UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
WASHINGTON, DC 20207

**Memorandum**

Date: AUG 29 2003

TO : The Commission
Todd A. Stevenson, Secretary

THROUGH: W. H. DuRoss, III, General Counsel
Patricia Semple, Executive Director

FROM : Jacqueline Elder, Assistant Executive Director
Office of Hazard Identification and Reduction
Arthur S. Lee, Electrical Engineer
Directorate for Engineering Sciences

SUBJECT : Contractor Report on *Smoke Alarms, Low Cost Batteries and Wireless Technology Technical Report and Literature Search, Phase I-Preparatory Study and Literature Search*

Attached is the report on the first phase of a study to incorporate wireless interconnect technology in battery-operated smoke alarms. This report was completed by the Naval Research Laboratory (NRL) under contract to the U.S. Consumer Product Safety Commission (CPSC).

In recent years, the Life Safety Code (NFPA 101) has required all smoke alarms in new construction to be interconnected and hard-wired to the home electrical system. Interconnected smoke alarms allow all of the alarms to sound if any individual alarm detects smoke. This results in increased egress time and life protection for an occupant if a smoke alarm detects smoke in the furthest part of the home. However, this requirement applies only to smoke alarms that are powered by 120 VAC, or house wiring. A large number of homes were constructed before any smoke alarms were required, and protection in these homes is now provided by battery-operated smoke alarms. These homes do not have the added protection provided by interconnected alarms.

CPSC staff believes that with today's technology, a battery-powered smoke alarm can communicate with other smoke alarms. The primary objective of Phase I of the NRL research was to determine the feasibility of incorporating wireless technology into battery-operated smoke alarms. The contractor considered potential designs that would retain a 9-volt alkaline battery as the primary power source and would not significantly increase manufacturing costs.

In its report, NRL identified various wireless technologies and battery sources that may be applicable for use in battery-powered smoke alarms. The concepts that show the most promise are sonic and radio frequency (RF) technologies. The sonic technology is expected to be less expensive to produce and would consume minimum battery power. An RF link would be relatively inexpensive, is available in integrated circuit form, has good rejection of interference, and would provide adequate range for signaling other alarms in a home.

In Phase II of this study, NRL will construct several wireless smoke alarm prototypes to demonstrate the wireless interconnect concept. The prototype smoke alarms are required to sound any of the other smoke alarms when the test button on any one of the alarms is pressed. A report of this work will be completed later in 2003.

Attached:
*Smoke Alarms, Low Cost Batteries and Wireless Technology Technical Report and Literature Search, Phase I-Preparatory Study and Literature Search*

**Naval Research Laboratory**

Washington, DC 20375-5320

NRL/MR/6180--03-8664

# Smoke Alarms, Low-Cost Batteries, and Wireless Technology Technical Report: Phase I—Preparatory Study and Literature Search

THOMAS T. STREET
FREDERICK W. WILLIAMS

*Navy Technology Center for Safety and Survivability*
*Chemistry Division*

FRANCIS R. PITAS

*Geo-Centers, Inc.*
*Lanham, MD*

July 11, 2003





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Thomas T. Street, Frederick W. Williams, and Francis R. Pitas*

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*Geo-Centers, Inc. 4540 Forbes Boulevard, Suite 130, Lanham, MD 20706

**14. ABSTRACT**
This report details the background research and current technology status of residential smoke alarms, low-cost battery state-of-the-art, and wireless communication technologies as Phase I of a study of modifying battery-powered smoke alarms to communicate an alarm condition that will cause all smoke alarms in a building to sound when any individual smoke alarm detects smoke. Phase II will aim at building a model of the operational system.

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# SMOKE ALARMS, LOW-COST BATTERIES, AND WIRELESS TECHNOLOGY TECHNICAL REPORT: PHASE I—PREPARATORY STUDY AND LITERATURE SEARCH

## 1.0 INTRODUCTION

The National Fire Protection Association (NFPA) 101, Life Safety Code [1] requires all residential smoke alarms in new construction to be interconnected. Interconnected smoke alarms allow all of the smoke alarms to sound if any individual smoke alarm detects smoke. Smoke alarms must be hardwired to an unswitched (excluding circuit breakers) 120 VAC power source, in addition to the hardwired interconnection between each smoke alarm. Many of the alarms that meet this requirement also incorporate a battery as a backup power source. This interconnection allows a decrease in egress times and an increase in life protection for the occupant if a smoke alarm happens to sound in the farthest part of the home. Homes constructed before hardwired and interconnected smoke alarms were required and homes with battery operated smoke alarms do not have the added protection of all smoke alarms sounding when a single smoke alarm has detected smoke. For these homes, today's technology could allow wireless communication between multiple, battery powered, single station smoke alarms.

An effort funded by the U.S. Consumer Product Safety Commission (CPSC) has been initiated to determine the feasibility of modifying existing battery powered, ionization and photoelectric single station smoke alarms with wireless communication capabilities that don't significantly increase the cost of smoke alarms. This report discusses the literature search for current battery powered smoke alarms, evaluates current wireless technologies to determine the feasibility of providing a wireless communication capability to battery powered smoke alarms and examines the currently available low-cost batteries to power these devices.

Using this information, off-the-shelf battery powered smoke alarms might be modified to include a wireless communication link, allowing single station battery powered ionization and photoelectric smoke alarms to communicate alarm conditions to other modified smoke alarms, initiating the alarm horn on all smoke alarms without hardwired power and signaling connections. This would allow wireless communication equipped smoke alarms that communicate alarm conditions between each other to be installed in place of single station smoke alarms in older structures. This could upgrade the NFPA 101, Life Safety Code for older structures to that of new construction without the costly hardwiring for power and signal between smoke alarms that was previously needed. It would also facilitate the installation of smoke alarms in hard-to-cover areas.

In the future, the advantage of this technology in smoke alarms may also be used to alert individuals with hearing aids, cause lights to flash for the hearing impaired and inform a monitoring station. The ability of bi-directional communication in a smoke alarm could allow products, such as a toaster or a clothes dryer, to transmit a signal to the smoke alarm if a fire has occurred in the appliance.

Manuscript approved June 17, 2003.

## 2.0 SMOKE ALARMS

Numerous companies manufacture smoke alarms, but six (6) companies manufacture 90% of the 120 VAC and 9 VDC powered single station alarms sold in the US today. This report will concentrate on those manufacturers. All of the manufacturers have a variety of ionization and photoelectric designs, powered by 9 VDC batteries, 120 VAC or 120 VAC with battery backup. All of the 120VAC powered smoke alarms that were examined can be interconnected to meet the Life Safety Code for new construction. None of the 9 VDC battery powered smoke alarms studied could be interconnected to meet the Life Safety Code except the 120 VAC units with battery backup. Some smoke alarms are single sensor photoelectric or ionization types (both single and dual chamber designs) and others are multiple sensor designs with both ionization and photoelectric sensors within the same package. Some incorporate sensors other than smoke or particle detectors into their multi-sensor smoke alarms such as heat and carbon monoxide (CO). Special requirements for hearing impaired individuals have added smoke alarms with xenon strobe lights, remotely operated vibrating pads, escape lights and remote activation of other attention getting devices through a relay option that is activated when the detector's alarm criteria is met.

### 2.1 Smoke Alarm Types

Two major types of smoke alarms are available, the ionization and the photoelectric. The most common is the ionization smoke alarm, which reacts to fast-flaming fires like paper and those fed by flammable fluids. When smoke enters an ionization alarm, ionized air molecules attach to the smoke particles and reduce the ionizing current, triggering an alarm. The ionization smoke alarm can be slow to detect the smokey slow-starting electrical fires and fires starting in upholstery and bedding. The photoelectric smoke alarms react much more quickly to smoke from smoldering fires than flaming fires. When smoke particles enter a photoelectric alarm, light from a pulsating light source is reflected off the smoke particles into a light sensor, triggering the alarm. Underwriters Laboratories (UL) tests have consistently shown that the light beams and sensors of photoelectric alarms react much more quickly to smoke from smoldering fires than flaming fires. Only battery powered combination alarms have been located which are not capable of being interconnected as required by the NFPA Life Safety Code for use in new construction, but this does not preclude their use in older residences built before the Life Safety Code requirement that all smoke alarms sound if any individual smoke alarm detects smoke. Combination alarms with ionization and photoelectric smoke sensors are recommended for older residences because they offer better coverage for flaming and smoldering fire types than do individual ionization and photoelectric types.

## 2.2 Current Smoke Alarm Technology

A complete list and description of currently available single station smoke alarms is listed in Table 1 (a. through f.). Each smoke alarm's description includes the manufacturer's code, sensor type, input power sources, the power consumption in standby and under alarm (when available), whether the smoke alarm has any false alarm control and the capability of being interconnected to satisfy the NFPA Life Safety Code.

Information on the particular processing chip that is used in each smoke alarm could not be found (proprietary information). Smoke alarm manufacturers have in-house numbering placed on the processor chips to keep this information proprietary to their company. However, many semiconductor technical data sheets on a wide variety of Application Specific Integrated Circuits (ASIC) processor chips used in many of the smoke alarms will be provided to the CPSC separately.

## 2.3 Candidate Battery Powered Smoke Alarms To Be Modified For Wireless Communication Demonstration

The primary objective of this program is to demonstrate that wireless technology can be incorporated into battery operated smoke alarms. Emphasis has been placed on wireless technologies that would not drastically increase the cost of a residential smoke alarm after modification for wireless operation. This modification should retain the primary power source as a 9-volt alkaline battery, not increase the general size of the smoke alarm and provide a reliable interconnection between smoke alarms within the same structure. A major goal of this effort is to design and implement the wireless solution using the minimum component count and to use the wireless technology that has the best chance of success and is most supported by integrated circuits and components that are off-the-shelf and readily available to support the implementation.

Two (2) battery powered smoke alarms from each of the six (6) companies this report details will be procured, examined and evaluated to determine the feasibility of each being modified for wireless operation. A battery powered ionization and a battery powered photoelectric smoke alarm manufactured by each of the six companies will be procured for this purpose. Each smoke alarm will be examined for component population levels, power consumption, battery type, space for wireless components, determination of processor manufacturer and type (if possible) and other operational considerations that may arise.

## Residential Smoke Alarms

| Name | Sensor Type | Power Source | Additional Info | Power Consumption | | False Alarm Control (FAC) | # of Units For Interconnect |
|---|---|---|---|---|---|---|---|
| | | | | *Standby* | *Under Alarm* | | |
| Manufacturer A | Dual Ion | 120VAC 9VBU | | .045 A | .045 A | | 18 |
| | Dual Ion | 120VAC 9VBU | | .045 A | .045 A | Silence Button | 18 |
| | Dual Ion | 120VAC 9VBU | 4120B W/Alk | .045 A | .045 A | | 18 |
| | Dual Ion | 120VAC 9VBU | 4120SB W/Alk | .045 A | .045 A | | 18 |
| | Ion | 120VAC | | .045 A | .045 A | | 18 |
| | Ion | 120VAC | Xenon Strobe | .053 A | .412 A | | 18 |
| | Photo | 120VAC 9VBU | | .025 A | .025 A | | 18 |
| | Photo | 120VAC | | .025 A | .025 A | | 18 |
| | Photo/Heat | 120VAC | heat sensor | .025 A | .025 A | | 18 |
| | Photo/Dual Ion | 9VDC | Test Button | | | | |
| | Photo/Ion | 9VDC | 2 Test Buttons | | | | |
| | Photo | 9VDC | Test Button | | | | |
| | Ion | 9VDC | | | | | |
| | Ion | 9VDC Lith | Perm Battery | | | | |
| | Ion | 9VDC Lith | | | | Silence Button | |
| | Ion | 9VDC Alk | | | | Silence Button | |
| | Ion | 2X 9VDC Alk | Escape Light | | | | |

Lith = Lithium Battery
Alk = Alkaline Battery

Table 1(a) Manufacturer A

## Residential Smoke Alarms

| Name | Sensor Type | Power Source | Additional Info | Power Consumption | | False Alarm Control (FAC) | # of Units For Interconnect |
|---|---|---|---|---|---|---|---|
| | | | | *Standby* | *Under Alarm* | | |
| Manufacturer B | Ion | 9VDC Alk | General Use | | | | |
| | Ion | 9VDC Alk | | | | Alarm Silencer | |
| | Ion | 9VDC Alk | Flashlight Test | | | | |
| | Ion | 9VDC Ex Life | Flashlight Test | | | | |
| | Ion | 9VDC Alk | Flashlight Test | | | | |
| | Ion | 9VDC Lith | | | | Alarm Silencer | |
| | Ion | 120VAC | Strobe Light | .59 A | | | 12 |
| | Ion | 9VDC Alk | Escape Light | | | | |
| | Photo | 9VDC Alk | | | | | |
| | Photo/Ion | 9VDC Alk | Dual Sensor | | | | |
| | Photo/Ion | 9VDC Alk | Remote Test | | | | |
| | Ion | 9VDC Lith | No Batt Change | | | | |
| | Ion | 120VAC | | | | | 12 |
| | Ion | 120VAC 9VBU | | .5 A | | | 12 |
| | Ion | 120VAC 9VBU | | .5 A | | Alarm Silencer | 12 |

Lith = Lithium Battery
Alk = Alkaline Battery

Table 1(b) Manufacturer B

## Residential Smoke Alarms

| Name | Sensor Type | Power Source | Additional Info | Power Consumption | | False Alarm Control (FAC) | # of Units For Interconnect |
|---|---|---|---|---|---|---|---|
| | | | | Standby | Under Alarm | | |
| Manufacturer C | Dual Ion | 120VAC | | | | | 6 |
| | Dual Ion | 120VAC | | | | | 18 |
| | Ion | 120VAC | | | | | |
| | Ion | 120VAC | | | | | |
| | Dual Ion | 120VAC | | | | | 18 |
| | Dual Ion | 9VDC Alk | | | | | |
| | Dual Ion | 9VDC Alk | | | | | |
| | Dual Ion | 9VDC Alk | | | | | |
| | Photo | 9VDC Alk | | | | | |
| | Photo | 120VAC | | | | | 18 |
| | Ion | 9VDC Alk | | | | | |
| | Photo | 9VDC Alk | | | | | |
| | Ion | 9VDC Alk | | | | | |
| | Photo/Ion | 9VDC Alk | | | | | |
| | Photo/Ion | 9VDC Lith | | | | | |
| | Photo | 120VAC 9VBU | | | | | 18 |
| | Ion | 120VAC 9VBU | | | | | 18 |
| | Ion | 120VAC 9VBU | | | | | 18 |
| | Dual Ion | 9VDC Lith | | | | | |
| | Dual Ion | 9VDC Lith | Perm Battery | | | | |
| | Ion | 120VAC 9VBU | | | | | 18 |
| | Dual Ion | 120VAC | | | | | 18 |
| | Ion | 120VAC 9VBU | | | | | |
| | Ion | 120VAC 9VBU | | | | | |

Lith = Lithium Battery
Alk = Alkaline Battery

Table 1(c) Manufacturer C

# Residential Smoke Alarms

| Name | Sensor Type | Power Source | Additional Info | Power Consumption | | False Alarm Control (FAC) | # of Units For Interconnect |
|---|---|---|---|---|---|---|---|
| | | | | *Standby* | *Under Alarm* | | |
| Manufacturer D | | 120 VAC 9VBU | 10 Yr Lith | | | | 18 |
| | Ion | 9 VDC Lith | | | | Silence Button | |
| | Ion | 9 VDC Lith | | | | Silence Button | |
| | Dual Ion | 120 VAC 9VBU | 3 Yr Super Batt | | | | 18 |
| | Dual Ion | 120 VAC 9VBU | 3 Yr Super Batt | | | | 18 |
| | Dual Ion | 120 VAC | | | | | 18 |
| | Ion | 9 VDC Alk | | | | Silence Button | |
| | Ion | 9 VDC | Test Button | | | | |
| | Photo | 120 VAC 9VBU | 3 Yr Super Batt | | | | 18 |
| | Dual Ion | 120 VAC 9VBU | Test Button | | | | 18 |
| | Dual Ion | 9 VDC | 2 Yr HD Batt | | | | |
| | Photo | 9 VDC | 2 Yr HD Batt | | | | |
| | Photo | 120 VAC 9VBU | 3 Yr HD Batt | | | | 18 |

Lith = Lithium Battery
Alk = Alkaline Battery

Table 1(d) Manufacturer D

# Residential Smoke Alarms

| Name | Sensor Type | Power Source | Additional Info | Power Consumption | | False Alarm Control (FAC) | # of Units For Interconnect |
|---|---|---|---|---|---|---|---|
| | | | | *Standby* | *Under Alarm* | | |
| Manufacturer E | Ion | 120 VAC | Test Button | | | | Yes |
| | Photo | 9 VDC | Test Button | | | | |
| | Ion | 9 VDC Lith | Test Button | | | Hush Button | |
| | Ion | 9 VDC | Safety Light/ Test Button | | | Hush Button | |
| | Ion | 9 VDC | Test Button | | | Hush Button | |
| | Ion | 9 VDC | Test Button | | | | |
| | Photo | 120 VAC 9VBU | Test Button | | | | Yes |
| | Ion | 120 VAC 9VBU | Safety Light/ Test Button | | | Hush Button | Yes |
| | Ion | 120 VAC 9VBU | Test Button | | | Hush Button | Yes |
| | Ion, CO | 120 VAC | Voice Warning/ Test/Reset Button | | | | Yes |
| | Ion, CO | 9 VDC | Voice Warning/ Test/Reset Button | | | | |
| | Ion | 2X 9 VDC | Exit Light | | | | |
| | | | Test Button | | | | |
| | Ion | 9 VDC Lith | Test Button | | | Hush Button | |
| | Ion | 9 VDC | Test Button | | | Hush Button | |
| | Ion | 9 VDC | Test Button | | | | |
| | Ion | 9 VDC | Test Button | | | | |
| | Ion | 120 VAC 9VBU | Test Button | | | | Yes |
| | Ion | 120 VAC | Test Button | | | | Yes |

Lith = Lithium Battery
Alk = Alkaline Battery

Table 1(e) Manufacturer E

# Residential Smoke Alarms

| Name | Sensor Type | Power Source | Additional Info | Power Consumption | | False Alarm Control (FAC) | # of Units For Interconnect |
|---|---|---|---|---|---|---|---|
| | | | | *Standby* | *Under Alarm* | | |
| | | | | | | | |
| Manufacturer F | Dual Ion | 9 VDC | | | | | |
| | Dual Ion | 9 VDC | | | | Alarm Silencer | |
| | Ion | 9 VDC | Test Button/ Operating Light/ Emergency Light | | | | |
| | Ion | 120 VAC | Test Button/ Operating Light | | | | 12 |
| | Ion | 120 VAC 9VBU | Test Button/ Operating Light | | | Alarm Silencer | 12 |
| | Photo | 9 VDC | Test Button/ Operating Light | | | | |
| | Ion | 9 VDC Lith | Test Button/ Operating Light | | | | |

Lith = Lithium Battery

Alk = Alkaline Battery

Table 1(f) Manufacturer F

## 3.0 BATTERY REQUIREMENTS

Battery powered residential smoke alarms listed to the Underwriters Laboratories (UL) 217 *Single and Multiple Station Smoke Alarms* must pass Section 63 Battery Tests for battery life [2]. This effort will modify selected residential smoke alarms to include circuitry to support a wireless communication link. Adding additional circuitry to implement a wireless communication link to a battery powered, residential smoke alarm will place an additional power requirement on the battery. If the manufacturer's recommended battery could be depleted within a year, an alternate battery source must be sought. This may require that the battery be upgraded or an additional battery be added to the smoke alarm in order to continue to meet the UL 217, Section 63 Battery Test requirement. If an additional battery is used to power the wireless circuitry it must last 10 years and the original battery (manufacturer's recommended) must be a 9-volt alkaline battery.

### 3.1 Battery Types

Batteries can be divided into two types, primary and secondary. A primary battery is usable one-time, and is not normally considered rechargeable. A secondary battery may be recharged some number of times depending on the battery technology and the operating conditions. Normally some characteristics are sacrificed with a secondary battery, such as Amp-hour capacity and shelf life, as compared to a similar size primary battery. For this application only primary battery types will be considered for the original or any added battery power sources, since no capability will exist to recharge a secondary battery and secondary batteries fail to meet the 10-year requirement stated above.

### 3.2 Current Battery Technology

A search of current batteries available to consumers has been conducted and where possible, the American National Standards Institute (ANSI) size 1604 (consumer standard 9 Volt) was used to determine the size. For completeness, this list includes all current battery technologies, regardless of applicability to smoke alarms. Data sheets for these batteries will be delivered to CPSC under separate cover.

1. Carbon Zinc/primary
   Size: ANSI 1604D
   Voltage: 9V
   Typical Application(s): Toys, flashlights and portable consumer electronics
   Amp-Hour Rating: 400mAH
   Shelf Life: 2 - 3 yrs.
   Cost: Low

2. Carbon Zinc Chloride/primary
   Size: ANSI 1604D
   Voltage: 9V
   Typical Application(s): Toys, flashlights and portable consumer electronics
   Amp-Hour Rating: 330mAH
   Shelf Life: 2 - 3 yrs.
   Cost: Low to medium

3. Zinc Air/primary
   Size: ANSI 7004Z
   Voltage: 9V
   Typical Application(s): Hearing aid
   Amp-Hour Rating: 1100mAH
   Shelf Life: >90% after 2 yrs if tab is not removed, >50% after 3-12 weeks
   Cost: Medium

4. Silver Oxide Zinc, NaOH/primary or (limited) secondary
   Size: cylinder, 12mm diameter x 5.5mm thick
   Voltage: 1.55V
   Typical Application(s): Watch, calculator and hearing aids
   Amp-Hour Rating: 200mAH
   Shelf Life: After charging/recharging, 6 months (secondary) to >85% after 7 yrs (primary)
   Cost: High

5. Silver Oxide Zinc, KOH/primary or (limited) secondary
   Size: Button, 11.6 mm diameter, 5.4 mm height
   Voltage: 1.55V/cell
   Typical Application(s): Emergency equipment, military & space
   Amp-Hour Rating: 200mAH
   Shelf Life: After charging/recharging, 6 months (secondary) to 2 yrs. (primary)
   Cost: High

6. Alkaline Manganese Dioxide Zinc/primary
   Size: ANSI 1604A
   Voltage: 9V
   Typical Application(s): CD players, camera flash and high drain applications
   Amp-Hour Rating: 565mAH
   Shelf Life: >85% after 5 yrs, 7 yrs max
   Cost: Low to medium

7. Alkaline Manganese Dioxide Zinc, extended life Titanium/primary
   Size: ANSI 1604A
   Voltage: 9V
   Typical Application(s): CD players, camera flash and high drain applications
   Amp-Hour Rating: 655mAH
   Shelf Life: >80% after 5 yrs
   Cost: Low to medium

8. Alkaline/secondary
   Size: ANSI 15LF (AA)
   Voltage: 1.5V
   Typical Application(s): Photoflash, Cordless telephones
   Amp-Hour Rating: 1600mAH initial, falls with successive charge cycles
   Shelf Life: approx. After charging/recharging, 70% after 1 year
   Cost: Medium

9. Lithium Manganese Dioxide/primary
   Size: ANSI 1604LC
   Voltage: 9V
   Typical Application(s): Computer memory, watches, portable electronics
   Amp-Hour Rating: 1200mAH
   Shelf Life: >85% after 5 yrs.
   >73% after 10 yrs. (self-discharge typically 0.3%/yr)
   Cost: Medium

10. Lithium Thionyl Chloride/primary
    Size: ANSI 1604 equivalent
    Voltage: 9V
    Typical Application(s): Memory back-up, smoke detectors, wireless security systems
    Amp-Hour Rating: 1200mAH
    Shelf Life: 15 – 20 yrs, >99% after 1 yr.
    Cost: Medium to high

11. Lithium Iodine/primary
    Size:
    Voltage:
    Typical Application(s): Cardiac pacemakers
    Amp-Hour Rating:
    Shelf Life: 20+ yrs
    Cost: High

12. Lithium Sulfur Dioxide/primary
    Size: D (ANSI)
    Voltage: 2.8V
    Typical Application(s): Military, aerospace
    Amp-Hour Rating: 7.5 AH
    Shelf Life: 80% after 10 yrs
    Cost: High

13. Lithium Vanadium Pentoxide/Secondary
    Size: Coin, 23 mm diameter, 3 mm Thick
    Voltage: 3 V
    Typical Application(s): Implantable defibrillator, neurostimulator
    Amp-Hour Rating: 50 mAH
    Shelf Life: >98% after I year
    Cost: Medium

14. Lithium Ion/secondary
    Size: (custom) 37 x 60 x 36mm
    Voltage: 7.2V
    Typical Application(s): Camcorder
    Amp-Hour Rating: 1600mAH
    Shelf Life: After charging/recharging, 90% after 1 month
    Cost: Medium

15. Lithium Iron Disulfide/primary
    Size: ANSI 15LF (AA)
    Voltage: 1.5V
    Typical Application(s): Photoflash
    Amp-Hour Rating: 2900mAH
    Shelf Life: 10+ yrs
    Cost: Medium

16. Lithium Poly - Carbon Monofluoride (also, Lithium CFX) /primary
    Size: 14 (C)
    Voltage: 3V
    Typical Application(s): Watches, calculators and memory backup
    Amp-Hour Rating: 5000mAH
    Shelf Life: 10+ yrs
    Cost: Medium

17. Nickel Metal Hydride (NiMH)/secondary
    Size: ANSI 1604
    Voltage: 7.2V (specified for 9V service by mfr.)
    Typical Application(s):
    Amp-Hour Rating: 150mAH (to 6.0V)
    Shelf Life: approx. After charging/recharging, 70% after 25 days
    Cost: Medium

18. Nickel Cadmium (NiCd)/secondary
    Size: (custom) 75 x 47 x 20mm
    Voltage: 6V
    Typical Application(s): Camcorder, cellular phone
    Amp-Hour Rating: 1200mAH
    Shelf Life: approx. After charging/recharging, 70% after 35 days
    Cost: Medium

19. Nickel Iron/secondary
    Size: 166 mm X 129 mm X 395 mm
    Voltage: 48 V
    Typical Application(s): Deep cycle industrial & railroad, stationary power
    Amp-Hour Rating: 300 AH
    Shelf Life:
    Cost: Medium

20. Sealed Lead Acid/secondary
    Size: (custom) 50 x 39 x 14mm
    Voltage: 4V
    Typical Application(s): Cordless phone, Office equipment, Power tools
    Amp-Hour Rating: 500mAH
    Shelf Life: After charging/recharging, 80% after 6 months
    Cost: Low to medium

### 3.3 Battery Candidates for Modified Smoke Alarm

In choosing appropriate battery technologies for residential smoke alarms, the following criteria were used:

1. Selected battery available to consumer in a compact size, preferably 9 Volt standard (ANSI 1604 or equivalent).

2. Selected battery to have a shelf life greater than 1 year with 80% or greater capacity remaining.

3. Selected battery to have an Amp-hour rating of at least 300mAH.

***The following battery technologies meet these criteria:***
Batteries from the previous list include: 1,2,6,7,9, and 10.

## 4.0 WIRELESS COMMUNICATION TECHNOLOGIES

The objective of this effort is to gain enough knowledge to demonstrate that wireless technology can be incorporated into battery operated smoke alarms. Applying some form of wireless communication to existing, off-the-shelf, single station, battery powered ionization and/or photoelectric smoke alarms could allow the communication of an alarm condition between a smoke alarm that detects smoke and other smoke alarms in the residence, thereby allowing all the smoke alarms to sound. This wireless communication between smoke alarms is meant to mimic the hardwired interconnection required by NFPA 101, Life Safety Code for new construction. If this effort is successful it could facilitate the use of modified battery powered smoke alarms to meet the same Life Safety Code for interconnected smoke alarms in older residences.

There are three (3) major wireless technology areas [3] [4] that most wireless communications, applicable to this effort, fall under. Those technology areas are Radio Frequency (RF), Optical (infrared) and Sonic (sound).

Typical RF Communication applications:

Garage Door Openers
Keyless Entry Systems
Wireless Security Systems
Wireless Phone Communications (Portable and Cell)
Remote Fan/Light Controls

Typical Optical Communication Applications (Infrared):

TV/VCR Remote Controls
Wireless Computer Peripherals
Remote Fan/Light Controls

Typical Sonic Communication Applications

No Known Applications Exist

## 4.1 RF Communication Links

RF data links are now commonly designed using a wide variety of frequencies and modulation types. All RF approaches use modulation of a carrier signal. The Federal Communications Commission (FCC) [5] has set aside some frequency bands for unlicensed Industrial, Scientific and Medical (ISM) use that could be used for wireless communication between smoke alarms. Licensing is not required if the transmitted signal is below levels specified by the FCC, depending on frequency and the form of modulation. Typically these levels allow communication for up to several hundred feet, and sometimes for miles. In every case the use of a sufficiently high frequency will allow smaller circuitry and, most importantly, a practical antenna size, since antenna length is usually a quarter wave length for efficient operation. For this application frequencies near 900 MHz allow inexpensive and small circuitry and an antenna length of a few inches. At still higher frequencies the antenna will get smaller, but the circuitry becomes significantly more expensive, and the radiated signal will tend to become line-of-sight, similar to optical transmission.

***Frequencies Of Operation For Wireless Communication***

Unlicensed operation of intentional radiators is allowed within almost the entire radio spectrum up to 38.6 GHz if power levels are below FCC specifications, except within certain frequency bands that are restricted such that only spurious emissions are permitted. There are 64 of these relatively narrow bands where vital service communications are located, as well as bands where unlicensed operation only for specific uses is permitted, such as 54 – 72 MHz, 76 – 88 MHz, 172 – 216 MHz, and 470 – 806 MHz.

Various types of RF data links and remote control devices are now commonly designed using a wide variety of frequencies and modulation types within frequency bands specified for Industrial, Scientific and Medical (ISM) use. The recent extensive use of UHF frequencies, 900 MHz and beyond, allows small circuitry and a practical antenna size.

*The Following is a list of typical wireless device operating frequencies*

A. 26.96 – 27.28 MHz: Radio Controlled Model Aircraft and cars.

B. 46.60 – 46.98 MHz and 49.66 – 50.00 MHz: Cordless telephones

C. 72.00 – 73.00 MHz and 75.40 – 76.00 MHz: Auditory assistance devices

D. 174 – 216 MHz: Biomedical telemetry devices

E. 170 – 450 MHz: Keyless entry, garage door openers, fan/light remote control and wireless security systems.

F. 902 – 928 MHz: Cellular telephones, RF data links/wireless Local Area Network (LAN).

G. 2400 – 2483.5 MHz: Cellular telephones, RF data links/wireless LAN.

H. 5725 – 5850.0 MHz: Cellular telephones, RF data links/wireless LAN.

The allowed power of an intentional unlicensed radiator depends on the frequency, the mode (continuous, periodic, and/or intermittent) and the modulation used. Typically, these levels allow communication for up to several hundred feet, and sometimes for miles. At specific places within the ISM bands spread spectrum transmission is allowed at considerably higher power levels than for other types of modulation. These bands are employed for cellular telephone, wireless LANs and other uses requiring security, long distance communication and relatively high data rates. For a complete list of restricted bands and a description of power, mode and modulation methods allowed at each frequency, refer to FCC part 15 Subpart C, Intentional Radiators.

## 4.2 Optical Communication Link (Infrared)

Optical data links such as those used in TV remote controls, wireless computer peripherals and remote fan/light controls, use a Light Emitting Diode (LED) or Laser Diode on the transmitter end and a photodetector on the receiver end to form a unidirectional communication link between the controller and the device to be controlled. These infrared links are grouped into two (2) broad types, unmodulated and modulated. In the unmodulated case the light energy at the transmit end is keyed ON and OFF as a direct representation of the incoming data bit stream; for example, ON for a bit HIGH and OFF for a bit LOW. This is referred to as On/Off keying, or OOK. OOK is a form of Amplitude Shift Keying (ASK). At the receive end a photodetector is followed by a simple level detector. This mode of operation is simple and inexpensive, but has inferior performance in terms of range and freedom from interference as compared to modulated schemes. A modulated system at the transmit end will key a carrier frequency (typically 38 KHz) ON and OFF, which is then used to blink an LED or Laser Diode. Light is transmitted as bursts of many cycles of the carrier frequency that represent (for example) the data bit HIGH state, followed by no light transmission for the data bit LOW state. The receiver after the photodetector is tuned to the carrier frequency, which serves to decrease broadband noise and reject various forms of interference such as that from 60 Hz room lighting and direct sunlight. Some data links do not use a carrier frequency, but On/Off key the light beam with a Direct Sequence spreading code imbedded into the data. This is a form of Direct Sequence Spread Spectrum (DSSS) Amplitude Shift Keying (ASK). The spreading code is a pseudo-random sequence, which is typically exclusive-ORed with the data. The receiver is designed to strip off the pseudo-random coding to recover the original data.

Typical Applications

A. TV/VCR Remote Controls - typically use the modulated type as described above. Range may be up to twenty-five (25) feet if line-of-sight exists between transmitter and receiver. If no line-of-sight exists between transmitter and receiver, the range depends on signal reflection from surrounding surfaces.

B. Wireless computer peripherals (wireless printer, wireless mouse and wireless keyboard) typically use no modulation, but the data has an error checking code applied to it to ensure data integrity. These links are designed for desktop computer use at small distances and sometimes use either modulated or unmodulated optical links.

C. Remote fan/light controls – sometimes use either modulated or unmodulated optical links.

D. Some data links employ DSSS ASK. These links are designed for use at small distances (5 to 10 meters).

### 4.3 Sonic Communication Link

A data link is possible using the smoke alarm's piezoelectric horn to signal remote units [6][7]. The horn output would be modulated in a specific coded pattern that would be received and recognized by remote smoke alarms. There would be a large amount of attenuation of the broadcast sound as it passes through interior walls and obstacles, but with a sensitive receiver tuned to the transmitting horn's carrier frequency and keyed to the modulating code sequence this may not be an insurmountable drawback.

Most commercial smoke alarm horns (buzzers) are rated in the area of 85 dB output. The operating frequency is typically 3 KHz, although piezoelectric horns are commonly available operating from 2 KHz to 4 KHz. The frequency is determined in part by practical considerations in the manufacture of the horn unit, and in part because the human ear is relatively sensitive at these frequencies, since the peak of human ear response is at about 4 KHz. Horns are commonly available with up to 106 dB output, but the 85 dB figure will be used as typical for this discussion.

For this application an important consideration is the attenuation of the alarm signal as it penetrates interior walls. For the range of frequencies from 2 to 4 KHz, the typical attenuation passing through one wall is 40 dB. This figure is for a wall with ½" gypsum wallboard on each side of 2" X 4" wall studs on 16" centers, with 2" of fiberglass insulation in the cavity. Passing through two rooms and two walls would then attenuate the signal somewhat more than 80 dB, perhaps 85 dB depending on room furnishings, arrangement of walls, etc. This results in a signal of 0 dB, which is at the lower limit of what the human ear is capable of perceiving, but not below the sensitivity of a properly designed receiver. In any event this is most likely a worst-case scenario, because doors allow significant leakage of sound from room-to-room and interior walls usually do not contain insulation, substantially reducing the 85 dB path loss. The transmission loss of a door depends on many factors, such as the effects of the framework extending from room-to-room and transmission through the door panel, but the space or gap under the door is often the point of greatest leakage. This leakage depends on the ratio between total door area and the area of the gap, and for even a precisely fitted door where the gap represents $1/1000^{th}$ of the door area, the transmission loss is 30 dB. This would be, for example, a 0.08" gap under an 80" tall door. Most residential doors are fitted this precisely, so the 30 dB figure would be a worst-case transmission loss. The path loss then, with doors in each wall, becomes approximately 65 dB, resulting in a 20 dB signal from the starting 85 dB alarm horn transmission level.

For this application the alarm horn could be modulated.

Typical Applications

No known application exists.

### 4.4 Other Wireless Communication Technologies (Protocols or Specifications)

Many communication protocols have been developed to support new and emerging communication technologies by providing specific configuration specifications. This allows manufacturers to build and sell equipment specific to these specifications, for example the IEEE 802.11 (a)(b)&(g) specification for wireless LANs. These specifications have been integrated into many products used to makeup the wireless infrastructures used by industry, government and individuals to transfer information and data and to tie together computers within networks for the purpose of handling data requirements. The complexity, cost and power requirements necessary to support specific protocols negates their use in providing a communication link between battery powered smoke alarms which are central to this effort.

## 4.5 Modulation

Modulation [4] is used to attach information to a carrier frequency and the modulation type selected can be as important as the selected frequency of operation. In harsh and noisy environments, the type of modulation used is specially important in the recovery of the transmitted data by improving the recoverability of the information. The modulation type also affects the receiver design by dictating the receiver bandwidth, gain and detector requirements, so the careful selection of a modulation type can lead to the successful implementation of a communications design. The following details modulation schemes regularly used to implement communications systems. One of these types will most likely be incorporated into this wireless smoke alarm communication design.

### 4.5.1 Amplitude Shift Keying (ASK)

The simplest modulation is ON/OFF keying, or OOK, which is a form of Amplitude Shift Keying (ASK). ASK is realized using simple, inexpensive circuitry and has good range and interference rejection if the data rate is low. Similar to the optical modulation scheme, RF is transmitted as bursts of many cycles of the carrier frequency that represent (for example) the data bit high state, followed by no RF transmission for the data bit low state. The receiver is tuned to the carrier frequency, which serves to decrease broadband noise and reject various forms of interference.

Typical Applications

A. Garage Door Openers typically use ASK modulation with a user-settable code sequence.

B. Automotive keyless entry systems often use ASK modulation. Wireless security systems often use ASK modulation.

C. Remote Fan/Light controls sometimes use ASK modulation.

### 4.5.2 Phase/Frequency Modulation

Another approach is phase or frequency modulation. This type of modulation modifies the carrier frequency by changing its phase or frequency by some amount, in step with the data. The transmitter and receiver are somewhat more complex and costly to implement than for ASK, but this type of modulation is more immune to interference than ASK.

Typical Applications

A. Wireless telephones have used narrow-band frequency modulation and more recently, spread spectrum formats similar to wireless LAN, allowing simultaneous communication of multiple units within a frequency band. Spread spectrum has excellent voice/data security.

B. Satellite data downlinks often use phase shift keying.

### 4.5.3 Combination Phase/FM & AM Modulation

Phase or frequency modulation (FM), and amplitude modulation (AM), are often combined for systems requiring high data rates. Historically phase and amplitude modulations were combined for use in telephone line modems, allowing higher data throughput.

Typical Applications

A. Wireless LANs – sometimes use complex modulation schemes with phase or frequency modulation combined with amplitude modulation to allow high data rates.

B. Telephone line modems.

### 4.5.4 Spread Spectrum

Spread spectrum methods modulate the carrier to "spread" the frequency of the transmitted signal, such that the transmitted signal has a much greater bandwidth than that required by the data being sent. This is commonly done by two methods, one of the most popular being frequency hopping (Frequency Hopping Spread Spectrum, FHSS), where the carrier is shifted between various frequencies in a pseudo-random pattern. A receiver that "knows" the correct pattern can synchronize to the hop pattern, but other receivers only receive noise. Another popular method used is direct sequence, (Direct Sequence Spread Spectrum, DSSS), where the carrier phase is inverted in time with a pseudo-random pattern. Once again, a receiver that has the correct pattern can synchronize and demodulate the signal, but other receivers only get noise. Because of the unique nature of the encoding pattern spread spectrum offers excellent data security and it will allow multiple users in a given frequency band because each receiver will only respond to the transmitted signal with matching encoding. Other signals will appear as noise, which does practically limit the total number of signals. Other methods of spread spectrum exist, but the two described, FHSS and DSSS, are specified by the FCC for use in the higher ISM frequency bands, 902–928 MHz, 2400–2483.5 MHz, and 5725–5850 MHz.

Typical Applications

A. Many modern cellular telephones use spread spectrum, allowing simultaneous communication of multiple units within the same frequency band. Spread spectrum communications have excellent voice/data security. Telephony is usually FHSS.

B. Wireless local area networks (LANs) and RF data links commonly use spread spectrum, either FHSS or DSSS.

## 4.6 Evaluation of Modulation Types for use in Smoke Alarms

*Modulation types commonly used with each communication technology type:*

Optical Communication

1. Unmodulated ASK/OOK
2. Modulated Carrier ASK/OOK
3. Direct Sequence Spread Spectrum

RF Communication

1. ASK/OOK
2. FSK
3. PSK
4. Hybrid Modulations; AM – PSK, etc.
5. Spread Spectrum
   a. Frequency Hopping (FHSS)
   b. Direct Sequence (DSSS)

Sonic Communication

1. ASK/OOK
2. FSK
3. PSK
4. Hybrid Modulations; AM – PSK, etc.
5. Spread Spectrum
   a. Frequency Hopping (FHSS)
   b. Direct Sequence (DSSS)

### 4.6.1 Modulation Types Pros and Cons

Amplitude Shift Keying (ASK)

Pros

Inexpensive and small circuitry, although the circuitry will most likely be slightly more expensive than an optical solution. Can be made "micro-power" by gating the receiver on for a small duty cycle. Relatively short design time using integrated (single chip) solutions.

Cons

Potentially susceptible to radiated interference unless bandwidth is small (low data rate) and a coded signal is used.

Phase/Frequency Modulation

Pros

Less susceptible to radiated interference at higher data rates as compared to ASK modulation.

Cons

More complicated and expensive than ASK modulation to implement. Longer design time.

Combination Phase/FM & AM Modulation

Pros

Allows higher data rates than AM or FM techniques alone in a limited bandwidth.

Cons

Much more complicated and expensive than ASK. The design time is much greater than for ASK modulation. Consumes more power than ASK modulation.

Spread Spectrum

Pros

Excellent data security, excellent utilization of limited bandwidth in multi-user situations, has excellent rejection of radiated interference.

Cons

Much more complicated and expensive to implement than ASK modulation. Design time much greater than for ASK modulation. Because of extra circuitry and time required for receiver to "Sync up", consumes considerably more power than ASK modulation.

### 4.7 Evaluation of Wireless Communication Types

As presented above, each communication type has its advantages and disadvantages, some are much more robust than others, while others have limitations that disqualify there use here. However, the application with its limitations must be the final determinant in selecting an appropriate communication type to facilitate a good and favorable demonstration. Many of the communication types support more capabilities than are justified due to the limited power resources available and the low communication and data rates needed for this application. It will be easy to eliminate potential communication types because they exhibit flaws that can't be tolerated in this application, such as optical communications links with their line-of-sight requirements are not suitable for this application due to the operational requirement to communicate through two (2) walls. Even reflected light would have a problem with this requirement. Other wireless communication technologies, specifically the communication protocols should also be eliminated due to the complexity, power requirements and costs of equipment and components. Using the protocols would deliver a \$300 to \$400 wireless smoke alarm. The sonic communication link using a smoke alarm's horn as the transmitter and a narrow band receiver should be considered due to its simplicity, low cost and ability to be quickly implemented. RF provides many and the best implementation choices due to the availability of transmitter and receiver "chips" which could be used to implement RF communications links at many frequencies using several different modulation schemes.

***Acceptable operational trade-offs for wireless communication***

A. The electronics must be as simple as possible, and small enough to fit within a standard smoke alarm housing in addition to the smoke detection circuitry.

B. Power consumption must be low enough for battery operation using a relatively inexpensive, compact battery, preferably a commercially available standard 9-volt battery.

C. The antenna must be small enough to be contained within the envelope of a standard smoke alarm. The antenna should be reasonably omnidirectional.

D. The receiver must be immune to common types of radiated interference found in the home and office: cellular telephones, microwave ovens, appliance remote controls, computer and computer monitors to name a few.

E. The effective communication range between alarms must be over 50 feet through any common types of intervening walls.

F. The receiver must be end-user settable such that it will only respond to the correct transmitter.

## 5.0 RECOMMENDATIONS

### *Low Cost Battery Choices*

Based on the characteristics of each battery technology and the requirements for a Wireless Smoke Alarm, the following 9V battery types are recommended, in order of preference:

A. Lithium Thionyl Chloride.
B. Lithium Manganese Dioxide
C. Alkaline Manganese Dioxide Zinc, extended life Titanium.
D. Alkaline Manganese Dioxide Zinc

Consideration was given to Amp-Hour capacity, Shelf Life, consumer availability of 9V size and overall life-of-product cost. Because secondary batteries have poor shelf life and there will be no facility for recharging, the batteries given are all primary, non-rechargeable types. If ten-year battery life is required, only the first two types should be considered. The second, Lithium Manganese Dioxide, is widely available wherever 9V batteries are sold. The first, Lithium Thionyl Chloride, is an emerging technology for consumer applications, but at least one manufacturer is currently producing consumer 9V batteries: LS C 9V and LS 9V. At the time of writing these were available at numerous outlets on the Internet. The Thionyl Chloride version of the Lithium cell offers a slightly greater amp-hour rating and a somewhat better self-discharge characteristic than the more common Lithium Manganese Dioxide type, especially above room temperature.

### *Wireless Communication Technology Choices*

Based on the characteristics of each wireless technology considered and the requirement for a Wireless Smoke Alarm, it is recommended that the Sonic communications approach and one of the Radio Frequency (RF) communications approaches below be implemented for demonstration. The approaches are listed in order of preference:

A. Sonic communication using OOK, ASK, FSK or PSK modulation.

***And one of the following;***

B. RF communication using OOK/ASK modulation.

C. RF communication using FSK or PSK modulation.

If proven feasible, the Sonic link will most likely be the cheapest to produce as well as consuming the least battery power during standby. The main question with this technology is the ability to reliably penetrate intervening walls. The RF OOK/ASK link is relatively inexpensive, available in integrated circuit form, offers good rejection of interference if an encoded data stream is used, and offers adequate range using legally permitted transmitted power levels, perhaps 100 feet or more depending on environment. RF FSK or PSK have essentially the same features as OOK/ASK, but will be somewhat more expensive, offer somewhat more rejection of interference, and require more complicated circuitry. To conserve battery power during standby, any RF technology will require the receiver to operate in a timed, low duty-cycle mode, periodically "waking up" to listen for the alarm signal. This will introduce a variable latency into the remote alarming, up to the OFF time of the receiver. A suitable compromise between battery life and latency will need to be achieved. There is the possibility of designing micro-power circuitry for the Sonic link because of the low frequencies involved, so it may not need a duty-cycle powered receiver, reducing circuit complexity and eliminating latency.

## 6.0 ACKNOWLEDGEMENTS

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## 7.0 REFERENCES


1. National Fire Protection Association (NFPA) "NFPA 101 Life Safety Code" 2000 Edition, February 11, 2000.

2. Underwriters Laboratories (UL) "UL217 Single and Multiple Station Smoke Alarms, Section 63, Battery Tests."

3. "Basic Modulation Principals" Prompt Publications, Irving Gottlieb, Author 1999.

4. "Wireless Communications *Principles and Practice*", Second Edition, Pearson Education, Theodore S. Rappaport, Author, No Publishing Date Found.

5. Federal Communications Commission, "Code of Federal Regulations (CFR), 47 CFR Part 15, Subpart C - Intentional Radiators", 1 October 1990.

6. Audio Engineering Handbook, K Blair Benson Editor. McGraw Hill Book Company, ISBN 0-07-004777-4.

7. Theory and Problems of Acoustics, By William W. Seto. Schaum's Outline Series, McGraw Hill Book Company, ISBN 07-056328-4.


## 8.0 DEFINITIONS Of ABBREVIATIONS

| | |
|---|---|
| AM | Amplitude Modulation |
| ANSI | American National Standards Institute |
| ASK | Amplitude Shift Keying |
| CPSC | US Consumer Product Safety Commission |
| DSSS | Direct Sequence Spread Spectrum |
| FCC | Federal Communications Commission |
| FHSS | Frequency Hopping Spread Spectrum |
| FM | Frequency Modulation |
| FSK | Frequency Shift Key |
| ISM | Industrial, Scientific and Medical |
| LAN | Local Area Network |
| LED | Light Emitting Diode |
| NFPA | National Fire Protection Association |
| OOK | ON/OFF Keying |
| PSK | Phase Shift Keying |
| RF | Radio Frequency |
| UHF | Ultra High Frequency |
| UL | Underwriters Laboratories |