

Reducing Leaking Electricity to 1 Watt

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ABSTRACT

In this study we examine some specific opportunities to reduce standby losses in electronic appliances. A review of power consumption levels for the major components responsible for standby functions indicates that nearly all standby functions can be performed with a total appliance standby power consumption of one watt or less. We therefore propose that standby losses be limited to one watt per appliance, a significant reduction from current levels for many appliances. This target could be achieved with little or no extra cost to manufacturers and could save over \$2 billion in annual U.S. energy costs. Globally, a one-watt plan would lead to a significant reduction in carbon emissions.

Introduction

Almost all electronic appliances consume power in their quiescent or "standby" modes. This wasted energy is commonly referred to as "standby loss" or "leaking electricity." Previous studies have shown that common household appliances such as televisions, audio equipment, and telephone answering machines have standby losses (Meier, Rainer & Greenberg 1992; Herring 1996; Meier & Huber 1997; Molinder 1997; Sanchez 1997; Webber 1998). Recently, standby losses have also begun to appear in traditional white goods, such as refrigerators, dishwashers, and ranges.

Ranging from less than one watt to as much as 25 watts, the typical loss per appliance is relatively low. However, when multiplied by the number of such appliances in a household and the amount of time each spends in standby, standby consumption represents a significant fraction of total residential electricity use. In Japanese homes, for example, standby losses account for over 10% of residential electricity consumption (Nakagami, Tanaka & Murakoshi 1997). In the United States, standby losses account for about 5% of total residential electricity consumption (Rainer, Greenberg & Meier 1996), adding up to more than \$3 billion in annual energy costs. Standby losses are expected to grow as traditionally electromechanical appliances become digital and home electronics become more widespread worldwide.

Despite the diversity of appliances with standby losses, relatively few components are actually responsible for standby functions. A large portion of standby losses can be attributed solely to low-voltage power supplies. Standby losses are also commonly caused by components that give an appliance the capability to be powered remotely, display information, maintain an internal clock or memory, or charge batteries in standby

mode (Huber 1997). Such features may require some components to continuously consume power. Frequently, however, components that do not need power in standby mode are powered unnecessarily.

This study investigates the power consumption of some of the key components responsible for standby losses and the engineering modifications needed to reduce those losses without sacrificing product functionality or convenience. With these results, we assess the feasibility of meeting a standby loss target of one watt per appliance.

Deconstructing Standby Power Consumption

Most appliances with standby losses can be viewed as consisting of three main parts: the low-voltage power supply, the circuitry, and the input/output (I/O) components. This collection of components appears in a wide array of appliances, from VCRs to dishwashers, from remote-controlled ceiling fans to refrigerators. For the most part we can ignore other components, such as motors or heaters, and focus on just those related to standby losses. A generic device with a low-voltage power supply, internal circuitry and I/O components is represented in Figure 1.

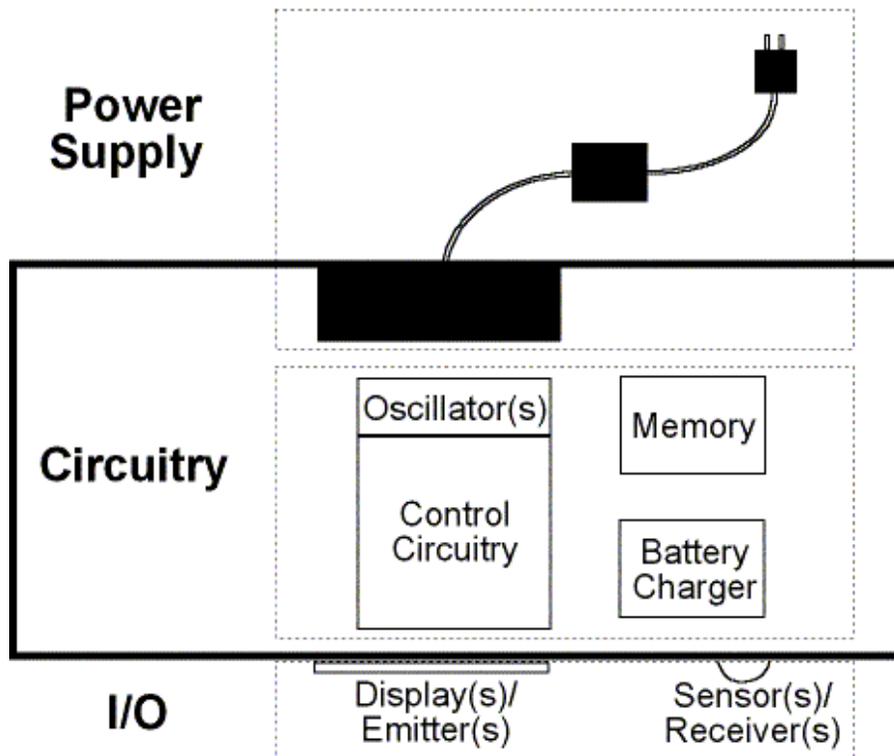


Figure 1. Top View of an Appliance, Showing Components Responsible for Standby Functions

When an appliance is in standby mode, power losses occur whenever current flows from the source through the power supply, usually to provide power for standby functions performed by the circuitry and I/O components. If the appliance needs power in standby mode, therefore, at least the power supply must be active. This nearly always generates some losses, the magnitude of which depends on the efficiency of the power supply. For each additional component that receives power, more losses accrue. Ultimately, the whole is equal to the sum of its parts; i.e. the appliance's standby loss is equal to the sum of its components' losses. Table 1 shows the typical component make-up of some of the most common consumer electronics.

Table 1. Typical standby components in consumer electronics

Appliance	Power Supply	Battery Charger	Real-time Clock	Sensor/ Receiver	Display/ Emitter
Amplifier	x			x	x
Boom Box	x		x	x	x
Cassette Player	x			x	
CD Player	x			x	x
Clock Radio	x		x		x
Equalizer	x				
Mini-System	x		x	x	x
Power Speakers	x				
Receiver	x			x	x
Tuner	x			x	x
Dishwasher	x			x	
Microwave Oven	x		x	x	x
Range	x		x	x	
Refrigerator/Freezer	x			x	
Garage Door Opener	x			x	
Security System	x	x	x	x	x
Motion Sensor Switch	x			x	
Timer	x		x		x
Battery Charger	x	x			

Modem	x			x	
Answering Machine	x			x	x
AnsMach/Cordless Phone	x	x		x	x
Cordless Phone	x	x		x	
DVD Player	x			x	x
Internet Appliance	x		x	x	x
Television	x			x	
TV/VCR Combo	x		x	x	x
VCR	x		x	x	x
Video Game	x				

In an ideal appliance, standby losses would be limited to the components responsible for standby functions. For example, an appliance with a power supply, a microcontroller, some memory, an infrared sensor for remote control capability, and a clock display could easily consume less than half a watt in standby mode if the standby components were made to be individually and cooperatively efficient. Table 2 shows typical standby consumption values for some components that are commonly responsible for standby functions.

The majority of standby components shown in Table 2 consume very little power; most consume less than a tenth of a watt. The highest consuming component shown here is the power supply, which must be active to provide power for standby functions. Other relatively high-power components can be found among the I/O components. These components, and some measures that can be taken to minimize their standby losses, are discussed in further detail in the following sections.

Table 2. Standby Power Consumption of Common Appliance Components

Component	Description or Use	Standby Power (Watts)
Power Supply		
Linear	Convert 110V AC to 5V DC	0.80
Switching	Convert 110V AC to 5V DC	0.30
Circuitry		
Oscillator	4 megahertz	0.001
Control Circuitry		
8-bit microcontroller	Governs appliance functions	0.05

16-bit microcontroller	Governs appliance functions	0.10
Memory		
Flash	Store several megabytes	0.00
Register	Store a few bytes	0.00
Input/Output		
Emitters		
Light emitting diode (LED)	per diode	0.04
Light emitting diode (LED)	per 3.5 x 5 mm character	0.30
Liquid crystal display (LCD)	not luminescent, per cm ²	0.002
Vacuum fluorescent display	per 3.5 x 5 mm character	0.05
Receivers		
Infrared	Remote control	0.05
Radio frequency	Remote control	0.20
Temperature Sensor	Portable computer	0.001
Visible light	Adjust display brightness	0.01

Low-Voltage Power Supplies

Low-voltage power supplies are the most ubiquitous component contributing to standby losses because they must be active for an appliance to perform standby functions. They are also, perhaps, the most readily improved. Low-voltage power supplies change the 110 volt current found in typical U.S. households to a lower voltage current required by almost all electronic appliances. Whenever current flows through a conventional low-voltage power supply – i.e. whenever the appliance is on or uses power for standby functions – as many as 3 watts are wasted. If the on/off switch is on the low-voltage side of the power supply, these losses also occur when the appliance is performing no function at all. The following measures can be taken to reduce or eliminate power supply losses:

Improve the efficiency of conversion to lower voltages. The two main types of power supplies used today are linear power supplies and the more efficient electronic "switching" power supplies. Currently, linear power supplies are used in many low-power appliances, such as answering machines and battery chargers. Changing from linear to switching power supplies in such appliances would not only reduce standby losses, but would also improve efficiency when the appliance is on (Meier & Huber 1997). For situations in which a switching power supply cannot be used, linear power supply efficiencies can be improved by using more metal, and more and thinner laminations in the core of the transformer (Rainer, Greenberg & Meier 1996).

Decrease the standby power consumption of the other components in the appliance. Because the standby power consumption of the low-voltage power supply is proportional to the amount of power it supplies at any given moment, decreasing the power it provides to the other standby components decreases its own standby losses as well.

Add a second power supply specifically for the lower power standby mode. Low-power power supplies waste proportionally less power than higher-power ones. Using a secondary power supply is already common practice in systems drawing more than 50 watts, such as personal computers, monitors, and televisions. With newer switching power supplies consuming only two or three hundred milliwatts, this option may now be cost-effective for lower power appliances as well.

Turn the power supply off when the appliance is off. A simple way to do this is to design the appliance so that the power switch is on the high-voltage side of the power supply. Other possibilities include designing a smart power supply that can sense when the appliance has been turned off, or offering an optional standby mode by using a power supply with a three-way on-ready-off switch – a feature offered on most non-US television sets. If an appliance needs just a few milliwatts of power in standby mode, rechargeable batteries can be used to provide power to components that need it. As photovoltaic and energy storage technologies improve, it may even become cost-effective to keep components or batteries charged with small photovoltaic cells.

Some of the most wasteful power supplies are external linear power supplies, or "wallpacks." An estimated one billion wallpacks are currently plugged into U.S. homes, each consuming about 2 watts on average. Replacing these power supplies with more efficient, switching power supplies could save the U.S. more than a gigawatt of power. Implementing the other efficiency measures described above could save several times this amount.

Circuitry

After the power supply, the next destination from an electron's perspective is the internal circuitry. Depending on the appliance, the circuitry almost certainly contains one or more oscillators and some kind of control circuitry, the combination of which allows the appliance to perform functions pre-programmed by the manufacturer or requested by the user. More complex circuitry may also contain memory where information such as consumer preferences can be stored. Existing power management technologies have the capability to reduce the standby power consumption of any circuitry to less than one microwatt (EPC 1998). (See Table 2.)

Oscillators. An oscillator is an object, typically a crystal, that vibrates at a very specific frequency when electricity passes through it. This vibration provides a tempo for the circuitry, synchronizing operations in a logic device. Higher frequency oscillators consume more power and cause all of the circuitry following that frequency to consume more power as well. When an appliance is in standby mode, a tempo must continue for standby components to be active, however, higher efficiencies can be obtained by switching to a lower frequency oscillator. Lower-frequency oscillators are already commonly used to conserve energy in battery-powered applications.

Control Circuitry. The components of many appliances are administered by some kind of control circuitry. Most home appliances have very simple control circuitry, consisting

of a single micro-controller chip and its firmware. An exception to this case is the computer, which uses a much more complex system of circuitry and integrated circuit (IC) chips to control the system.

Control circuitry power consumption depends on the complexity of the system. In general, more and bigger chips need more power. However, because portions of circuitry, and even portions of chips, can be shut down while other portions remain powered, even the most complex circuitry needs a very small amount of power to respond when needed.

Memory. There are a several different types of memory commonly used in electronic devices. The most common memory storage device is the register. Most appliances have several registers, for example, to maintain a clock or pre-programmed channels for a receiver. This type of memory is composed of just a few transistors, each requiring only microwatts of continuous power to retain information. This tiny amount of power is often supplied by a battery or supercapacitor to protect against power failure.

Non-volatile memory, by definition, uses no power to retain information. Some disadvantages associated with today's non-volatile memory technologies are high cost, slow speed, and limited number of read/writes. Memory technologies are expected to improve quickly due to the high demand for low-power components needed for portable applications. One such technology is non-volatile ferroelectric RAM (FeRAM), which promises unlimited read/writes, high speed, and low power, at prices equal to or less than existing memory. Volume production of FeRAM is expected before the end of 1998 (Matsumoto & Hara 1998).

Battery Chargers. Some battery chargers continue to provide power even when the battery is fully charged. This is particularly true for alkaline and nickel cadmium batteries because there is little consequence for over-charging. Existing technology, such as that used for lithium ion battery charging, is capable of halting the flow of current when it is not needed.

Input/Output

The input/output or "I/O" system consists of emitters and receptors that allow an appliance to communicate with the user and other electronic devices and also to monitor itself and its environment. Some of the most common I/O devices and their standby consumption values are shown in Table 2. These are only a tiny fraction of the emitters and receivers available on the market, but are the most commonly used in residential appliances.

Emitters. An emitter is any device that sends out light or some other type of signal. A display is a specific type of emitter, frequently used to show time, status, or simply to illuminate buttons on an appliance in standby mode. The most common luminescent displays are light emitting diodes (LEDs) and vacuum fluorescent displays (VFDs). These displays come in the form of round or oval lights that can be used alone or assembled to create shapes and characters. A commonly used non-luminescent display is

the liquid crystal display (LCD) which is typically black and white. In some applications, such as portable computers, LCDs are enhanced with color and background lighting.

Some emitters may consume non-trivial amounts of power depending on how strong the signal must be. Often, this depends on how far the signal must travel to its intended receptor. Power consumption in displays also depends on the size and complexity of the display. A simple standby light, for example, consisting of a single LED, consumes only about one-twentieth of a watt. A full four-digit clock display, on the other hand, requires about 30 LEDs and about 30 times as much power. Newer display technologies accomplish the same goals, with significantly less energy.

Receivers. Receivers are devices that sense an incoming signal and relay the message to components that can interpret and/or react to the message. Receivers are regularly on at all times so that appliances in standby mode can respond to external conditions or signals. The most common receivers are radio or infrared sensors for reception of remote control signals. Some other common receivers include temperature sensors, motion detectors, and analog and digital signal detection devices. As shown in Table 2, most of these devices consume less than one-tenth of a watt.

Case Studies

We conducted two case studies to illustrate how the better engineering technologies described above can be used to reduce standby power consumption. The first study involves an Internet set-top box slated for mass production in 1998. The second case study investigates the power consumption of a garage door opener currently on the market. Similar case studies presented by Meier & Huber (1997) involved utilizing more efficient power supplies for a disk drive and cell phone charger. The two cases described below are more complex because, in addition, they examine improving the efficiency of the circuitry and I/O.

Internet Appliance

In the spring of 1998, we worked with an electronics hardware and software design company developing a TV set-top box that provides access to the Internet through an ordinary television set. This investigation is particularly relevant because the TV set-top box ranks among the largest sources of standby loss in the United States and belongs to the fastest growing category of residential appliances. Moreover, the original power consumption values of the prototype set-top box are based on actual design approaches found in Silicon Valley during early 1998. The reduced consumption values presented in our proposed design, therefore, reflect savings obtained by improving a state-of-the-art design, rather than savings obtained by improving an older, obsolete design.

The manufacturer provided detailed information about their product, the major components of which are listed in Table 2. The "Original" values are the standby consumption levels of components as designed by the manufacturer. Values under

"Proposed" are the estimated standby power consumption levels of components after implementation of the better engineering practices described above.

Table 2. Standby Power Consumption of Components in a Case Study Set-Top Box

Component	Original Proposed		Change
	(Watts)	(Watts)	
Power Supply	2.00	0.50	Use a secondary switching power supply
Circuitry	4.06	0.01	Power critical on/off circuitry only
Oscillators	0.25	0.001	Reduce clock speed
Control Circuitry			
Chipset	1.00	0.00	Off
Modem (28.8k)	0.50	0.00	Off
I/O Controllers	0.60	0.00	Off
TTLs	0.87	0.00	Off
PAL	0.63	0.00	Off
Regulators	0.08	0.00	Off
I/R Decoder	0.01	0.01	No change
Memory			
System (DRAM, 8 MB)	0.05	0.00	Off
Video (DRAM, 1 MB)	0.02	0.00	Off
Cache (SRAM, 0.2 MB)	0.06	0.00	Off
Flash (4 MB)	0.01	0.00	Off
Other	1.39	0.00	Off
Input/Output	0.05	0.05	
Infrared Sensor	0.05	0.05	No change
Total	7.50	0.56	

The majority of savings in this study were obtained by simply discontinuing power to the components that are not needed when the appliance is switched off. Beyond the power supply, the only components that must remain active to maintain the same level of convenience are the components associated with turning the appliance on and off remotely: the infrared receiver and decoder.

Garage Door Opener with Remote Control

The second case study presented here focuses on a typical remotely controlled garage door opener. In comparison to the Internet appliance discussed above, a garage door opener is both simpler and a more mature product. Garage door openers are present in about 28% of homes (Sanchez 1997).

The garage door opener studied here consists of four standby components: a linear power supply, a radio receiver for the remote control, and an infrared emitter and its receiver used to sense objects (e.g. a child) in the path of a closing door. Together, these components consume 3.6 watts in standby. The manufacturer was able to redesign the product to consume less than one watt in standby mode and estimated that the new design would increase the cost to the consumer by about five dollars (about 5% of the retail price). Although the power savings would repay this cost in about two years, the marketing division felt that consumers would be unwilling to pay the extra cost, causing the company to lose market share. (Note that the incremental cost would probably vanish within the next product cycle.)

The Global 1-Watt Proposal

This paper presents evidence that it is technically feasible to reduce standby losses in domestic appliances to less than one watt. Innovative manufacturers for many products, including televisions and audio equipment, are already meeting, or are close to meeting, the 1-watt target without any sacrifice in services or increase in the purchase price. The costs of key low-loss technologies are rapidly falling, so that the incremental cost to meet a 1-watt target is also falling. If all appliances were replaced by units meeting the 1-watt target, aggregate standby losses would fall at least 70% (Webber 1998), saving the U.S. over \$2 billion annually.

Large reductions in standby losses are not likely to occur without intervention. Some reductions may occur incidentally, as a result of improvements in technologies, but they are likely to occur only for certain appliances and will occur slowly. Market forces alone are not effective in reducing standby consumption because manufacturers have no reason to even consider standby losses when designing products. On the demand side, consumers lack a means of comparing the standby consumption of competing goods. The opportunities for significant energy savings, combined with the absence of incentives and information on both sides of the market, are good reasons for government action.

A global plan to reduce standby losses to one watt per appliance has been proposed by Alan Meier of Lawrence Berkeley National Laboratory. The key elements of the proposed plan are shown in Figure 2. This plan recognizes that each country's situation is unique and encourages local action suitable for the conditions. Some countries may choose to rely on regulations, while others use incentives or mass purchasing to transform the market. In any case, manufacturers still face the same overall and long-term goals in all countries. Some manufacturers would no doubt continue to offer high standby loss products because the technical obstacles are too great or because they simply are not interested, but a transformed market would ensure that most components offered are designed for low standby losses.

Obstacles to a 1-Watt Limit

While it is technically feasible to greatly reduce standby losses in most appliances, there remain obstacles that will need to be addressed. Some obstacles that have been brought to our attention are discussed below.

Personal Computers. Personal computers (PCs) are generally not manufactured by a single company. A variety of components from several different manufacturers are usually assembled by a retail company or even by the consumer. The power supply must therefore be capable of supplying power to an undetermined number of components having undetermined standby power requirements. The Intel NLX specification includes a provision for up to 3.6 watts consumption in the standard PC's off-mode (Intel Corp. 1997).

One way to reduce this maximum standby consumption is to use currently existing technology originally developed to allow networked computers to enter a deep sleep mode without losing the ability to respond to network signals (AMD 1998). This technology gives the signal receptor, in this case the network chip, the capability to decode signals and inform the rest of computer when it needs to respond. In this way, all components are off when the computer is in standby and powered only when an incoming message is intended for that computer. The standby power supply would therefore only be required to provide enough power to keep the network chip active, at most a few hundred milliwatts. Since the technology to solve this problem already exists, the greatest challenge in this case is for the computer industry to agree to a standard.

System on a Chip. The internal circuitry of many appliances is being designed with increasing reliance on a single chip to perform functions that were previously done by multiple chips. This all-in-one system chip is commonly referred to as system-on-a-chip (SoC). Theoretically, this trend should save power because operations within a chip use substantially less power than operations between chips. In addition, engineers can easily implement efficient power management techniques within a chip because they do not have to accommodate other companies' chip specifications. It is expected, however, that some companies will use existing architecture in the new integrated chip, without re-designing power management (VSI 1998). The result would be that the entire SoC may need to remain powered at a relatively high level for individual functions to remain available.

Digital Satellite Systems. Existing standards require that digital satellite systems transmit power at 18 volts to switches on the dish. This relatively high operating voltage makes low standby losses difficult to achieve. In this case, the specifications regarding communications between components would need to be re-written before standby losses could be reduced.

Reasons for an International Effort

Reducing standby losses in appliances is suitable for international action because the market for these goods is international. At the same time, a coordinated effort would bring much greater benefits than would individual efforts by a few countries. The savings would be both economic, in reduced consumer costs of operating the appliances, and environmental, in the form of reduced carbon dioxide (CO₂) emissions. Compliance with the 1-watt target in the U.S. alone could eventually lead to a 9 megaton reduction in annual CO₂ emissions (Webber 1998). Although this is a relatively small contribution to the United States' total Kyoto obligations, which require reducing forecasted 2010 CO₂ emissions by about 600 megatons, we believe it can be accomplished without economic hardship.

Global action to reduce standby losses could reduce global CO₂ emissions by about three times as much, or 27 megatons per year (Webber 1998). This is a large reduction compared to other actions under consideration. At the same time, appliance suppliers can manufacture appliances to a single, global specification and reduce both production and inventory costs. These benefits cannot be understated because the market for electronic appliances is unusually global in that design, manufacture of components, assembly, and final purchase frequently take place in different countries.

A coordinated international effort can also transform the entire global appliance market. All manufacturers of final products and components will shift to low-loss components and designs. In this way, countries not directly participating in this plan will benefit because low-loss devices will become the standard rather than the exception. The poorer countries will therefore also enjoy operating savings and reduced CO₂ emissions.

Finally, the global appliance market is evolving rapidly, and life cycles of electronic appliances are short. This means that new specifications can be incorporated into new designs and be marketed within a few years.

Conclusions

This study has shown that most standby losses occur as a result of powering relatively few components. Analyses of individual components with standby losses suggest that several different paths to decrease standby losses are already available. The results of this study imply that it is feasible to establish a uniform 1 watt ceiling for nearly all appliances. Technical obstacles remain for certain appliances, but these represent a small fraction of total appliances with standby losses.

An international effort to reduce standby losses has unique advantages. The global nature of the appliance market prevents any single country from effectively addressing the issue. At the same time, an international approach improves the likelihood of completely transforming the market, carrying along even those countries that do not formally participate. The next challenge will be to devise a global program to achieve this goal. Such efforts are now underway.

Acknowledgments

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