POSSIBLE TECHNOLOGIES FOR IMPROVING THE AUDIBILITY OF RESIDENTIAL SMOKE ALARMS FOR OLDER ADULTS

September 2005

CPSC-ES-0505

The views expressed in this report are those of the CPSC staff and have not been reviewed or approved by, and may not necessarily reflect the views of, the Commission.

U.S. CONSUMER PRODUCT SAFETY COMMISSION
WASHINGTON, D.C. 20207-0001

U.S. CONSUMER PRODUCT SAFETY COMMISSION

The U.S. Consumer Product Safety Commission (CPSC) was created in 1972 by Congress under the Consumer Product Safety Act and began operating in 1973. In the Consumer Product Safety Act, Congress directed CPSC to protect the public "against unreasonable risks of injuries associated with consumer products."

CPSC is charged with protecting the public from unreasonable risks of serious injury or death from more than 15,000 types of consumer products under the agency's jurisdiction. Deaths, injuries and property damage from consumer product incidents cost the nation more than $700 billion annually. The CPSC is committed to protecting consumers and families from products that pose a fire, electrical, chemical, or mechanical hazard or can injure children. The CPSC's work to ensure the safety of consumer products - such as toys, cribs, power tools, cigarette lighters, and household chemicals - contributed significantly to the 30 percent decline in the rate of deaths and injuries associated with consumer products over the past 30 years.

U.S. CONSUMER PRODUCT SAFETY COMMISSION
DIRECTORATE FOR ENGINEERING SCIENCES

POSSIBLE TECHNOLOGIES FOR

IMPROVING THE AUDIBILITY OF

RESIDENTIAL SMOKE ALARMS

FOR OLDER ADULTS

July 2005

CPSC-ES-0505

Arthur Lee
Electrical Engineer
Division of Electrical Engineering
Directorate for Engineering Sciences

The views expressed in this report are those of the CPSC staff and have not been reviewed or approved by, and may not necessarily reflect the views of, the Commission.

No Text on This Page

EXECUTIVE SUMMARY

In 2003, there were an estimated 36 million people in the United States over the age of 65 years – just over 12% of the U.S. population. During the 20th century, the number of people 65 years and over grew from 3 million to 35 million, and is projected to grow to almost 87 million by 2050.

According to a 1999 report by the U.S. Fire Administration (USFA), residential fires injure approximately 3,000 older adults each year. In comparison to the rest of the population, older adults – those over 65 years of age – represent one of the highest fire risk groups in the United States. For 1999, the fire death rate for people over 65 is 25.3 fire deaths per million, or more than twice the national average. The fire death rate increases for older age groups. For those over the age of 75, the fire death rate (32.9 fire deaths per million) is about three times the national average. Causes for the higher death rates among older adults may be associated with the physical and mental challenges related to aging. One concern is that seniors may not adequately hear or respond to smoke alarms because they commonly experience hearing loss in the frequency range at which smoke alarms operate.

In 2003, the U.S. Consumer Product Safety Commission (CPSC) staff initiated a project to review the audibility effectiveness of residential smoke alarms. Currently, residential smoke alarms operate at sound frequencies that may produce alarm sound characteristics poorly suited for the older population. A report of the CPSC staff work, *A Review of the Sound Effectiveness of Residential Smoke Alarms*, was released in 2004. The report presented a literature review of the sound effectiveness of residential smoke alarms in producing audible signals suitable for alerting older adults and for waking sleeping children. The staff also reviewed possible alternatives or modifications to current smoke alarms, such as changes in smoke alarm horn frequency, cues, or other methods that may improve alarm sound effectiveness.

This report summaries work conducted by the CPSC staff to examine the feasibility of applying technical solutions, such as modifications to residential smoke alarms or the addition of secondary devices that could be triggered by an activated smoke alarm, to improve the sound effectiveness for smoke alarms. The CPSC staff built several prototype smoke alarms that could communicate with secondary devices capable of alarming at lower frequency tones. The ultimate goal of these improvements is to increase the available escape time for occupants, especially for older adults.

The CPSC staff believes that improvements in smoke alarm sound effectiveness could lead to an increase in available escape time for occupants in a residential fire. The use of interconnected smoke alarms and lower frequency alarm tones may result in improved audibility, especially for older adults, which could lead to a reduction in the number of fire deaths and injuries.

No Text on This Page

Table of Contents

List of Figures

List of Tables

1.0 INTRODUCTION

In 2003, the U.S. Consumer Product Safety Commission (CPSC) staff initiated a project to review the audibility effectiveness of residential smoke alarms. Currently, residential smoke alarms operate at sound frequencies that may produce alarm sound characteristics poorly suited for the older population. A report of the CPSC staff work, *A Review of the Sound Effectiveness of Residential Smoke Alarms,* was released in 2004. The report presented a literature review of the sound effectiveness of residential smoke alarms in producing audible signals suitable for alerting older adults and waking sleeping children. The staff also reviewed possible alternatives or modifications to current smoke alarms, such as changes in smoke alarm horn frequency, cues, or other methods that may improve alarm sound effectiveness.

This report examines the feasibility of applying some of these alternatives or modifications and presents the results of CPSC staff tests to demonstrate potential concepts that address some of the issues outlined in the 2004 CPSC staff report.

1.1 Fire Hazard

In 1999, the CPSC staff estimates that there were 337,300 unintentional residential structure fires resulting in 2,390 civilian deaths, 14,550 civilian injuries, and $4.24 billion in property losses (Miller, et al., 2003). The National Fire Protection Association (NFPA) reports that, during the 25-year period from 1977 to 2001, home fires and home fire deaths dropped 49% and 47%, respectively, excluding the events of September 11, 2001. The NFPA report for 2001 states that four of every five fire deaths occurred in home fires.

1.1.1 Older Adults at Risk

In 2003, there were an estimated 36 million people in the United States over the age of 65 years – just over 12% of the U.S. population (Federal Interagency Forum, 2004). During the 20th century, the number of people 65 years and over grew from 3 million to 35 million, and is projected to grow to almost 87 million by 2050. (Federal Interagency Forum, 2004).

According to a 1999 report by the U.S. Fire Administration (USFA), residential fires injure approximately 3,000 older adults each year (USFA, 1999). In comparison to the rest of the population, older adults – those over 65 years of age – represent one of the highest fire risk groups in the United States. For 1999, the fire death rate for people over 65 was 25.3 fire deaths per million, or more than twice the national average of 10.5 fire deaths per million (Hall, 2004). The fire death rate is even higher for older age groups. For those over the age of 75, the fire death rate (32.9 fire deaths per million) is about three times the national average. Causes for the higher death rates among older adults may be associated with the physical and mental challenges related to aging. One concern is that seniors may not adequately hear or respond to smoke alarms because they commonly experience hearing loss in the frequency range at which smoke alarms operate.

1.1.2 Hearing Loss for Older Adults

Impairments associated with the aging process, such as decreased physical abilities and difficulty of hearing, predispose the elderly to accidental injuries, including injuries from fires (USFA, 1999). One-third of all persons 70 years of age and older have some form of hearing impairment. This number remained constant for the period 1984 to 1995. As the older population increases over the next 30 years, the number of older persons with hearing impairments may increase significantly (CDC, 2001).

Hearing loss caused by noise exposure can occur acutely as a result of acoustic trauma from exposure to extremely loud noises (>120 decibels, or dB); or it may occur more gradually and insidiously over time, as a consequence of accumulated exposure to loud but not necessarily painful noise, i.e., noise-induced hearing loss. Given the general lack of knowledge of a person's lifetime noise exposure, it is difficult to determine whether the hearing loss manifested in a significant proportion of the elderly population is due to a natural aging effect and/or to cumulative lifetime noise exposure. Age-related hearing loss is more significant in men than women, and it is the upper frequency ranges that are most affected (Yost, 2000).

Overall hearing loss can be measured by threshold in dB HTL, decibel Hearing Threshold Level (or dB HL, Hearing Level, in Europe) averaged for the frequencies 0.5, 1, 2, and 4 KHz. A large scale survey in the United Kingdom by Davis (1995) indicated that for survey participants in the age range of 61-71 years, 51% had a hearing loss greater than 20 dB and 11% had a hearing loss greater than 40 dB. As the age range of participants increased, so did the percentage who experienced hearing loss. For example, for participants in the age range of 71-80 years, 74% had a hearing loss greater than 20 dB and 30% had a hearing loss greater than 40 dB. If the average threshold at high frequencies (4, 6, and 8 KHz) was used as a measure, the percentage with significant hearing loss increased markedly. For example, for participants in the age range of 71-80 years, 98% had a hearing loss greater than 20 dB and 81% had a hearing loss greater than 40 dB.

1.2 Project Objectives

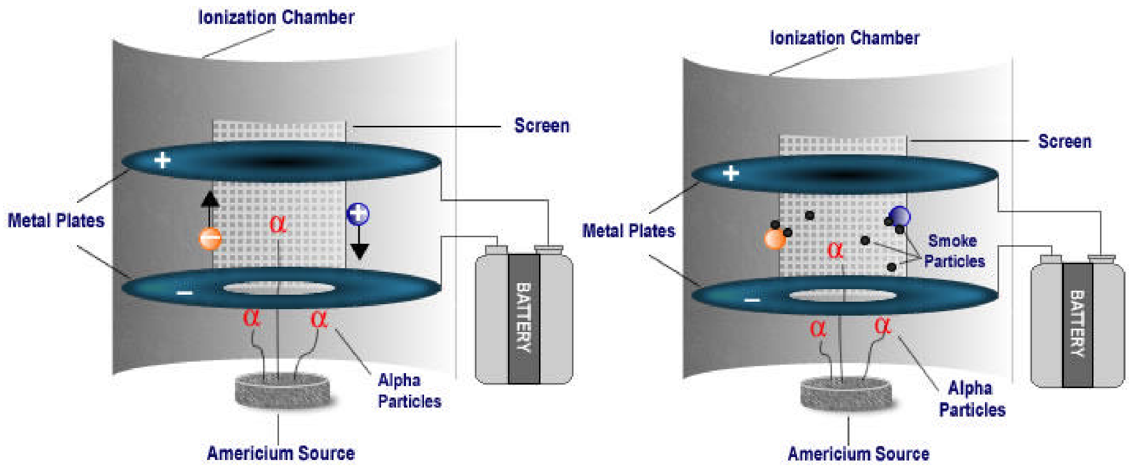
In 2004, the CPSC staff initiated a project to examine the feasibility of applying technical solutions, such as modifications to residential smoke alarms or the addition of secondary devices that could be triggered by an activated smoke alarm, to improve the sound effectiveness of smoke alarms. The goal of these improvements is to increase the available escape time for occupants, especially older adults, in a residential fire.

2.0 RESIDENTIAL SMOKE ALARMS

2.1 Sensors Used in Residential Smoke Alarms

There are two main types of sensors used in residential smoke alarms: ionization sensors and photoelectric sensors. A smoke alarm can use one or both types of sensors.

Ionization sensors have an ionization chamber and a source of ionizing radiation – a very small quantity of Americium-241. The Americium constantly releases alpha particles, which knock electrons off of the atoms in the air that is inside the chamber. The ionization chamber consists of two plates that are charged; one plate is positively charged, and the other plate is negatively charged. Positive ions are attracted to the negative plate, and the electrons (negative ions) are attracted to the positive plate. This generates a small, continuous electric current, as shown in Figure 1.



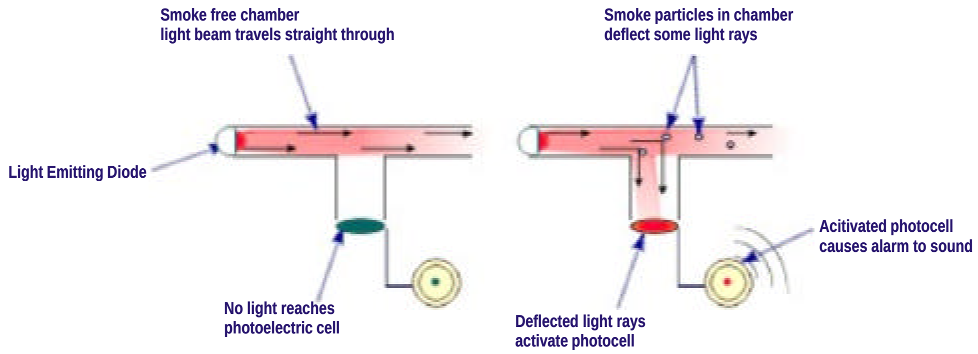
No Smoke　　　　Smoke

(Courtesy of U.S. Environmental Protection Agency. www.epa.gov/radiation/sources)

Figure 1. Ionization Chamber

When smoke enters the ionization chamber, the smoke particles attach themselves to the ions, neutralizing them. This causes a reduction in electrical current, which is sensed by the smoke alarm's circuitry, causing it to sound an alarm.

Photoelectric sensors have a light beam and a photocell in a "T" shaped chamber. Typically, for a photoelectric unit, the photocell is placed out of direct line of the light beam. When smoke particles enter the photo chamber – in the path of the light beam – it causes the light to scatter onto the photocell, as shown in Figure 2. The photocell, when exposed to light, generates a current that is detected by the smoke alarm's circuitry, causing it to sound an alarm.



(Courtesy of U.S. Environmental Protection Agency. www.epa.gov/radiation/sources)

Figure 2. Photoelectric Chamber

Both ionization and photoelectric sensors are effective smoke sensors. Recent testing by the National Institute of Standards and Technology (NIST, 2003) showed that "smoke alarms of either the ionization type or the photoelectric type consistently provided positive escape times." Ionization type alarms provided somewhat better response to flaming fires than photoelectric alarms did, and photoelectric alarms provided considerably faster response to smoldering fires than did ionization type alarms. However, the NIST testing also showed that, in many cases, available escape time would be sufficient only if the occupants slept with their doors closed, all smoke alarms were interconnected to provide an audible alarm in each bedroom, and pre-movement (gathering of personal items, getting dressed, etc.) and movement times (exiting the residence) were minimized during egress.

2.2 Piezoelectric Horns Used in Residential Smoke Alarms

Smoke alarms (both the ionization and photoelectric types) use a piezoelectric horn to indicate to an occupant that the smoke alarm has activated. The sound source for a piezoelectric horn is the piezoelectric diaphragm. The diaphragm consists of a piezoelectric ceramic plate, which has electrodes on both sides, and a metal plate typically made of brass or stainless steel, as shown in Figure 3. The ceramic plate is attached to the metal plate with an adhesive. The typical diameter of the piezoelectric diaphragm is approximately 30 mm.

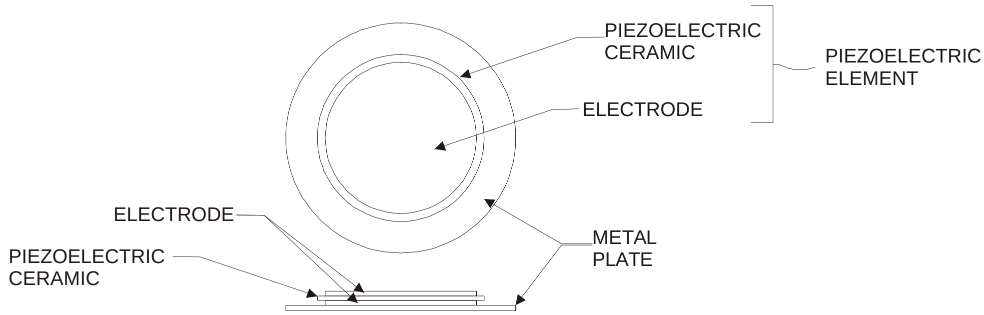


Figure 3. Piezoelectric Diaphragm

When a DC (direct current) voltage is applied to the electrodes of the piezoelectric diaphragm, it causes mechanical distortion of the piezoelectric element. Depending on the polarity of the voltage applied to the piezoelectric element, the piezoelectric element either expands or contracts, as shown in Figure 4. The metal plate, which is bonded to the piezoeletric element, does not expand. When an AC (alternating current) voltage is applied to the electrodes, expansion and contraction are repeated alternately, producing sound waves in the air.

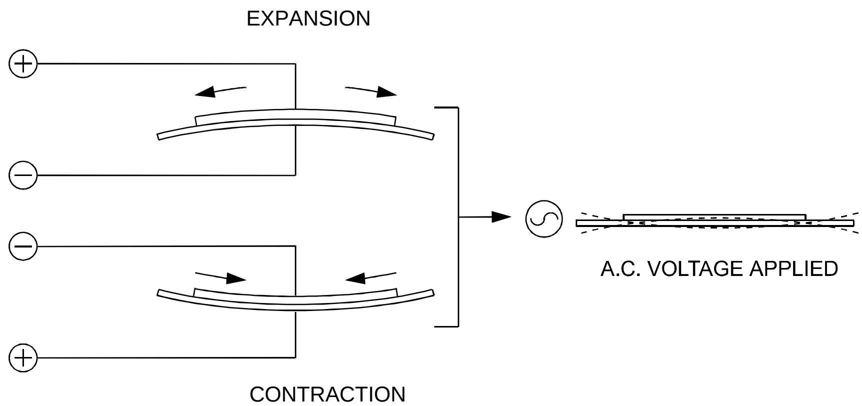


Figure 4. AC Voltage Applied to the Piezoelectric Element

These types of horns are popular in smoke alarms because they can output significant sound levels without using much power. Depending on the piezoelectric horn design, the current draw can vary; but typically, a piezoelectric horn draws between 10 to 20 milliamps (mA) at 9 volts. The most common unit used to measure sound intensity is the decibel, or dB. The decibel scale is a logarithmic scale – that is, an increase of 10 dB in sound intensity represents a 10-fold increase in sound power and a 100-fold increase in sound pressure (since sound power is directly proportional to the square of the sound pressure). Depending on the type of piezoelectric horn design used, the maximum sound level can vary but smoke alarms are typically rated at a minimum of 85 dB at 10 feet for a specific room configuration.

Sound pressure is measured using a sound-level meter. The American National Standards Institute (ANSI) and the American Standards Association have established a standard for sound-level meters. This standard requires that three different weighting networks (A-weight, B-Weight, and C-weight) be built into the instruments. Each network responds differently to low and high frequencies according to standard frequency-response curves. When sound intensity is referenced, the specific weighting network used for measuring is specified (e.g., 85 dBA or 85 dB A-weight).

2.3 Temporal-Three Pattern for Residential Smoke Alarm Signals

Residential smoke alarms are required to use a temporal-three pattern alarm signal. The temporal three pattern was standardized to be used as an audible emergency evacuation signal. The American National Standard document, *Audible Emergency Evacuation Signal* (ANSI S3.41), specifies the requirements for the temporal-three pattern. The signal is used to indicate imminent danger and signify unambiguously that evacuation from the building is immediately necessary (ASA, 2001).

This requirement is also defined in the voluntary standard, UL 217, *Single and Multiple Station Smoke Alarms*. Specifically, UL 217, *Section 34.3, Standardized alarm signal*, requires an audible signal to have a "three pulse" temporal pattern. The signal must have an "ON" phase (sound for 0.5 seconds), followed by an "OFF" phase (silent for 0.5 seconds), as shown in Figure 5. An ON and OFF phase is considered to be a single pulse. Thus, the pattern shown is repeated for three pulses. After the third pulse, a 1.5-second OFF, or silent period, follows before the three-pulse pattern begins again. Prior to this requirement, smoke alarms produced a continuous sound when alarming and, thus, required more power during alarming.

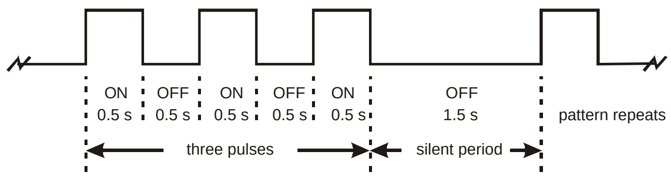


Figure 5. "Three Pulse" Temporal Pattern

UL 217 also requires an A-weighted sound pressure level of at least 85 decibels (dBA) when measured at a distance of 10 feet from the horn, in a room of a specific configuration and under specific conditions (UL, 1997).

There is no requirement in UL 217 for the frequency of the horn output for a residential smoke alarm; however, it is typically between 3,000 to 4,000 Hz (cycles per second). The temporal-three pattern does not limit the signal to one sound (such as a bell, horn, ring, chime, or electronic sound); and it does not limit the combinations of sound types that can be used. In addition, the standard allows supplemental instructions to be incorporated into the temporal-three pattern. For example, the audible words FIRE, GET OUT, etc. may be inserted during the 1.5 second OFF phase.

The CPSC staff tested a residential smoke alarm to determine its operating frequency. As shown in Figure 6, the frequency of the alarm was measured at 3.2 kHz. (The figure also shows aliasing[*] at higher frequencies at multiples of 3.2 KHz; this is a testing-related artifact of digitizing the data.)

[*] The process where a sinusoid changes from one frequency to another as a result of sampling or other nonlinear action.

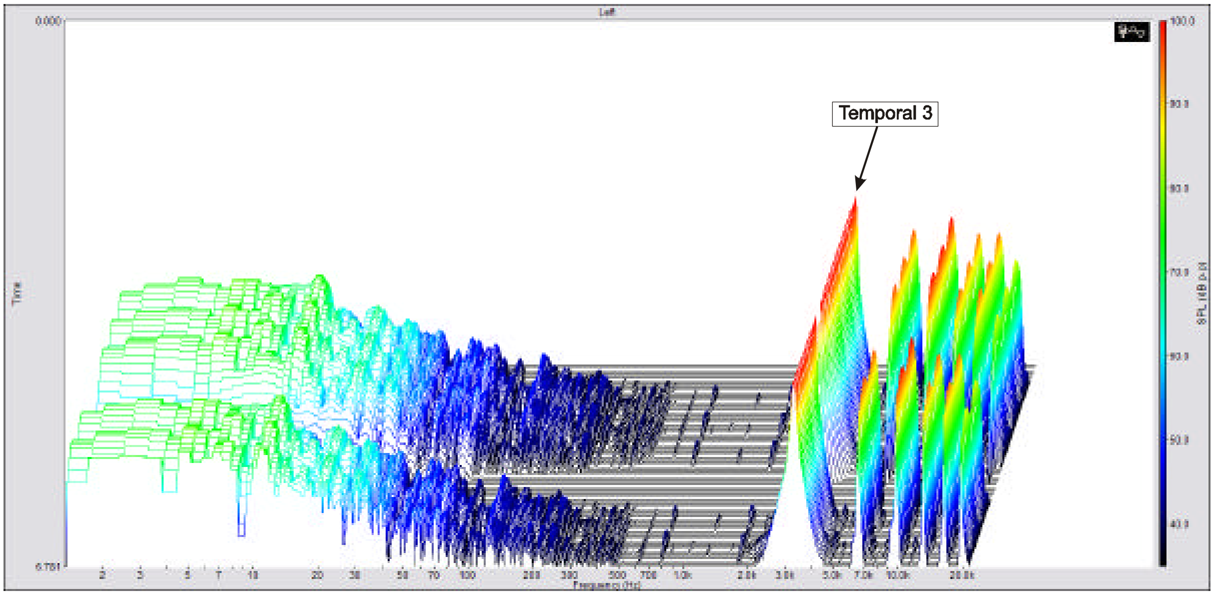


Figure 6. “Three Pulse” Temporal Pattern (No weighting)

2.4 Powering a Residential Smoke Alarm

A smoke alarm can be powered by the household electrical system (120 VAC) or solely from a battery, but one cause of smoke alarm failure/non-function is lack of power. In 1992, the CPSC sent surveys to consumers’ homes to find out how many had smoke alarms and what proportion of these installed smoke alarms were functional. This study showed that in one-fifth (20%) of the homes with at least one smoke alarm, none were working (Smith, Nov 1993). A primary reason for non-functional smoke alarms was attributed to dead, missing, or disconnected batteries or AC power (Smith, January 1995). Occupants may disconnect the power source (battery or AC) from the smoke alarm because of repeated nuisance alarming or because of constant low battery chirping.

Most AC powered with battery back-up or battery-powered smoke alarms use the 9-volt battery in the ANSI 1604 configuration. The ANSI 1604 configuration is the box shape battery case with the positive and negative snap terminals on the same side. The 9-volt ANSI 1604 batteries are typically carbon/zinc (carbon or Leclanché), alkaline-manganese (alkaline), or lithium-manganese (lithium) type batteries (Linden, 2002). The chemistry used with carbon battery cells can vary, but most commonly it is carbon manganese dioxide. The alkaline battery, the dominant battery system in the portable battery market, most commonly uses alkaline manganese dioxide. Typical 9-volt carbon and alkaline batteries use a Leclanché cell configuration, named after the developer George-Lionel Leclanché, as shown in Figure 7.

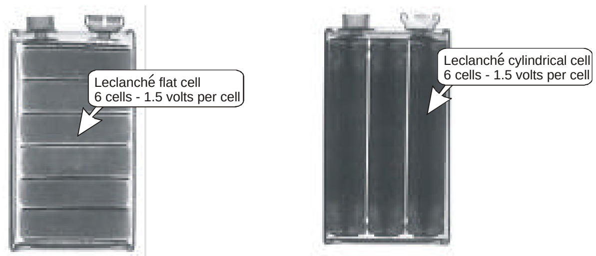


Figure 7. 9-Volt Carbon/Zinc and Alkaline Battery Configurations

Some smoke alarm manufacturers also provide smoke alarms with “longer-life” batteries. These batteries are typically lithium batteries which use lithium manganese dioxide. The lithium 9-volt battery contains three cells in a prismatic configuration, as shown in Figure 8; each cell is 3 volts. The cells are constructed using a “jelly-roll” method that uses layers of an anode, cathode, and a separator.

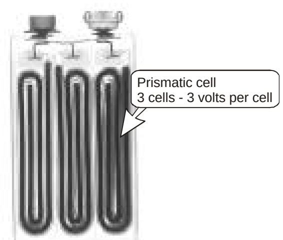


Figure 8. 9-Volt Lithium Battery Configuration

Battery design, chemistry, and configuration greatly determine the rated capacity (milliamp-hours, or mAh) of a battery. The life of a battery, when used in a smoke alarm, can be estimated based upon the smoke alarm’s current drain characteristics, or power consumption. In another study (CPSC, 2002), CPSC staff used measurements taken from a battery-powered smoke alarm to estimate the battery life for a lithium battery in a smoke alarm application (see *Table 6, “Worst Case” Scenario*). The mAh drain from a smoke alarm – minimum, average, maximum, and worst case – was estimated as 63.4, 67.6, 78, and 93.6 mAh, respectively. Using these numbers, the battery life for other battery chemistry types can be estimated. Figures 9 through 11 show approximate battery life in a smoke alarm – before it will begin to emit a low battery chirp – for a carbon/zinc battery, an alkaline battery, and a lithium battery. The shaded area in each figure shows the variation in the time it would take for a battery to drop from 9 volts to 7.5 volts in a smoke alarm application, where the alarm would begin to emit a low battery chirp.

Manufacturer data sheets for carbon/zinc batteries typically specify a rating between 350 to 450 mAh @ 0.8 volts per cell, or 4.8 volts (0.8 x 6). Even though a smoke alarm can still operate with a battery voltage of 4 volts, it would begin to emit a low battery chirp at approximately 7.5 volts. The battery discharge curve typically has a slow steady downward slope until it drops below a specific voltage. At this voltage, the discharge curve begins to take a steeper and faster slope, a greater ? voltage/? time. This voltage usually is around 7.5 volts. At a battery voltage of 7.5 volts, the estimated capacity (mAh) is between 150 and 250 mAh, which translates to a battery life for a carbon/zinc battery in a smoke alarm of between 1.75 to 4 years, as shown in Figure 9.

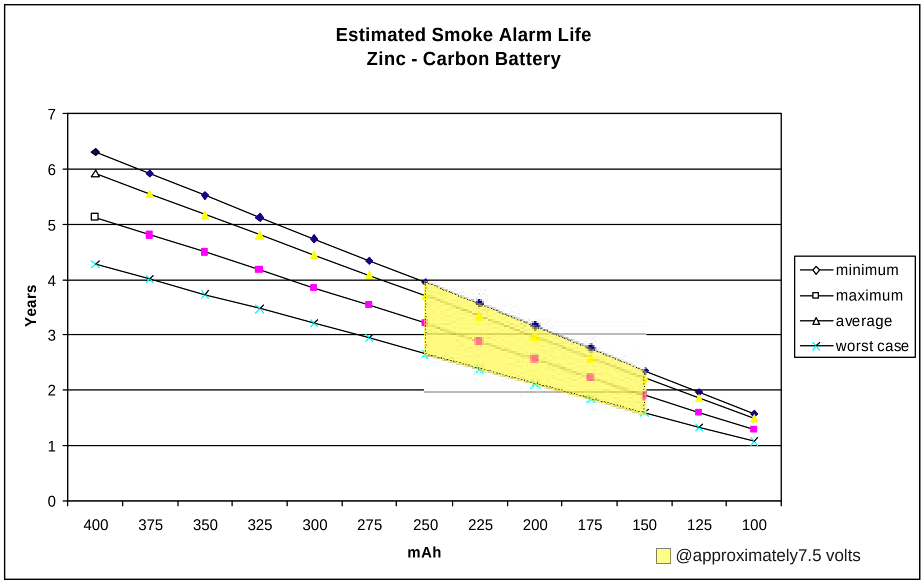


Figure 9. Estimated Smoke Alarm Life with a Carbon/Zinc Battery

Manufacturer data sheets for alkaline batteries typically specify a rating between 575 to 625 mAh @ 0.8 volts per cell, or 4.8 volts (0.8 x 6). Similar to the zinc/carbon batteries, the discharge curve is fairly flat until the voltage drops below 7.5 volts and the battery begins to take on a steeper discharge slope. At a battery voltage of 7.5 volts, the estimated capacity is between 250 and 350 mAh, and the battery life for an alkaline battery in a smoke alarm would be between 3 and 5.5 years, as shown in Figure 10.

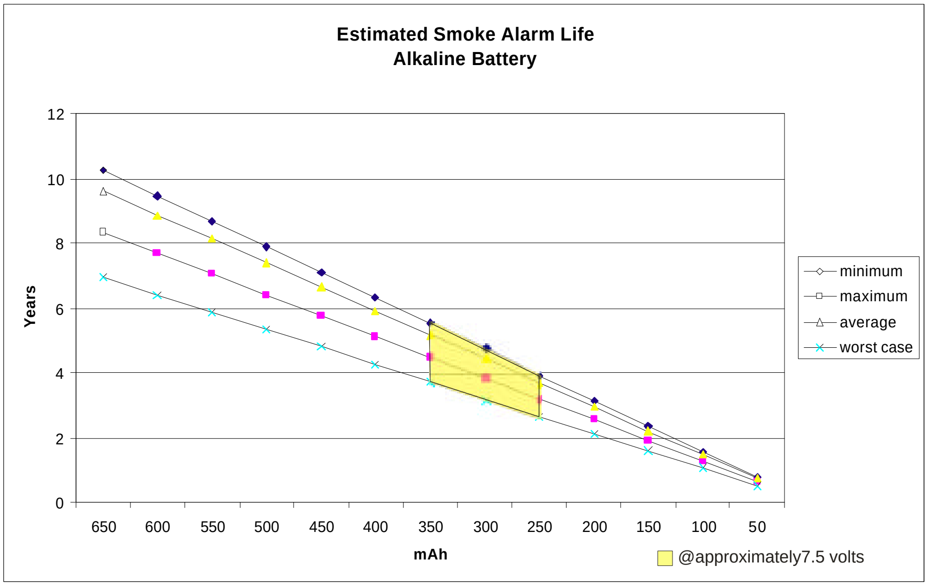


Figure 10. Estimated Smoke Alarm Life with an Alkaline Battery

Manufacturer data sheets for lithium batteries have an approximate capacity of 1200 mAh @ 1.8 volts per cell or 5.4 volts (1.8 x 3). The lithium battery typically has a flatter discharge curve than for zinc/carbon or alkaline batteries. The flatter portion is not only less steep, but also extends for a longer period, thus giving it longer life in electronic products. At a battery voltage of 7.5 volts, the estimated capacity is between 850 and 950 mAh, and the battery life of a lithium battery in a smoke alarm would be between 9 and 15 years, as shown in Figure 11.

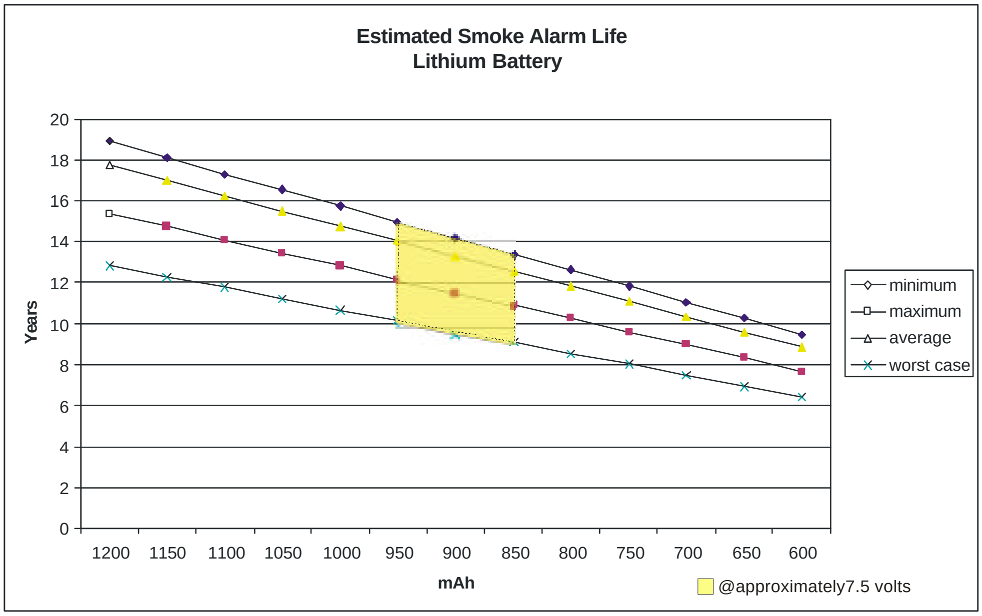


Figure 11. Estimated Smoke Alarm Life with a Lithium Battery

3.0 IMPROVING SMOKE ALARM AUDIBILITY

Available data shows that a significant number of older adults may not adequately hear or respond to smoke alarms because they commonly experience hearing loss in the frequency range at which smoke alarms operate. As the population of older adults increases – an estimated 20% of the U.S. population by 2030 – it is possible that the overall level of protection provided by current smoke alarm technologies may decline. This section examines possible technical solutions that manufacturers and safety organizations could use to increase the audibility of smoke alarms for older adults and, possibly, for all age groups.

3.1 Interconnected Smoke Alarms

Interconnected smoke alarms allow all of the smoke alarms in a home to sound if any individual smoke alarm detects smoke. This can result in an increase in the amount of time available for an occupant to egress the home, if the initiating smoke alarm sounds in the farthest part of the home. Many homes do not have the added protection provided by interconnected smoke alarms. Most homes in the U.S. were constructed before hardwired and interconnected smoke alarms were required by the National Fire Alarm Code (NFPA 72).

Before 1989, battery-only-powered smoke alarms were typically installed in homes. Depending on the size and layout of the home, if a fire occurred in a remote section of the home – away from the bedrooms, as shown in Figure 12 – the closest smoke alarm to the fire would sound. However, such a remote alarm may not be sufficiently audible to be heard by some occupants or to awaken sleeping occupants. As the fire progresses and smoke travels to activate a smoke alarm that is closer to the bedrooms, the alarm level may be sufficient to awaken or be heard by the occupants. The delay before a closer smoke alarm notifies the occupants may dramatically reduce the amount of escape time and options for egress, perhaps leaving the occupants with only seconds to exit the home.

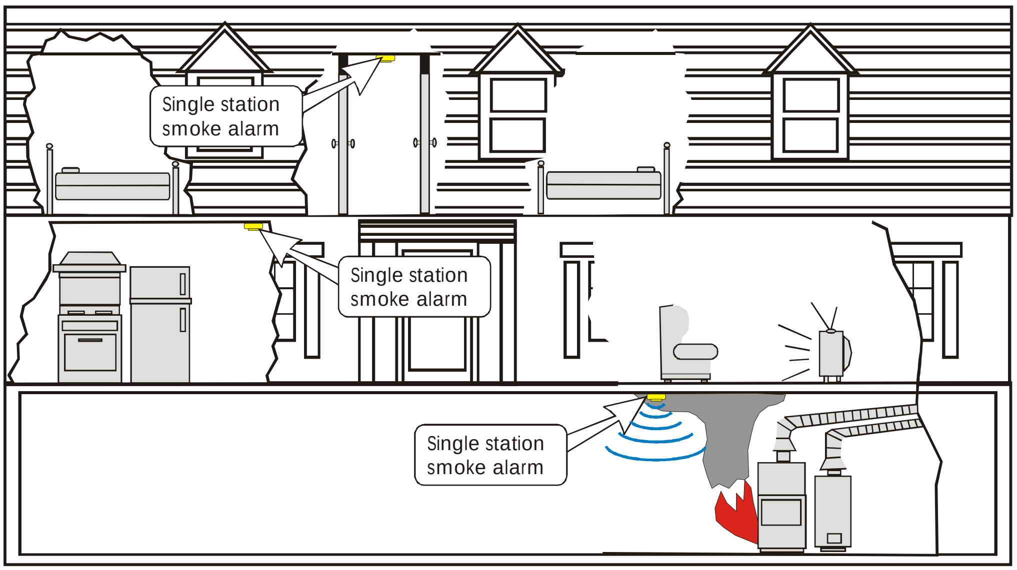


Figure 12. Single Station Smoke Alarms in Older Homes

Beginning in 1989 (for new construction), NFPA 74-1989 *Standard for the Installation, Maintenance and Use of Household Fire Warning Equipment*, required interconnected smoke alarms on every level of the home and outside the sleeping areas. This is typically referred to as "hardwired" smoke alarms. The installation of hardwired smoke alarms generally uses 3-conductor wiring between the smoke alarms – two wires to power the smoke alarms and the third wire to interconnect the alarms. With interconnection of the alarms, the smoke alarm closest to a fire would sound and cause all the smoke alarms in the home to sound, as shown in Figure 13. The standard did not require existing homes to be retrofitted with interconnected smoke alarms, largely because of the financial burden this would place on homeowners.

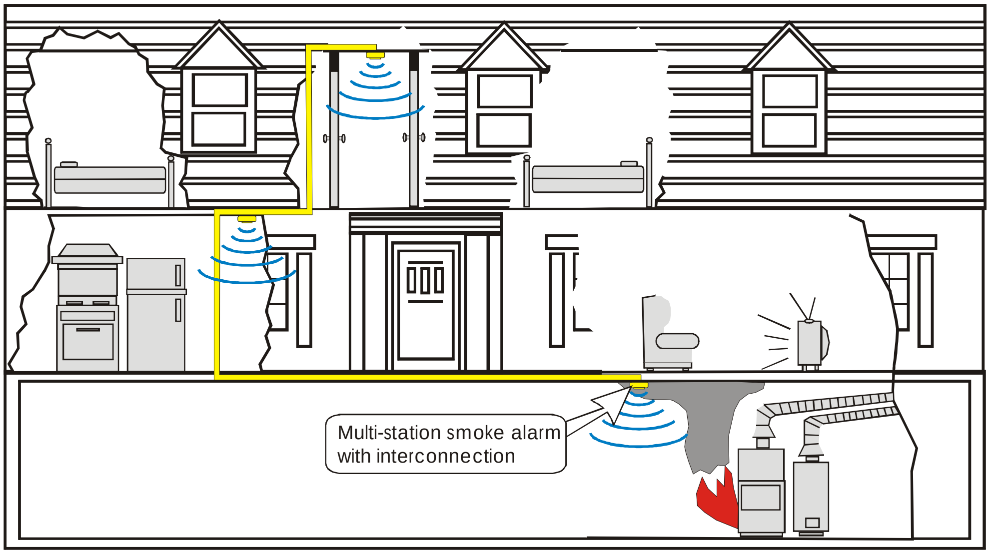


Figure 13. Every Level and Outside Sleeping Rooms Interconnected

In 1993, NFPA 72 *National Fire Alarm Code* added a requirement for interconnected smoke alarms in the bedrooms for new construction. This change to require smoke alarms in the bedrooms was to address the concern associated with the loss in sound level when occupants sleep with the bedroom doors closed. The interconnected smoke alarm in the bedroom provides increased assurance that the alarm sound level will be sufficient to wake sleeping occupants, and it also provides additional protection if the bedroom is the room of fire origin. This provides maximum audibility throughout the home, even if the bedroom doors are closed, as shown in Figure 14.

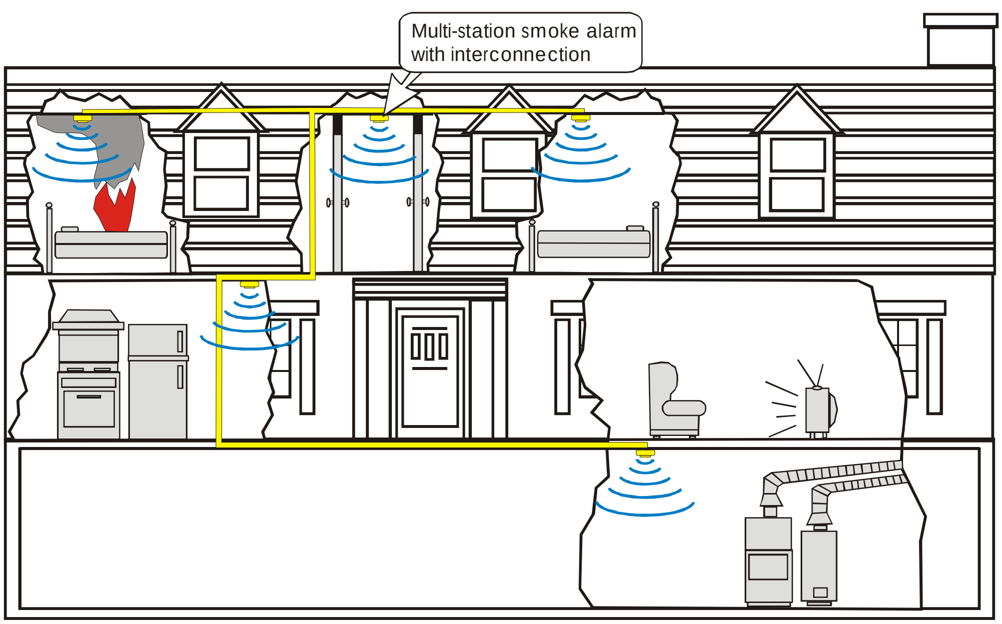


Figure 14. Every Level, Outside and Inside Sleeping Rooms for New Construction

Hardwired smoke alarms with battery back-up were not required for new construction until the 1996 edition of NFPA 72. In 1996, the requirement to have hardwired smoke alarms with battery back-up in new construction was to address the non-operability during power outages.

3.1.1 Benefits of Interconnected Smoke Alarms

In 2000, CPSC staff coordinated the evaluation of current and emerging smoke alarm technology responses to common residential fire scenarios and nuisance alarm sources. CPSC staff worked with interested parties such as the U.S. Fire Administration (USFA), the National Institute of Standards and Technology (NIST), the Centers for Disease Control and Prevention (CDC), the U.S. Department of Housing and Urban Development (HUD), the National Fire Protection Association (NFPA), and Underwriters Laboratories, Inc. (UL) in developing and funding a two-year project for evaluating smoke alarms in full-scale fire tests.

The project was initiated in October 2000 and completed in December 2002 by NIST under the direction of a steering committee of the sponsoring organizations along with NFPA, the University of Maryland, and the National Research Council of Canada. At the completion of the project, NIST released a technical report, *Performance of Home Smoke Alarms, Analysis of the Response of Several Available Technologies in Residential Fire Settings (NIST Technical Note 1455)* December 2003.

Tests were intended to represent real life fires in actual homes of representative sizes and floor plans, using actual furnishings and household items for fire sources, and smoke alarms currently sold in retail stores. Smoke alarm performance was quantified in terms of the escape time provided by groups of alarms installed in accordance with typical code provisions.

The NIST testing showed that using alarms in the bedrooms, in addition to placement of alarms on every level, reduced the time to alarm for every fire scenario tested with most alarm technologies. Adding an alarm in the bedroom provided an additional 3 to 923 seconds (15 minutes, 23 seconds) of available egress time, depending on the fire scenario. As expected, alarm times for the bedroom fire scenarios were most affected by the additional alarms, since alarms were now included in the room of fire origin.

Adding interconnected smoke alarms in bedrooms increased the escape time provided, especially for smoldering fires. Smoke alarms in the bedrooms increased the escape time as much as 900 seconds (15 minutes). The report states that the test data provides a basis for evaluating whether smoke alarms should be required in bedrooms of homes built prior to 1993.

The CPSC staff conducted tests to demonstrate sound loss of smoke alarms. In one test, a single station smoke alarm was mounted on the ceiling at the bottom of the basement stairs of a 3,000 sq. ft. home. A recording device situated 5 feet from the floor and directly below the smoke alarm measured the sound level at 95 dBA. When the recording device was placed in the master bedroom on the second floor, with the master bedroom and basement doors open, the loss in sound level was 40 dBA – or a sound level of 55 dBA in the master bedroom, as shown in Figure 15. When the bedroom and basement doors were closed, the sound level in the bedroom was less than 30 dBA, or about the same level as low conversation. Details of this testing are in CPSC staff draft report, *The Audibility of Smoke Alarms in Residential Homes*, February 2005.

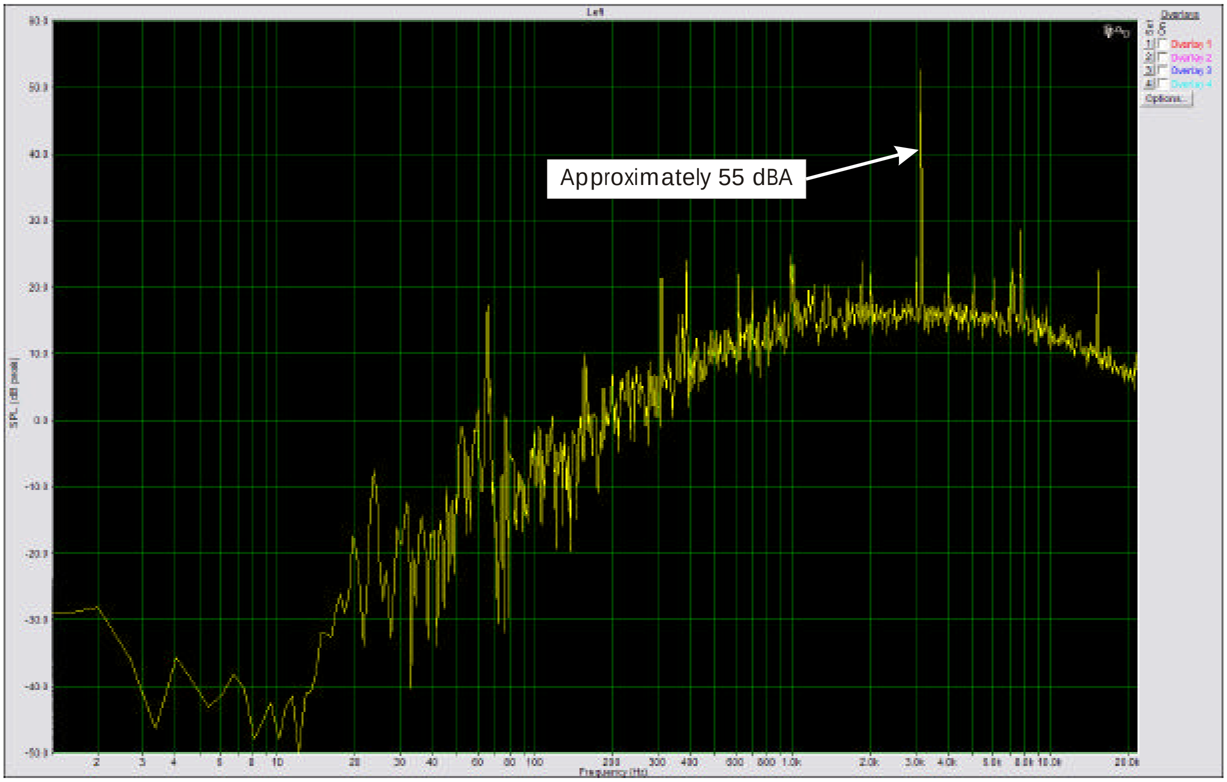


Figure 15. Alarm Sound Level (dBA) in the Master Bedroom with Source in the Basement

Interconnection of smoke alarms is an effective method to improve the audibility of the smoke alarm system by distributing the alarm warning throughout the home. However, it may not adequately improve audibility for older adults who experience hearing loss at the alarm frequency; additional methods may be needed.

3.2 Using Voice with Temporal-Three Pattern

As discussed previously, the temporal-three pattern was standardized for use as an audible emergency evacuation signal. However, the temporal-three pattern does not restrict the variations in frequency, combinations of sound types, or incorporation of supplemental instructions that could be used. For example, the audible words DANGER, WAKE UP NOW, etc. may be inserted during the 1.5 second OFF phase, as shown in Figure 16.

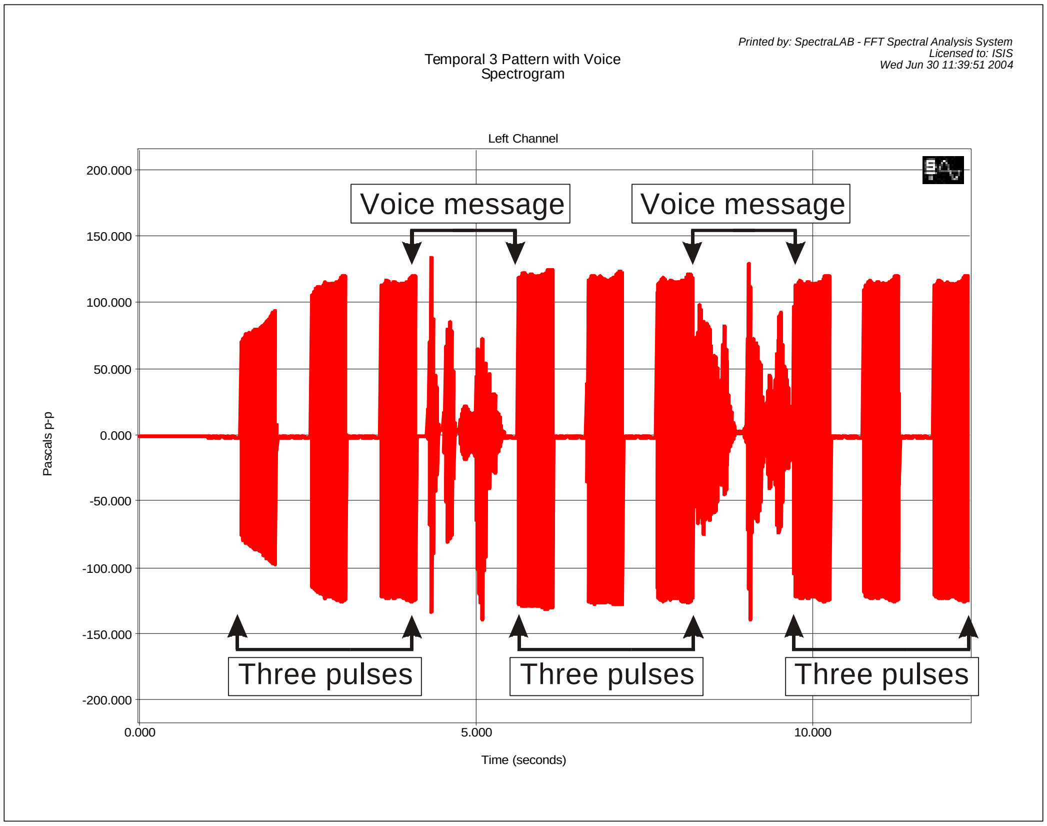


Figure 16. Temporal-Three Pattern with Voice Message

One advantage of using voice is that it is typically a lower frequency. Figure 17 shows a 3-Dimensional surfacing spectrum of the signal in Figure 16. The voice message is centered around 1 kHz or less, which is in a more audible range for older adults. (This figure also shows aliasing at the higher frequencies at multiples of 3.2 KHz, which is a testing-related artifact of the digitizing hardware.)

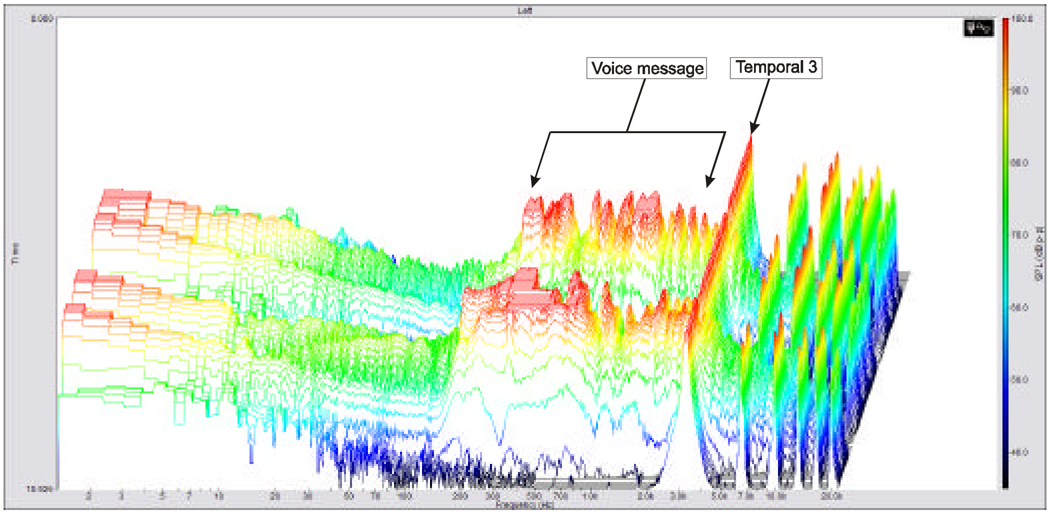


Figure 17. Temporal-Three Pattern with Voice Message (No weighting)

The piezoelectric horn used in current residential smoke alarms cannot produce a low frequency sound or output a voice message at the required dB level and still satisfy the battery requirements in UL 217, *Single and Multiple Station Smoke Alarms*. A piezoelectric diaphragm is typically around 30 mm in diameter; a piezoelectric diaphragm of 50 mm would produce frequencies around 1 kHz but would require considerably more power to operate. A different horn with more dynamic range that uses low power would be ideal.

A small speaker, between 20 to 30 mm in diameter, has more dynamic range than a piezoelectric horn and can produce the lower frequency sounds that may be suitable for smoke alarms. These 20 to 30 mm speakers have resonating frequencies around 1000 Hz or less. However, they can draw between 0.1 to 0.5 watts, or roughly 11 to 55 mA at 9 volts. Also, the speakers typically do not have as high a dB output as piezoelectric horns, if using similar driving circuitry. At 4 inches away, the speakers may output a maximum of 90 dB, but at a distance of 10 feet, the sound output would be significantly less than the 85 dB required in UL 217.

If power was not a concern, (for example, powered by AC), an amplifying circuit used to drive the speaker may produce sound levels in the 90 dB range. Another alternative might be to use a combination speaker and piezoelectric horn that would satisfy the sound level output requirement in the voluntary standard. The piezoelectric horn would output the temporal-three signal at the required high dB level, and the speaker could output a voice message during the OFF phase of the temporal-three pattern, at a slightly lower dB level. This combination method may not require as much power as solely amplifying the speaker to the required dB sound level in UL 217.

To determine whether power consumption would be a limiting factor in combining a speaker and piezoelectric horn (i.e., whether there would be sufficient power to meet the battery requirement in UL 217), CPSC staff calculated the power requirements using previous smoke alarm current drain measurements. Assuming that a small speaker and its electronics draw an additional 0.60 mA for 1.5 seconds for every temporal three pattern, the life of a carbon/zinc battery would be reduced between 3.5 to 5 months, depending on the battery's discharge rate. The life of an alkaline battery would be reduced between 2 to 3.75 years depending on the battery's discharge rate. In either battery type, the battery would still last over one year in a smoke alarm that is tested weekly.

3.3 Incorporating a Remote-Dependent Device with a Residential Smoke Alarm

The Naval Research Laboratory, under contract to CPSC (CPSC-I-02-1290), showed that it is feasible to incorporate wireless technology in battery-powered smoke alarms, which allows them to communicate with each other (NRL, December 2003). Wireless technology in a smoke alarm could also be used to trigger remote-dependent devices that output sound at a frequency lower than a piezoelectric horn. The remote-dependent devices could be powered by 120 VAC with battery back-up and could plug into a household receptacle.

A wireless transmitter that triggers a remote sounding device could be incorporated into a conventional smoke alarm. The remote sounding device could be located in the areas of the home where they are most needed. This would be beneficial for homes with either battery-powered smoke alarms or hardwired smoke alarms (or hardwired alarms with battery back-up). Depending on how the smoke alarm is powered, the method of incorporating the wireless transmitter may differ.

3.3.1 Incorporating a Wireless Transmitter in a Battery-Operated Smoke Alarm

The work by the Naval Research Laboratory demonstrated that it is feasible to incorporate wireless technology into battery-powered smoke alarms (NRL, July 2003 and December 2003). NRL built prototype smoke alarms using a transmitter and receiver circuit in each of the prototype alarms. If any smoke alarm detected smoke, it transmitted a signal to the other smoke alarms. Each receiving smoke alarm also acted like a repeater; thus, a smoke alarm that may have been too far away to be activated by the initiating smoke alarm could be activated by a closer smoke alarm that was transmitting an alarm signal. The transmitting range and the rate at which the receiver checked for an alarm signal were factors in determining the power requirements. To be an effective system, all the smoke alarms in the home would need to include RF transmitter/receiver circuitry. This method would improve audibility by sounding all smoke alarms when any one smoke alarm detected smoke. However, this would not address the problem of audibility for older adults who experience hearing loss at the alarm frequency, unless a lower frequency alarm or voice was incorporated into the smoke alarms.

One possible solution is to use a secondary sounding device. This method may cost less per smoke alarm and may also be technologically more feasible. Only an RF transmitter would be required in the smoke alarm, which would signal the secondary audio/receiver devices placed in different locations in the home, as shown in Figure 18.

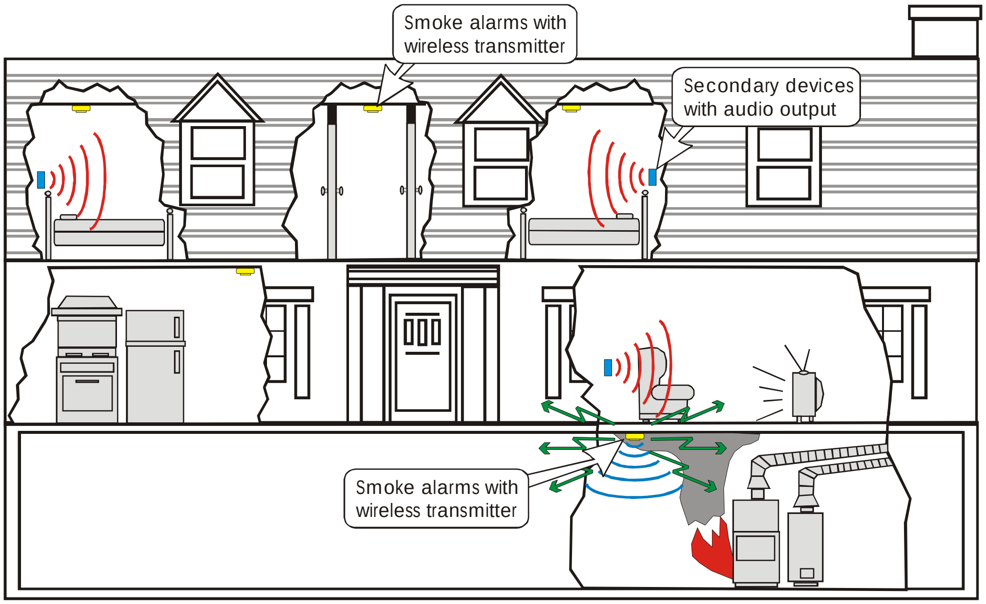


Figure 18. Single Station Smoke Alarm with RF Transmitter and Secondary Audio Devices

The secondary sounding device would act as a remote alarm that can be placed anywhere within range of the RF transmitter as shown in Figure 19. Since the secondary audio devices are stand-alone units, multiple units could be located throughout a home. These areas may include bedrooms and areas with loud noises, such as rooms with media devices (television, stereos), kitchens, and work shops with power tools. The number of secondary units installed in a home would, in part, depend on its size and configuration. The secondary sounding unit could have an audio output (speaker, horn, etc.) capable of delivering a high sound level and wide frequency range, thus accommodating people with partial frequency range hearing loss. The unit could output both a lower frequency, such as voice, and the typical higher temporal-three frequency. The unit could also have an option for selecting the system code combination, which would reduce the chance of false alarming from other RF devices. The homeowners may also be able to select the audio tones and messages that best suit their needs.

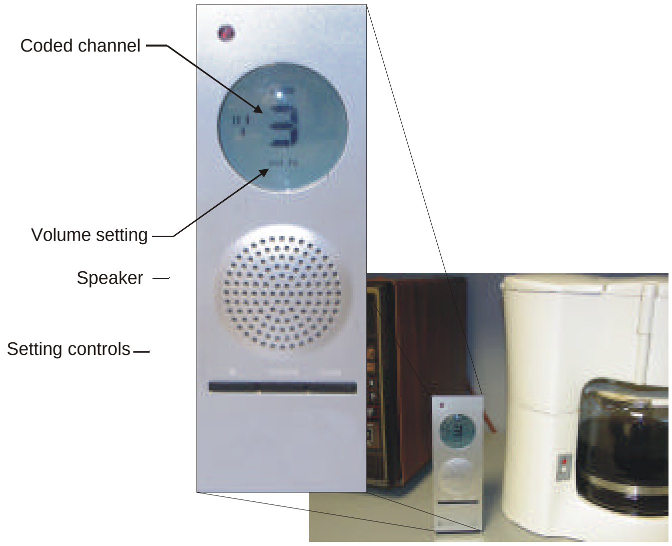


Figure 19. Secondary Audio Device

To demonstrate this application using RF technology, CPSC staff used an RF transmitter and receiver from a wireless doorbell. The RF transmitter was removed from the plastic housing and installed in a battery powered smoke alarm, as shown in Figure 20. The transmitter circuit board was only 1.25 inches x 1.5 inches. The board with the components was only 3/8 inch thick. The wireless doorbell had a 16-code combination and 3 channel system that could be used to play different sounds. The operating frequency of the doorbell unit was 433 MHz. The bell push button unit used 3 AAA batteries, and the receiver sounding unit used 2 AA batteries. The receiver unit could be designed to be powered by AC power with battery back-up.

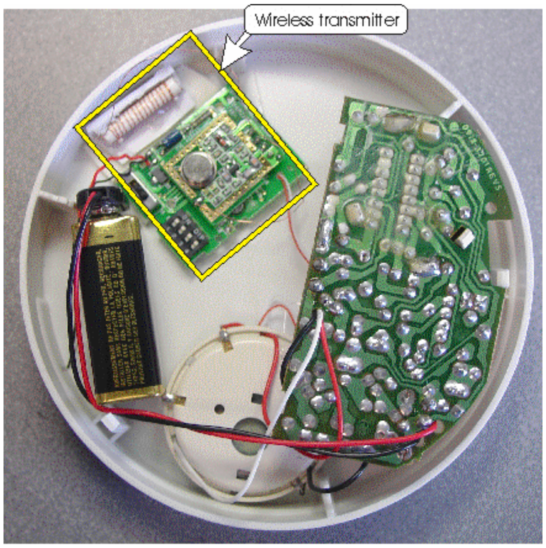


Figure 20. RF Transmitter Installed in Smoke Alarm

The signal to the horn on the smoke alarm circuit board was used to trigger the transmitter and select the RF channel. A comparator was used to distinguish between a low battery signal and an alarm signal. If the signal pulse width was about 10 ms in width, it would select the low battery channel. If the signal pulse width was longer than 10 ms, it would select the alarm signal channel. The output of the comparator provided the input to a channel selector on the wireless transmitter board. Several transistors and resistors were used to interface the transmitter with the smoke alarm. Figure 21 shows the block schematic of the wireless circuitry incorporated into the smoke alarm.

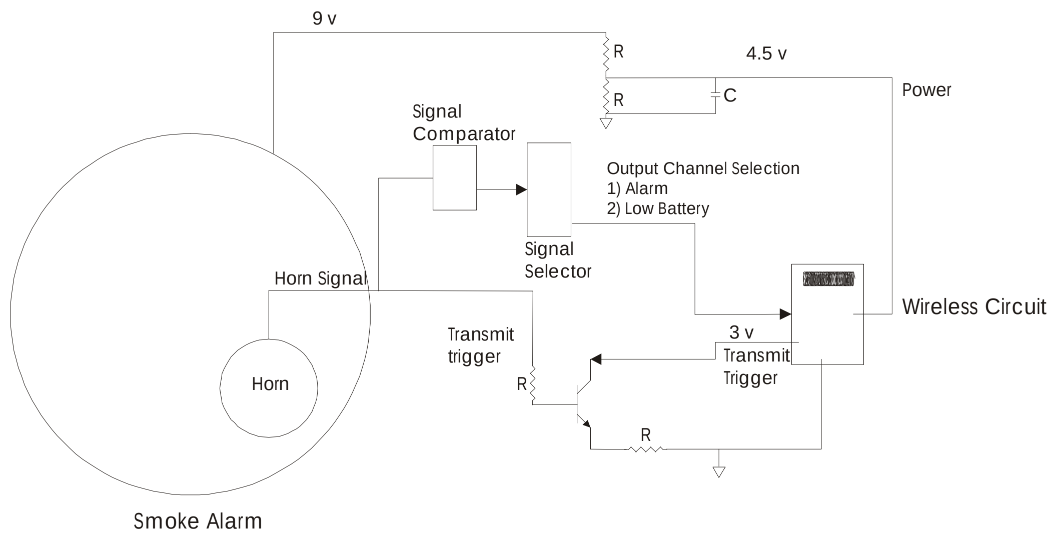


Figure 21. Schematic of Smoke Alarm and RF Transmitter

The RF transmitter did not consume any power until it had to transmit. When it did transmit, it drew approximately 3 mA for 0.5 seconds. Using the earlier calculations for smoke alarm power consumption and testing frequency, either a carbon/zinc or an alkaline battery should be able to power a smoke alarm with a RF transmitter for a minimum of 1 year, as required in UL 217.

The circuit board was capable of transmitting on three different channels, which allowed three distinctive “doorbell” sounds. In its original intended use, this feature would permit a consumer to install a doorbell push button on Channel 1 at the front door, for example, and a separate doorbell push button on Channel 2 at the side door. Depending on which push button was pressed, the receiver unit would sound a specific pre-programmed sound, allowing a homeowner to tell which doorbell had been pressed.

For the smoke alarm, these channels could also be used to specify to the receiver unit which audio message to play. For example, if a smoke alarm was indicating a low battery signal, this information could be transmitted on a specific channel to the receiver, which could then produce a specific audio output. This might be in the form of a lower frequency signal or a prerecorded voice saying, for example, “Low battery in the smoke alarm.” If the smoke alarm has detected smoke, it could transmit a signal on another channel to the receiver, which could output a lower frequency temporal-three pattern or a prerecorded voice stating “fire” or “leave the home” or a combination of temporal-three pattern and voice.

3.3.2 Incorporating a Wireless Transmitter in an AC Powered Smoke Alarm

Incorporating a wireless transmitter in a smoke alarm that is powered by 120 VAC is simpler than in a battery-powered smoke alarm. In this application (if alarms are mounted on all levels of the home as well as in bedrooms), the distance between the RF transmitter and receiver may be reduced, thus requiring less power to transmit. This may be beneficial when the smoke alarm would be operating on battery back-up, in the event of a power outage. Multiple secondary audio receivers in adjacent rooms or one level away would be triggered by a nearby interconnected smoke alarm with an RF transmitter, as shown in Figure 22.

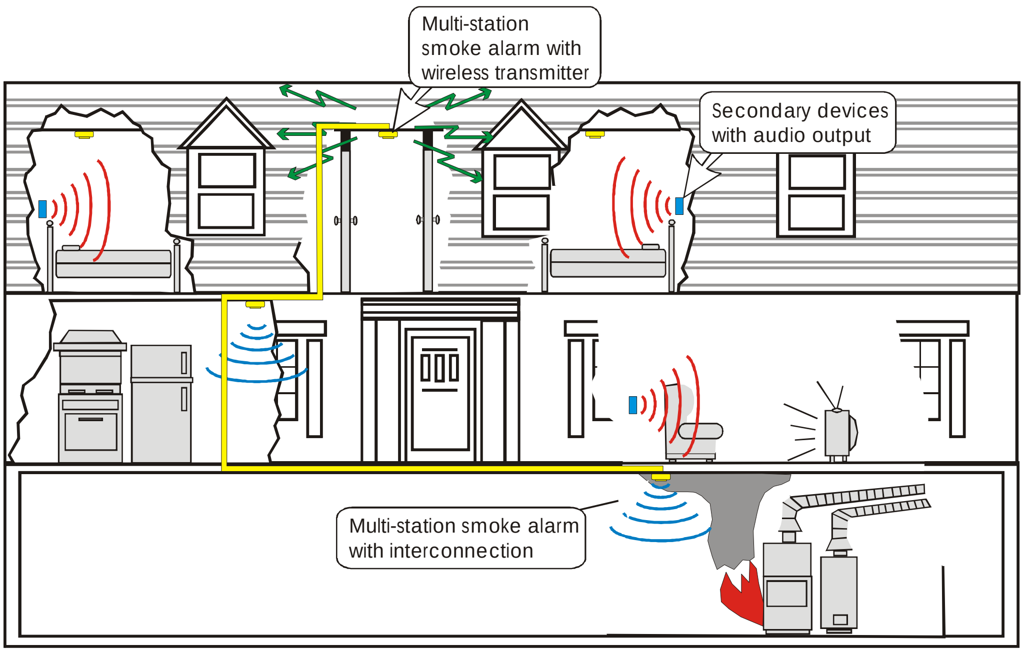


Figure 22. Multi-Station Smoke Alarms with RF Transmitter and Secondary Audio Devices

To demonstrate this application, CPSC staff used the same RF transmitter used in the previous example and incorporated it into an AC powered smoke alarm with battery back-up, as shown in Figure 23.

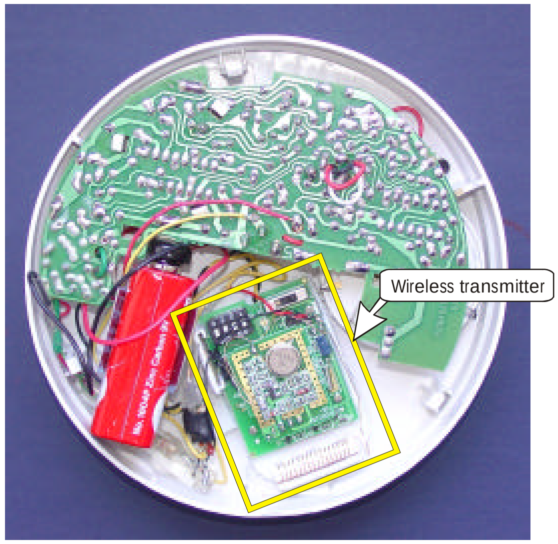


Figure 23. RF Transmitter Installed in AC-Powered Smoke Alarm

Several transistors and resistors were used to interface the transmitter with the smoke alarm. Figure 24 shows the block schematic of the wireless circuitry incorporated in the smoke alarm. In this application, the interconnected signal conductor of the smoke alarm was used to trigger the RF transmitter when the smoke alarm was activated. The horn signal was used to trigger the wireless transmitter when the smoke alarm was in low battery mode.

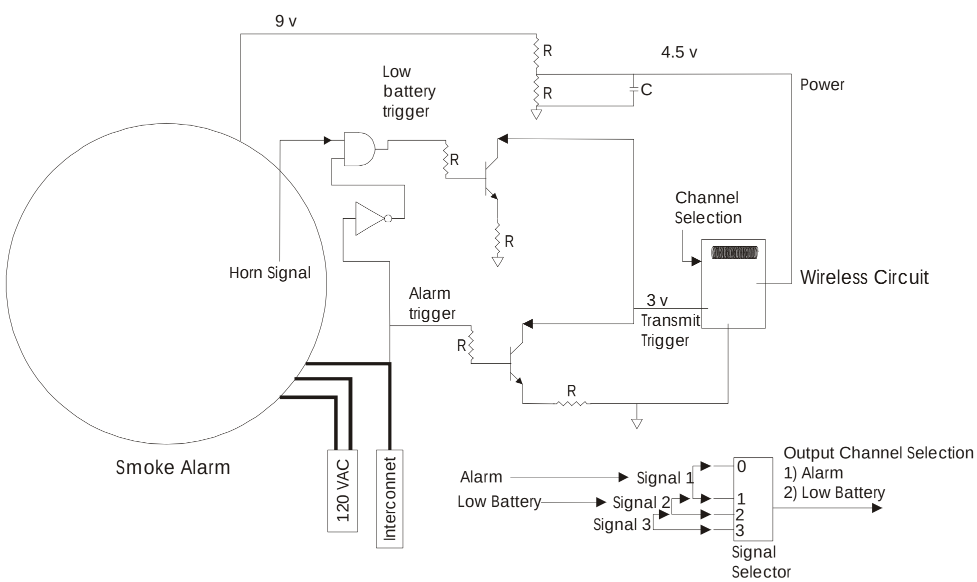


Figure 24. Schematic of Smoke Alarm and RF Transmitter

As with the battery-powered smoke alarm, the RF transmitter did not consume any power until it had to transmit. Since the smoke alarm was AC powered, the battery power was in reserve until it lost AC power. To meet the UL requirement for battery life, the battery would have to power both the smoke alarm and RF transmitter for seven days during a low battery warning signal and 4 minutes of alarming. For this prototype, the calculations show that the unit would operate for at least 1 year with routine testing.

3.3.3 RF Transmitter "Piggy Backed" on an AC Powered Smoke Alarm

An option that would not require modification of an existing smoke alarm is to have a separate RF transmitter or transmitter-receiver (transceiver) unit that "piggy backs" onto the smoke alarm. The RF unit would transmit a signal to a secondary device or other RF unit. The RF unit could also receive signals from other smoke alarms if equipped with transceivers. Similar to the previous example, the secondary unit or receiving smoke alarm would have the capability of outputting a lower frequency in the 1,000 kHz range.

An AC powered smoke alarm is typically mounted to an electrical box on the wall or ceiling. Three conductors – hot, neutral, and alarm interconnect – are used to power and interconnect the alarm signals between smoke alarms, as shown in Figure 25.

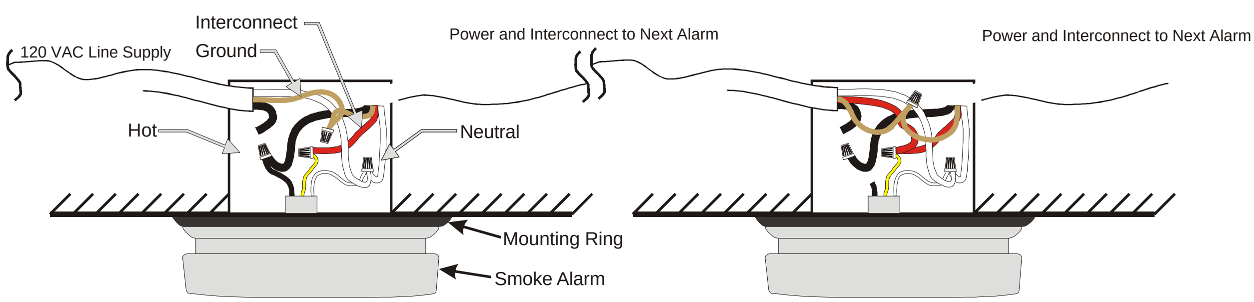


Figure 25. Connections for Hardwired, Interconnected Smoke Alarms

In this application, the wireless RF transmitter only or transceiver unit could be mounted between the smoke alarm and the electrical box. The separate wireless unit would monitor the smoke alarm interconnect wire, as shown in Figure 26. The wireless unit would be powered by its own power supply, which could be either battery power (e.g., three "AAA" batteries) or 120 VAC with battery back-up.

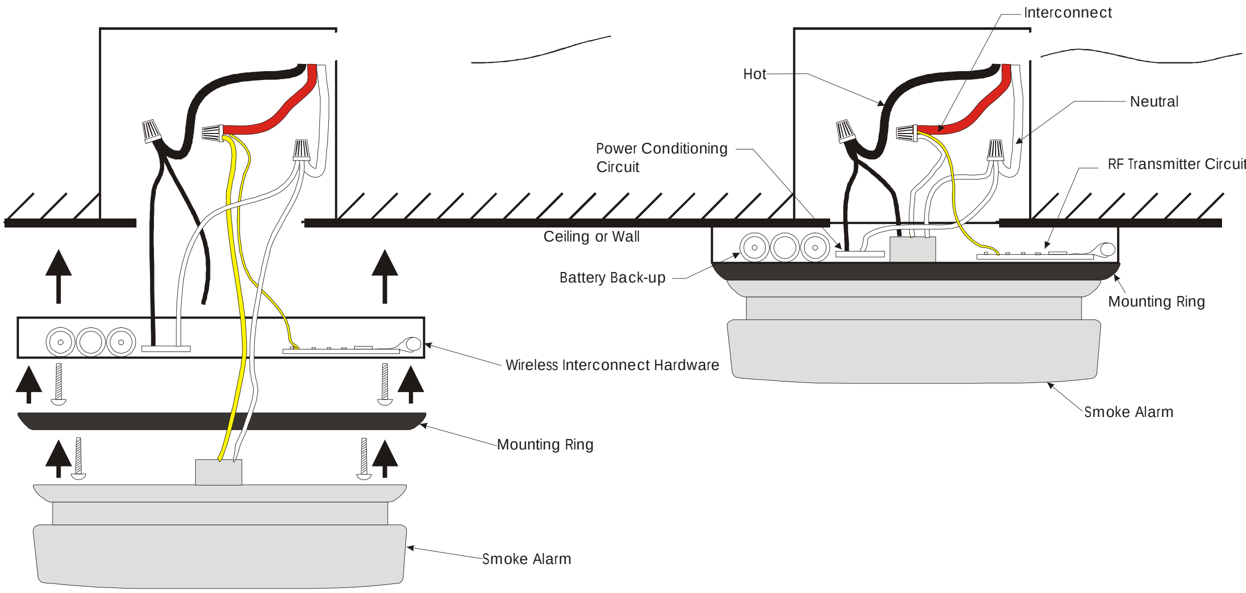


Figure 26. Wireless System that "Piggy Backs" onto a Smoke Alarm

A variation to this design would be to have a low frequency audio speaker built into the piggy-back unit. Each multi-station smoke alarm would be installed with the piggy-back units. The piggy-back unit would monitor the interconnect wire on the smoke alarm. When the smoke alarm sounds, it would cause the piggy-back unit to also sound, but at a lower frequency. A combination of RF transceiver and built-in speaker would offer the occupant more flexibility. Not only would the piggy-back unit sound, but it could also signal any secondary audio device or receive a signal from other piggy-back units.

4.0 TECHNOLOGY COMPARISON AND ECONOMIC CONSIDERATIONS

Even if new smoke alarms with lower frequency alarm tones become available on the market, the cost to retrofit hardwired, interconnected smoke alarms in homes that previously had only battery-operated smoke alarms could be high. The cost to retrofit a home with interconnected smoke alarms will depend, in part, on the area of the country. Table 1 provides an example of the estimated cost breakdown for an electrician to install interconnected smoke alarms in an existing home in the Washington, DC area. Labor hour rates for the electrician's time may be adjusted by as much as 200% depending on the difficulty encountered in running wires in finished walls. These costs also do not include the cost for patching and painting any holes in the walls that are created by the electrician. Phone quotes from two licensed electricians had estimated costs of between \$800 to \$1,200 for installing hardwired smoke alarms in a three-bedroom, two-level home.

Table 1. Estimated Cost to Retrofit Home for Interconnected Smoke Alarms[1]

Material Costs and Labor							
Two Story Home with 3 Bedrooms and No Basement							
Description	Quantity	Cost	Units	Extension	Labor (hours)	Units	Extension (hours)
Smoke Alarms							
AC Powered with battery back-up, ionization	5	$20.00	E	$100.00	0.25	E	1.25
Electrical Boxes							
Plastic round	5	$1.91	E	$9.55	0.25	E	1.25
Wire							
No. 14-3 NM-B (14 AWG, 3-conductor, non-metallic sheath)	650 ft	$151.60 /1,000 ft	M	$98.54	3.60	M	2.35
				$208.09			4.85

E – each
M – thousand feet

LABOR HOUR CALCULATION	
Labor-Unit Estimated Hours	4.85
Labor-Unit Adjustment –Remodeling, +100%	+4.85
Total Hours	**9.70**

ADJUSTED MATERIAL COST	
Total Material Costs	$208.09
Miscellaneous Items, +10%	$20.81
Waste, +5%	$10.41
Small Tool Allowance, +3%	$6.24
Sales Tax (+7%)	$14.57
Total Adjusted Material Cost (plus Tax)	**$260.12**

ESTIMATED CONSUMER COST	
Labor Cost at $11.00 per Hour (9.70 x $11.00)	$106.70
Total Adjusted Material Cost	$260.12
Direct Job Cost (Permit Cost)	$375.00
Total Cost (Labor + Total Material + Permit)	$741.82
Overhead (+40%)	$296.73
Estimated Break Even Cost (Total + Overhead)	$1,038.55
Profit, +15% (Break Even Cost x 15%)	$155.78
Consumer Cost	**$1,194.33***

*Rounded to the next whole dollar

[1] These estimates are for the Washington D.C. area and may be lower in other parts of the country. These costs do not include any repairing of the walls.

The high cost to retrofit a home with hardwired, interconnected smoke alarms may discourage homeowners, even though it would increase life safety in the event of a fire.

Incorporating wireless technology to interconnect smoke alarms or "talk" to secondary audio alarm units would provide a less costly solution. The Naval Research Laboratory (NRL, Dec 2003) estimated that the material cost would be an additional $20 to incorporate an RF transmitter ($10) and receiver ($10) in a smoke alarm, bringing the total material cost for such an alarm to roughly $40. This smoke alarm cost does not include the additional manufacturer recovery cost for research and development of the product. The estimated retail cost of the wireless smoke alarm would be between $60 to $80. Even with the increased cost of this smoke alarm, the cost savings over hardwiring interconnected smoke alarms would be substantial.

Table 2 provides estimated cost savings for a homeowner (using the same two-story home as in the previous example) to install smoke alarms and/or secondary audio devices that use wireless technologies. These costs are used for illustrated purposes and does not represent the actual product cost for any specific smoke alarm model or manufacturer. The estimated costs for retrofitting with hardwired smoke alarms are taken from Table 1, which are estimates for the Washington D.C. area and do not represent national average costs. These costs do not include repairing of the walls.

If the homeowner installed battery-operated smoke alarm units that incorporate transmitters/receivers, the cost would be approximately $70 each for 5 units, or $350. The homeowner would save approximately $844 over hardwiring interconnected smoke alarms. Similarly, if the homeowner installed 5 battery-operated smoke alarm units that contained transmitters and installed four secondary audio devices, the cost saving would be approximately $744.

If a homeowner already had hardwired smoke alarms, and replaced them with new hardwired smoke alarms with interconnect, "piggy back" units could be installed with all new smoke alarms and secondary units could be placed in the home. The cost would be approximately $450; and the cost savings would be $744. The greatest saving would occur if only the smoke alarm outside the bedrooms was replaced with a smoke alarm with an interconnect and a "piggy back" unit. Four secondary audio units could be located throughout the home. The cost savings would be about $944. In this last case, however, none of the smoke alarms would be interconnected.

Recently, wireless smoke alarms have been available at major home improvement stores. These smoke alarms are available with different options, which allows home owners to install interconnected smoke alarms that best suite their needs. Battery powered only smoke alarms with wireless interconnect capability are retailed between $45 to $55. AC powered with battery back-up smoke alarms with wireless interconnect capability are retailed between $55 to $60. Combination smoke and carbon monoxide (CO) alarms with wireless interconnect capability are retailed around $75. External sounder units that can be triggered by the wireless smoke alarms are retailed around $60.

Table 2. Estimated Cost Saving using Various Wireless Technologies in a Smoke Alarm[2]

Two Story Home with 3 Bedrooms and No Basement				
Wireless Smoke Alarm Configurations	Estimated Unit Cost	Quantity	Estimated Total Cost	Estimated Savings over Hardwiring
Smoke Alarms with Transmitter/Receiver in each unit	70.00	5	$350.00	
	Total Cost		$350.00	$1,194-$350 =$844
Smoke Alarm with Transmitter and Secondary Audio Units				
Smoke alarm with transmitter only	50.00	5	$250.00	
Secondary Audio Units (Each bedroom and first floor)	50.00	4	$200.00	
	Total Cost		$450.00	$1,194-$450 =$744
"Piggy Back" Transmitter Unit on all smoke alarms				
Transmitter Unit	30.00	5	$150.00	
Smoke Alarms AC powered with interconnect	20.00	5	$100.00	
Secondary Audio Unit (Each bedroom and first floor)	50.00	4	$200.00	
	Total Cost		$450.00	$1,194-$450 =$744
"Piggy Back" Transmitter Unit on smoke alarm outside the bedrooms only				
Transmitter Unit	30.00	1	$30.00	
Smoke Alarms AC powered with interconnect	20.00	1	$20.00	
Secondary Audio Unit	50.00	4	$200.00	
	Total Cost		$250.00	$1,194-$250 =$944

Each smoke alarm system that would incorporate either wireless technology within the unit or piggy-back existing (or new) smoke alarms has advantages and disadvantages. The transmitter/receiver in each smoke alarm allows true interconnection between the smoke alarms. In this system, however, the smoke alarm would still need to incorporate a lower frequency alarm or use secondary audio devices to be effective in warning older adults who have higher frequency hearing loss.

The combination transmitter smoke alarm and secondary audio device provides an easy method to implement lower frequency alarms, which requires some thoughtful consideration as to the number and placement of secondary audio alarms. The transmitter unit that piggy backs smoke alarms would be best for a home that already has interconnected smoke alarms but needs to incorporate a lower-frequency alarm tone. Secondary audio devices could be placed in areas of the home where they are most needed. Table 3 lists some of the factors that might be expected with each type of wireless system.

[2] These estimates are for the Washington D.C. area and may be lower in other parts of the country. These costs do not include any repairing of the walls.

No Text on This Page

Table 3. Comparison of Technologies

Previous Smoke Alarm Configuration in the Home	SYSTEM REPLACEMENT		
	Transmitter and Receiver in Smoke Alarm	**Transmitter Only in Smoke Alarm, Secondary Wireless Receiver Audio Devices**	**Piggy-Back Transceivers Units, Secondary Wireless Receiver Audio Devices**
Battery Powered Smoke Alarms	-Warns the occupants of fire if any smoke alarm sounds. - Would need to replace all existing smoke alarms for complete interconnection. - Interconnects all smoke alarms. - Additional smoke alarms can be placed in other areas of the home. - Allows the flexibility of using secondary devices that "talk" with the smoke alarms (such as lower frequency sounders).	- Would need to replace all existing smoke alarms for complete coverage. - Does not trigger other smoke alarms. - Additional smoke alarms can be placed in other areas of the home. - The secondary units could use a lower frequency to sound an alarm. - Secondary devices add cost. May need the same number of secondary units as smoke alarms throughout the home.	- Warns the occupants of fire if any smoke alarm sounds. Would need to replace all existing smoke alarms for complete coverage. - Additional smoke alarms can be placed in other areas of the home. - Secondary units could use a lower frequency to sound an alarm. - Can be used with existing smoke alarms sold at retail. - Requires additional maintenance of replacing batteries in piggy-back units.
Interconnected and AC Powered, Every Level and Outside Bedrooms	- Warns occupants in the bedrooms if any smoke alarm sounds. - Would need to replace only one of the existing smoke alarms. - Additional smoke alarms can be placed in other areas of the home. - Interconnects all smoke alarms. - Allows the flexibility of using secondary devices that "talk" with the smoke alarms (such as lower frequency sounders).	- Warns occupants in the bedrooms if any smoke alarm sounds. - Would need to replace only the smoke alarm outside the bedrooms. - The secondary units could use a lower frequency to sound an alarm. - Secondary devices add cost. May need the same number of secondary units as sleeping areas in the home.	- Warns occupants in the bedrooms if any smoke alarm sounds. - Would need to piggy back only the smoke alarm outside the bedrooms. - The secondary units could use a lower frequency to sound an alarm. - Secondary devices add cost. May need the same number of secondary units as sleeping areas in the home. - Additional piggy-backed units with smoke alarms can be placed in the bedrooms for added protection.
Interconnected and AC Powered, Every Level, Outside and Inside Bedrooms	- Additional smoke alarms can be placed in other areas of the home. - Would need to replace only one of the existing smoke alarms. - Allows the flexibility of using secondary devices that "talk" with the smoke alarms (such as lower frequency sounders).	- Would need to replace only one of the existing smoke alarms. - The secondary units could use a lower frequency to sound an alarm. - Secondary devices add cost May need the same number of secondary units as smoke alarms throughout the home.	- Additional smoke alarms can be placed in other areas of the home. - Would need to piggy back only one existing smoke alarm. - The secondary units could use a lower frequency to sound an alarm. - Secondary devices add cost. May need the same number of secondary units as sleeping areas in the home. - Additional piggy-backed units with smoke alarms can be placed in other areas of the home for added protection.

No Text on This Page

5.0 CONCLUSION

According to a 1999 report by the U.S. Fire Administration (USFA), residential fires injure approximately 3,000 older adults each year. In comparison to the rest of the population, older adults – those over 65 years of age – represent one of the highest fire risk groups in the United States.

Impairments associated with the aging process, such as difficulty hearing, predispose the elderly to accidental injuries, including deaths from fires. Causes for the higher death rates among older adults may be associated with the physical and mental challenges related to aging. One concern is that seniors may not adequately hear or respond to smoke alarms because they commonly experience hearing loss in the frequency range at which smoke alarms operate.

In 2004, the CPSC staff conducted an examination of the feasibility of applying technical solutions, such as modifications to residential smoke alarms or the addition of secondary devices that could be triggered by an activated smoke alarm, to improve the sound effectiveness of smoke alarms. The CPSC staff built several prototype smoke alarms that could communicate with secondary devices capable of alarming at lower frequency tones. Three different methods were used:

1. Incorporating a low-frequency speaker in the smoke alarm.
2. Using a wireless transmitter in the smoke alarm to trigger a secondary audio device (the secondary audio device would have the capability of alarming at a lower frequency).
3. Using a piggy-back system, mounted between the smoke alarm and the ceiling or wall, that would monitor the interconnect wire on the smoke alarm. If the piggy-back system detected that the smoke alarm had gone into an alarm mode, it could either transmit a signal to a secondary audio device or would alarm its own low frequency audio speaker.

Incorporating a lower frequency alarm in the smoke alarm is more challenging than using a secondary audio device. Each method has advantages and disadvantages.

The following considerations may be drawn from this report:

- Older adults over the age of 65 constituted 12% of the population in 2003 and will increase rapidly starting in 2010.
- The population over the age of 65 has a higher fire death rate – at least twice the national average.
- Older adults typically experience hearing loss in the frequency range at which residential smoke alarms operate.
- Interconnected smoke alarms result in increased audibility of an alarm signal throughout the home; however, this may not adequately improve audibility for older adults with higher frequency hearing loss.

- Additional smoke alarms in the bedrooms that are interconnected with the other smoke alarms in the home provide improved life safety.
- Incorporating lower frequency alarms either within the smoke alarm or as external sounding devices is feasible and provides a substantially less expensive method than hardwiring for existing homes.

The CPSC staff believes that the use of interconnected smoke alarms and lower frequency alarm tones may result in improved audibility of smoke alarm signals, especially for older adults. The goal of these improvements is to increase the available escape time for occupants, especially for older adults, in a residential fire. As the number of adults over the age of 65 increases, improved audibility of alarms could have a significant impact in reducing the number of fire deaths and injuries in that age group.

6.0 REFERENCES

Acoustical Society of America (ASA). Reaffirmed 2001. *American National Standard, Audible Emergency Evacuation Signal*. ANSI S3.41-1990 (ASA 96-1990). Accredited Standards Committee S3, Bioacoustics. New York, New York.

Ahrens, Marty. June 2003. *The US Fire Problem Overview Report Leading Causes and Other Patterns and Trends*. Quincy: National Fire Protection Association.

Ahrens, Marty. November 2003. *US Experience with Smoke Alarms and other Fire Alarms*. Quincy: National Fire Protection Association.

Bruck, D. 2001. "The who, what, where and why of waking to fire alarms: A review." *Fire Safety Journal* 36: 623 –39.

Bruck, D. & Horasan, M. 1995. "Non-arousal and non-action of normal sleepers in response to a smoke detector alarm." *Fire Safety Journal* 25: 125-139.

Centers for Disease Control and Prevention. March 2001. *Trends in Vision and Hearing Among Older Americans*.

Duncan, C. 1999. "The effectiveness of the domestic smoke alarm signal. Fire Engineering Research Report 99/5." Supervised by Charles M. Fleischman. Presented as a project report in partial fulfillment of the M.E. (Fire) degree of the University of Canterbury, Christchurch, New Zealand. ISSN 11734996.

Federal Interagency Forum on Age-Related Statistics. 2004. *Older Americans 2003: Key Indicators of Well-Being.* Washington DC: United States Government Printing Office.

Hall, John. May 2004. *Characteristics of Home Fire Victims Including Age and Sex*. Quincy: National Fire Protection Association.

Huey, R.W.; Buckly, D.S. and Lerner, N.D. 1994. "Audible Performance of Smoke Alarm Sounds." *Designing for an Aging Population:* 6-10.

Keay, DG and Murray. 1988. "Hearing loss in the elderly: a 17-year longitudinal study." *Clinical Otolaryngology* 13: 31-35.

Lee, A. December 2, 2002, *Final Report on Lithium Batteries (UltraLife, ANSI 1604) Used in Residential Smoke Alarms*. Washington DC: U.S. Consumer Product Safety Commission.

Linden, D and Reddy, T. 2002, *Handbook of Batteries*, Third Edition. New York: McGraw-Hill Inc.

Miller, D. November 2003. *1999 Residential Fire Loss Estimates.* Washington DC: U.S. Consumer Product Safety Commission.

National Fire Protection Association. 2000. *NFPA 101, Life Safety Code 2000 edition.* Quincy, MA.

National Fire Protection Association. 1999. *NFPA 72 National Fire Alarm Code, 1999 edition.* Quincy, MA.

Smith, Charles. November 1993. *Smoke Detector Operability Survey – Report on Findings.* U.S. Consumer Product Safety Commission, Bethesda, Maryland.

Smith, Linda. January 1995. *Fire Incident Study: National Smoke Detector Project.* U.S. Consumer Product Safety Commission, Bethesda, Maryland.

Street, T.T. and Williams, F.W. July 2003. *Smoke Alarms, Low-Cost Batteries, and Wireless Technology Technical Report: Phase I – Preparatory Study and Literature Search.* Naval Research Laboratory, Navy Technology Center for Safety and Survivability Chemistry Division.

Street, T.T. and Williams, F.W. December 2003. *The Implementation and Demonstration of Wireless Communications Capabilities in Off-The-Shelf, Battery Powered Smoke Alarms, Phase II Report*. Naval Research Laboratory, Navy Technology Center for Safety and Survivability Chemistry Division.

Underwriters Laboratories. February 1997. *UL 217 Single and Multiple Station Smoke Alarms.* Northbrook.

United States Fire Administration. October 1999. *Fire Risks for Adults.* TriData Corporation under subcontract to Ogiluy Public Relations Worldwide for the United States Fire Administration.

Bregman, A.S. 2001. *Auditory Scene Analysis, The Perceptual Organization of Sound*. MIT: MIT press.

Everest, F.A. 2001. *Mastering Handbook of Acoustics.* Fourth Edition. New York: McGraw-Hill.

Hartman,W.M. 1998. *Signals, Sound, and Sensation.* New York: Springer.

Moore, B, C.J. 2003. *An Introduction to the Psychology of Hearing.* Fifth Edition. USA: Elsevier Science.

Yost, W.A. 2000. *Fundamentals of Hearing.* Fourth Edition. USA: Elsevier Science.

Additional headquarters contact information

Toll-free consumer hotline: 800-638-2772 (TTY 800-638-8270). Call to obtain product safety information and other agency information and to report unsafe products. Available 24 hours a day, 7 days a week.

Compliance information
301-504-7912
sect15@cpsc.gov

Commission meeting agendas
301-504-7923
cpsc-os@cpsc.gov

Employee locator
301-504-6816

Employment information
301-504-7925
recruitapps@cpsc.gov

Freedom of Information Act
301-504-7923
cpsc-os@cpsc.gov

Media relations/Information and Public Affairs
301-504-7908

National Injury Information Clearinghouse
301-504-7921
clearinghouse@cpsc.gov

Office of the Executive Director
301-504-7907

Office of the General Counsel
301-504-7922

Publications
publications@cpsc.gov

U.S. CONSUMER PRODUCT SAFETY COMMISSION

Headquarters

Mailing address:
U.S. Consumer Product Safety Commission
Washington, D.C. 20207-0001

Street address:
4330 East-West Highway
Bethesda, Maryland 20814-4408
Tel. (800) 638-2772
Fax (301) 504-0124 and (301) 504-0025
E-mail: info@cpsc.gov