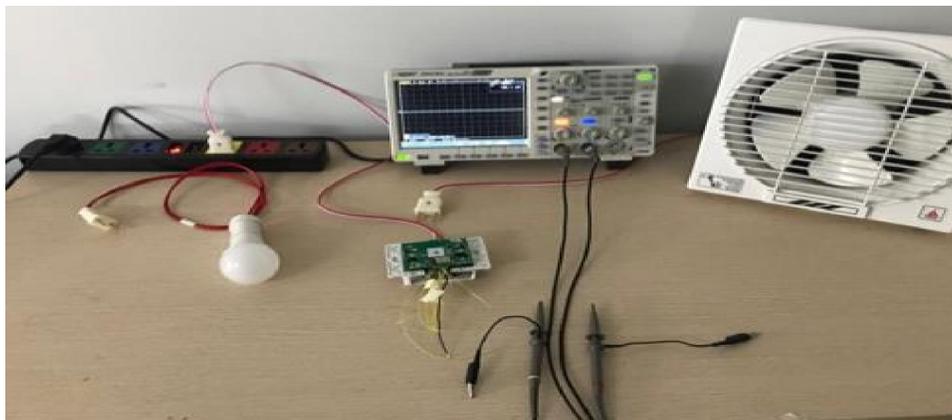
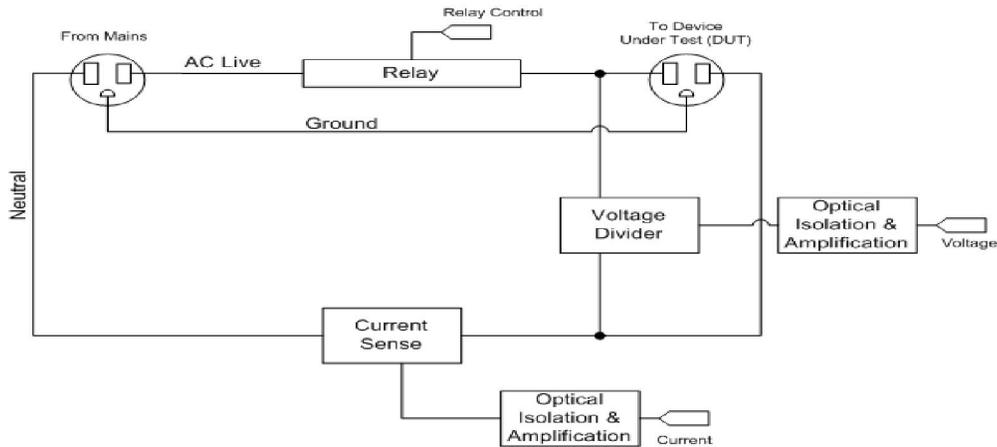
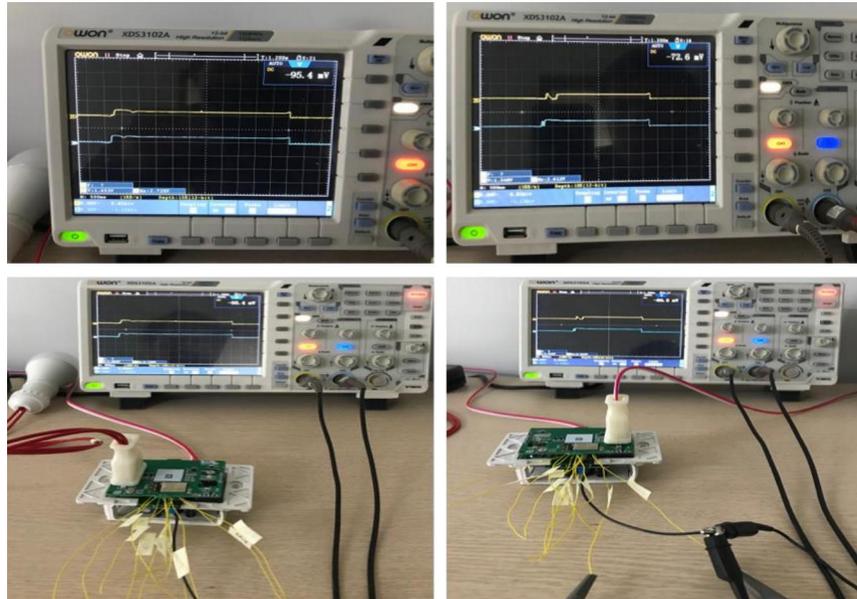


Figure 6. Experiment setup

### 3.2. Appliance detection

In order to detect an appliance plugging into the socket's terminals, the infrared sensors circuit is implemented as shown in the figure. The output pins of sensor circuit are connected to an oscilloscope XDS3102A to figure out its response. Once the plug's pins plug into the socket, the infrared sensor circuits response as signals of high level. The circuit returns to a signal of low level if the plug is drawn out from socket. The experiment results are shown in the figure 7.



*Figure 7. Deteced Signals of plugged appliances*

### 3.3. Current and Voltage Monitoring

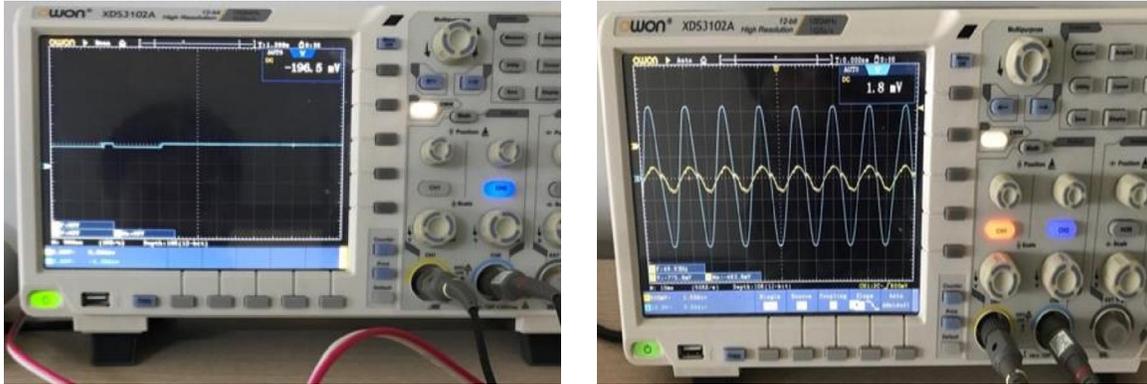
We designed this device to measure stable devices, so the 1 Hz report time is not terribly slow as there are very few devices that have power draw that changes faster than once a second. The designed application for this device is for power monitoring over duration of time, as it also keeps track of total energy used through the plugs. Also, the commercial power measuring device that we have also only updates at 1 Hz.

The error in measurement can be from opto-isolator noise as well as the lack of precision in ADC and data calculation. To test the accuracy of our project, we used a commercial power measuring device to measure the statistics of power drawn by a single 50W light bulb. The results are organized in Table 1.

*Table 1. Accuracy Comparison for a 50 Watt Light Bulb*

	Our Project	Commercial Product	Error
Total Power Draw (W)	51.9	50.6	2.57%
RMS Voltage (V)	120.0	121.5	1.23%
RMS Current (A)	0.43	0.409	5.13%

The absolute difference in the power measurement is about 1W, which we consider pretty good. We feel that with higher load or even a calibration our device can achieve better accuracy. According to this result, any vampire current will be detected and household appliances will be insulated for protection functions.



*Figure 8. Voltage and current measurement*

#### 4. Conclusion

Our final design of the device mostly met our original goals. We not only planned to be able to monitor and control the device remotely by wifi protocol, but also the socket can be detected with risks of shock, fire, vampire current, etc. to isolate household appliances or human from electricity network. We decided to finish a working version of the project on a timely basis and implement other features such as power factor and the power based auto shutoff. In conclusion, the designed socket has good performance of safety functions.

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