Switching System, a Zero Power Standby Solution

Stefan Mozar FIEEE[1], Nobuo Funabiki[2]

Department of Electrical and Communications Engineering, Okayama University, Japan

Abstract— *This paper describes a novel standby system. The actual power consumption in standby mode is zero Watts. In this standby system the appliance is completely disconnected from it mains supply during standby mode. In addition from saving on electricity costs, it also has the added benefit of preventing hazardous situations whilst in standby mode. This novel standby system will set a new goal for manufacturers of consumer products to achieve.*

Keywords— Energy efficiency, energy harvesting, green design, standby, zero power.

I. INTRODUCTION

Standby power is a major concern for power companies, and for consumers. Consumers are becoming aware of how much it costs to have appliances in standby. Governments have introduced energy rating labels on products. Standby goals and guidelines are produced by minimum performance standards (MEPS) for a number of different products. The International Energy Agency (IEA) has started the" One Watt Initiative" which aims to reduce standby power to not more than 0.5W. In order to have a common way of measuring standby power, IEC standard 62301 was developed. The challenge is how to reduce standby power. A number of different techniques have been developed. This paper will describe a "standby" solution which achieves zero power consumption. With this new system, the appliance is completely disconnected from the mains supply, when switched off by remote control. Once switched off the remote control can be used to the appliance on again.

II. BENEFITS OF THE NEW STANDBY SYSTEM

The obvious benefit of this system is that no power is drawn during what would be called "standby". In this mode the appliance is completely disconnected from the mains supply. Thus there is complete isolation from the mains supply. With current technology about 10% of household electricity is used for standby. That means 10% of a household energy bill is wasted. With increasing energy costs, that is a potential for saving. More importantly than saving is the environmental impact due to wasted standby energy. Thus reducing energy that is waste from standby has a big impact on society.

Having the appliance completely disconnected from the mains supply has another advantage. It is safety. An appliance that is in active or standby mode can through a fault condition become unsafe. Data collected on household fires shows that about 17% of domestic fires in Tokyo are due to faulty consumer products. In Germany the figure is 30% of household fires. In Germany top of the list appliances that contribute towards household fires are washing machines and dryers. Safety issues of consumer product are in the news frequently. The ability to isolate an appliance from the mains helps improve safety and reduces the electricity bill. A further benefit of the proposed system is the low cost to implement it. Cost is a critical factor in consumer electronics.

III. REVIEW OF STANDBY INNOVATIONS

Many studies have been done on the energy wasted in households by standby. Mohanty [6] has done such a study, which highlights the wasted energy due to products being in standby mode. The studies not only show the energy waste in consumer households, but they also include standby energy consumption in offices.

In early consumer products, standby systems just disconnected high power loads from the power supply. In standby the product had to appear to be switched off. For example a TV set had a dark screen, and no sound. To indicate the set is in standby mode, some form of indication was used. Typically a LED was lit up. In these systems the main power supply was live in standby, with a reduced load. Flyback power supplies perform poorly under low load conditions and have very low efficiency. Typical standby power consumption has been 30W and upward, depending on the type of appliance and its total power rating.

Flyback power supplies are the most common topology used in consumer applications. This is because of their simplicity, and lower component count compared to other topologies, and they can have multiple isolated secondary supplies. The disadvantage of flyback supplies is their poor efficiency under low load conditions. For consumer products with higher power demands the inefficiency of the power supply is significant. In standby mode the only load are the microprocessor and the standby components. These draw very little power. The losses in such a supply can be higher than the prescribed newer standby requirements. The solution was to use a second, smaller auxiliary power supply for standby. The smaller supply is more efficient than the main supply at low power. This solution resulted in a significant reduction in standby power, but it added extra cost which can only be justified in high end products. The power consumption of such circuits would go down to one or two Watts.

Burst mode, also known as pulse skipping technology was the next step in standby evolution. When the load is reduced as is the case with standby mode, the switching frequency of the power supply is changed. In normal operation the switching frequency is high and the switching transistor is on for most of the time. In standby mode, less energy needs to be supplied to the load, so the switching frequency is dropped, and the switching transistor is off for most of the time. The skipping of switching pulses (burst mode) reduces the switching losses and thus increase the low load efficiency. This is shown in the fig. 1 below.

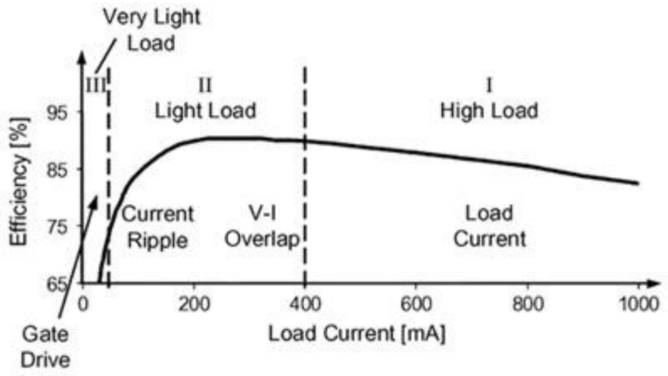

FIG. 1. EFFICIENCY VERSUS LOAD CURRENT [12]

During burst mode the losses are in the startup up circuit, the losses in the switching device, and power losses in the control IC circuit, and hysteresis losses in the transformer.

Lower the switching frequency requires a number of design tradeoffs. Reducing the switching frequency, reduces the losses in the switching device, but it may result I poor regulation of the output voltage. The low switching frequency may result in audible noise. The noise level can be reduced by limiting the peak switching current. This in turn reduces the supply efficiency. Thus the designer must find a balance between noise and efficiency.

As microprocessors became available with a sleep mode which would reduce the micro's energy consumption to micro Watts, new standby concepts were proposed [7]. Generally these were able to achieve very low power consumption levels. This led to the development of a variety of new approaches for standby mode. Many of these that were published by academic researchers had practical limitations. Many have proposed the use of solar panels as a standby supply, thus claiming zero power standbys. But these methods still consumer power in standby. They don't draw current from the mains supply. Given the requirements of a product that consumers will buy, these solutions fall short, as they have many unsolved problem. For example what if there is no light, and then their standby system will not work. They also have not included solutions for safety, and interference issues. Thus their concept models are often not practical and too expensive.

IV. SWITCHING SYSTEM

The zero power solution to be described has the following advantages:

- It does not require any internal power source to operate.
- It disconnects the appliance from the mains supply
- It is safer in "Standby mode"
- It can help improve Electro Magnetic Interference (EMI)

This standby solution is actually an on-off switch; therefore the patent for this invention describes it as a switching device. This is a more accurate name, than standby. Standby has been used in this paper, as it makes it easier to understand the function of this system. The aim of this system is to use a remote control to switch an appliance, like a TV set, on or off. A conventional standby system needs internal power to be able to receive the Infra-Red (IR) signal from the remote control transmitter. This new system does "energy harvesting" from an RF signal that is emitted from the remote control transmitter. The signal transmitted is in the unlicensed frequency band. A block diagram of the prosed system is shown in fig. 2.

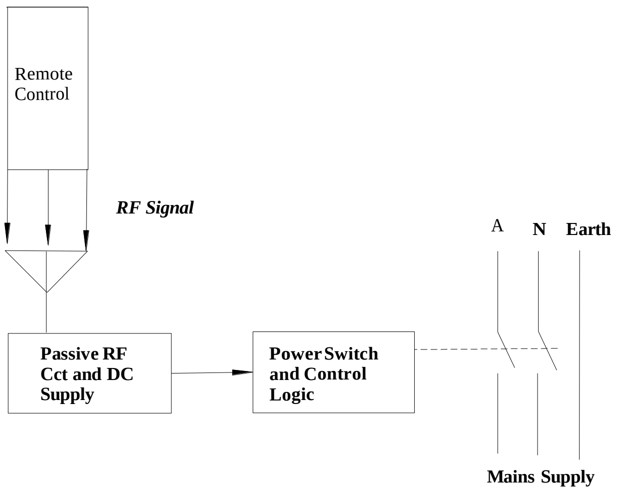

FIG. 2. SWITCHING SYSTEM BLOCK DIAGRAM

The system consists of an antenna which is connected to a passive RF module that rectifies and filters the received signal. The voltage obtained from this signal is then used to activate an electronic switch, which in turn connects the appliance to the mains supply. Thus this system does not have a standby mode. It only has two states, on or off. This shown in the state diagram of figure 3 below. The conventional standby system has three states, compared to the two states of the switching system. This system also isolates the appliance from the mains supply in the off state, thus contributing to safer operation.

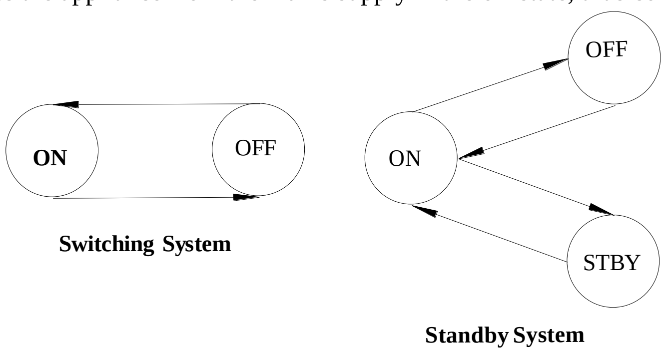

FIG. 3. STATE DIAGRAM

V. SWITCHING CIRCUIT DESIGN CONSIDERATIONS

This section provides an overview of some of the design considerations and issues.

5.1 RF Frequency Selection

The first consideration is the frequency selection. A frequency needs to be chosen that falls in the unlicensed bands. Choice of the frequency affects the antenna size. The size of the antenna is determined by equation (1).

$$\lambda = \frac{c}{f} \quad (1)$$

Where c= wave velocity ($3x10^8$ m/s)
f = frequency in Hz
λ = wavelength in m

The Frequency determines energy required to transmit the on/off signal to the appliance, which in our example is a TV receiver. The energy drops at the rate of the cube of the distance. The trade-offs in the frequency selection are:

5.1.1 Frequency Selection

A low frequency will require a larger antenna, and if data transmission is to be by RF, it may result in too slow data transmission. If the frequency is higher it will require more energy for a given distance than a lower frequency.

5.1.2 RF or IR

In its simplest form the RF signal may only be used for the on-off function, and the other remote control functions may continue to be performed by an Infra-Red system (IR). For either choice the RC-6 or other existing protocols can be used.

5.1.3 Passive RF Stage

The switching system is not connected to any power, when switched off (or in "standby mode"). The only energy source is the transmitted RF signal from the remote control transmitter. It needs to be converted in to a DC voltage. Figure 4 show the basic circuit that will generate the DC voltage. The RF signal is rectified and its energy is stored in a capacitor. In order to get a large enough voltage to activate the switch, the following must be done.

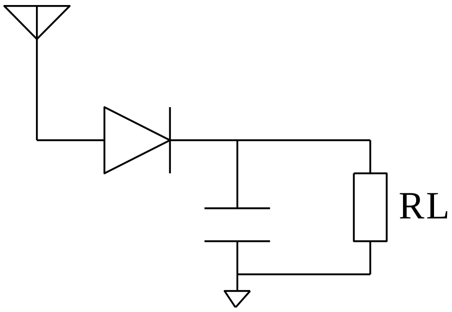

FIG. 4. PASSIVE RF CIRCUIT

5.2 Voltage Magnification Factor

There are number of tradeoffs to make in order to supply the switching circuit with an initial startup voltage. The proper selection of components allows the Q of the input circuit to produce a larger voltage to the input of the electronic switch.

$$Q = \frac{f}{BW} \tag{2}$$

From equation 2 we can see a relationship that can be used to determine the voltage multiplication factor of the input circuit. In our design we used 900 MHz, which is in the unlicensed band in most countries. The bandwidth in this band (860 MHz to 960 MHz) is 100 MHz. This gives a Q of about 9 to 10. At 900 MHZ, the cycle time T is 1.1ns. The load resistance can be calculated based on the voltage we need to drive the switch and the current or power requirement. This resistance is the load (R_{Load}). As a rule of thumb, the time constant τ to uphold the supply should be about 100 µs at this frequency. From this the filter capacitor can be calculated by equation 3.

$$C = \frac{\tau}{RLoad} \tag{3}$$

If the RF circuit is also to be used for data reception, then a second circuit is required. One path of the circuit will be required to supply DC voltage. Here a larger capacitor will be required to store the required energy for the switch to operate. The second path needs to be able cope with data signals. Therefore a separate circuit is used for the data path. Here a smaller filter capacitor is used. The concept of this circuit is shown in figure 5.

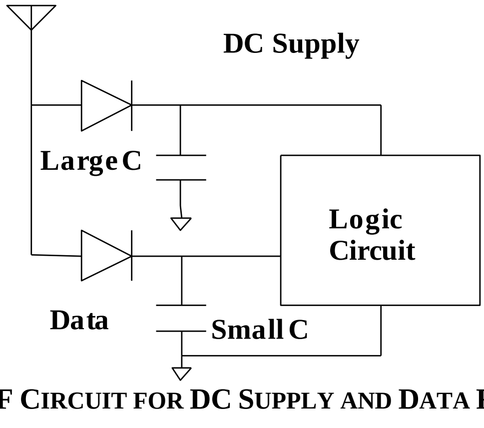

FIG. 5. RF CIRCUIT FOR DC SUPPLY AND DATA RECEPTION

5.3 The use of a Voltage Doubler

A voltage of about 1V is need to drive the switch. Although the input circuit Q factor will help, a charge pump, also known as voltage doubler, may be needed. Figure 6 shows the circuit of the doubler. The voltage can be scaled by adding one or more stages to the voltage doubler. It must be noted that we cannot just add n multipliers to obtain a desired voltage. The energy that can be extracted from the RF signal is limited by the signal strength. The signal must supply enough energy to overcome the diode voltage drops.

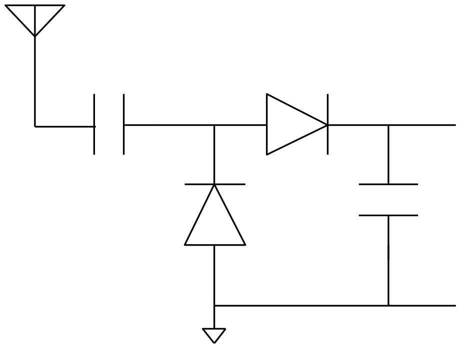

FIG. 6. VOLTAGE DOUBLER CIRCUIT

5.4 Switching System

5.4.1 Mains Switch

The mains switch can be implemented with a variety of devices that are compliant to IEC 65. For appliances that consume 35 W or more, a mains switch must be used. Below 35 W, the switch is optional.

5.4.2 Solid Sate Switch

The choice for a switch can be a solid state device such as a SCR or Triac. Using these devices extra components will be needed to meet the safety requirements. A further consideration is that devices will need to have noise suppression components so that false triggering won't occur. They will also contribute towards an increase in EMI. Very large noise spikes may also affect the performance of an electronic switch.

5.4.3 Mechanical Switch

A mechanical switch can be used. In this application, a mechanical switch can be placed at a location in the receiver, where the mains cable layout will result in minimal EMI pickup. A relay may also be used as an electro mechanical switch. This is easy to control with a simple transistor that can handle the latching and holding currents. The circuit controlling the relay will need to be compliant with all safety standards as specified in IEC 65. This generally results in extra components to prevent safety issues under fault conditions. A relay has an advantage that the switching noise is audible. This noise can be good feedback that the appliance is changing state, i.e. from on to off or vice versa. An optical indicator of whether the appliance is drawing current form the mains supply needs to be included in the circuit.

5.5 Control Logic

The appliance needs to be able to distinguish between valid signals and keep track of several functions associated with switch control. As the signal is RF and disperses, it may be that a command is received from another appliance that is located close by. The circuit needs to be able detect if it is a valid signal that has arrived. These type of logic control functions can be implemented in hard or software.

5.6 Safety Issues

The switching system designed was for a TV receiver, thus IEC 65 was used as a reference for safety issues. As the circuit interfaces with high energy parts, safety tests will need to be done. The actual solutions to ensure a safe design, will depend on the method used to disconnect from the mains supply.

The switching device has a number of benefits regarding safety. In the OFF Mode, the appliance is completely disconnected from the mains supply. This is in contrast to current standby systems, where the appliances are always connected to the mains supply. Being disconnected makes the appliance safer.

VI. CONCLUSION

The switching circuit has many advantages over current standby systems. Its greatest advantage is that it is an on-off system. Unlike other standby solutions, it is completely isolated from the mains supply when the appliance is not in use. The appliance can be switched on or off from the comfort of one's armchair, with the aid of a remote control unit. Other benefits are that no energy is consumed in the off state, and that some of the implementations, if designed correctly will result in better EMI performance, and it will make the appliance safer. A benefit of switching the appliance off is that the micro controllers and system busses get reset on power on. This standby solution is cost effective, reliable, and improves safety.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of their families. Without the support of our wives Choo and Naomi, and our children Christine, Mina, Yuya, and Ryoji we would not have been able to complete this project and many others.

REFERENCES

[1] Huang B.T., Lee K.Y., Lai Y.S., 2007, Design of a Two-Stage AC/DC Converter with Standby Power Losses Less than 1W, IEEE Power Conversion Conference, Nagoya, 2007, Pages 1630-1635.

[2] Kang S., Park K., Shin S., Chang K., Kim H., 2011, Zero Standby Power Remote Control System using Light Power Transmission, IEEE Transactions on Consumer Electronics Vol.57, No. 4, November 2011, Pages 1622-1627.

[3] Kim M.S. et al, 2013, Advanced Burst Mode of Control to Reduce Standby Power of Flyback Converter, Scientific Research, Engineering 2013, 5, pages 137-141.

[4] Lee BH, Moon GW, 2013, Zero No-Load Power AC/DC Adapter for Electronic Equipment With Embedded Battery, IEEE Transactions on Power Electronics Vol.28, No.7, July 2013.

[5] Madigan M., 2006, Green-Mode Power by the Milli-Watt, Texas Instruments Power Supply Design Seminar SEM1700, Topic 2, TI Literature Number: SLUP290.

[6] Masswood A.I., Yoong Z.K., 2008, Switching Loss Reduction Through Digital Burst Technique in TV Power Supply, IEEE Industrial Electronics Magazine, September 2008.

[7] Mohanty B, 2001, Standby Power Losses in Household Electrical Appliances and Office Equipment, The French Agency for the Environment and Energy Management (ADEME).

[8] Mozar S. 2000, Intelligent Standby Concept, IEEE Transactions on Consumer Electronics**,** Volume: 46, Issue: 1, Feb 2000, Pages 179-182.

[9] Mozar S, Switching System, US Patent 7911087, March 22, 2011.

[10] Taranovich S., 2017, The Next Best Power Management Solution to Zero Power in Nano Power, EDN Network 2017 March 14.

[11] Tsai C.H., et al, 2010, Design and Implementation of a Socket with Zero Standby Power using a Photovoltaic Array, IEEE Transaction on Consumer Electronics, Vol.56, No.4, November 2010, pages 2686-2693.

[12] http://electronics.stackexchange.com/questions/285029/the-meaning-of-burst-mode**.**