Investigating the Utility of Global Positioning System (GPS) Technology to Mitigate the Carbon Monoxide (CO) Hazard Associated with Portable Generators – Proof of Concept Demonstration

June 2013

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EXECUTIVE SUMMARY

The CPSC Directorate for Engineering Sciences' Division of Combustion and Fire Sciences (ESFS) staff has conducted a limited, exploratory exercise to demonstrate the feasibility of using Global Positioning System (GPS) technology to distinguish indoor and outdoor environments, with the intent of shutting down portable generator operation when a generator is used indoors. Through a series of experiments, ESFS staff demonstrated that a modified, off-the-shelf, commercially available GPS receiver unit, with a staff-developed electromechanical shutoff system installed on a portable generator, can distinguish indoor and outdoor environments and shut off the generator accordingly, with the exception of a dense tree cover scenario.

If ultimately proven effective and reliable, this technology may not suffice as a sole carbon monoxide (CO) mitigation technology because it does not protect against all generator use scenarios that pose a CO poisoning risk. To protect against CO poisoning resulting from outdoor operation near an opening into a home, as well as to minimize CO accumulation from a generator operating indoors before the GPS receiver/shutdown system can shut it off, additional technology would be needed to reduce the generator's engine CO emission rate. As noted in Reference [1], page 5, deaths have occurred when generators were operating outside the home, near open windows, doors, or vents. CO emission reduction is CPSC staff's primary strategy to reduce the generator CO poisoning hazard; and staff has demonstrated that current emission control technology adapted onto a prototype generator is effective in greatly reducing portable generator CO emissions in generator indoor use scenarios that are commonly fatal. The high CO emission rate of current generator designs can rapidly create an unsafe exposure in the space where the generator is operating, as well as in adjoining spaces. Implementation of a shutoff strategy, without requiring a reduced CO emission rate, can create a hazardous CO exposure if the generator runs for even a brief period of time before indoor operation is detected. Therefore, CPSC staff views a GPS receiver shutoff strategy as a supplemental means of further reducing the risk of CO poisoning [1].

The issue of dense tree cover requires further exploration by GPS technology experts. ESFS staff believes that the challenge posed by the scenarios in this study that involved dense trees can be met as GPS receiver technology continues to evolve and become more sophisticated. However, ESFS staff recommends that the appropriate experts in the GPS/radio frequency (RF) engineering community explore the issue of dense tree cover or any additional situational limitations, as they influence this unique engineering challenge.

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BACKGROUND

In support of the CPSC Portable Generator Rulemaking activity, ESFS staff explored the application of GPS technology to differentiate between indoor and outdoor portable generator operation. The goal was to determine if existing GPS receiver-based technology could be used to sense when a generator is operating in an enclosed location, and then, in combination with an electromechanical shutoff system, shut off the generator to prevent continued unsafe operation and mitigate the carbon monoxide (CO) hazard.

The scope of portable generators examined for this study is limited to a class of internal combustion engine-driven generators rated at 15 kW (20 hp) or less, 250 V or less, which contain receptacle outlets for alternating current (AC) output circuits. Marine generators, recreational vehicle generators, and stationary generators are excluded from the scope [4]. Portable generators generally are equipped with wheels for ease of transport. The stated class of portable generators also comes in smaller sizes, where those generators are equipped with handles for hand carrying.

This investigation was conducted to perform the following: (1) determine if there is utility in pursuing this GPS receiver strategy, and if initial field tests with a modified GPS system proved hopeful, (2) develop a prototype shutoff system with the ability to sense that a generator is running indoors and to shut the generator down. This exploratory exercise was <u>not</u> intended to demonstrate every possibility/scenario; it was strictly limited to documenting the concept's utility. CO emission tests were not conducted; nor was there an attempt to analyze the time needed to shut down the generator.

If ultimately proven effective and reliable, this technology may not suffice as a sole CO mitigation technology because it does not protect against all generator use scenarios that pose a CO poisoning risk. To protect against CO poisoning resulting from outdoor operation near an opening into a home, as well as to minimize CO accumulation from a generator operating indoors before the GPS receiver/shutdown system can shut it off, additional technology would be needed to reduce the generator's engine CO emission rate. As noted in Reference [1], page 5, deaths have occurred when generators were operating outside the home, near open windows, doors, or vents. CO emission reduction is CPSC staff's primary strategy to reduce the generator CO poisoning hazard; and staff has demonstrated that current emission control technology adapted onto a prototype generator is effective in greatly reducing portable generator CO emissions in generator indoor use scenarios that are commonly fatal. The high CO emission rate of current generator designs can rapidly create an unsafe exposure in the space where the generator is operating, as well as in adjoining spaces. Implementation of a shutoff strategy, without requiring a reduced CO emission rate, can create a hazardous CO exposure if the generator runs for even a brief period of time before indoor operation is detected. Therefore, CPSC staff views a GPS receiver shutoff strategy as a supplemental means of further reducing the risk of CO poisoning [1].

CPSC staff has explored another shutoff system alternative. CPSC staff contracted work to the University of Alabama (UA) to develop a shutoff system onto a prototype generator using sensors such as intake air temperature and manifold air pressure and an algorithm to detect and shutdown the generator, as described in Reference [1], Tab G. The UA approach differs substantially from the GPS receiver approach. The GPS receiver approach, as discussed in this paper, presents another supplemental alternative to the UA shutoff strategy.

THE CONCEPT

GPS receiver technology is ubiquitous, portable, and relatively inexpensive. Generally, GPS receiver units do not function properly indoors because the indoor structures attenuate the satellite signals the unit uses to identify its location. When this happens, some GPS receiver units activate a visual "Poor Satellite Reception" display to alert the user. ESFS staff hypothesized that it may be possible to exploit this feature and evaluated a commercially available GPS receiver unit in a variety of indoor and outdoor settings to investigate the capability to discriminate between indoor and outdoor operation. The degree of satellite signal attenuation will vary from receiver unit to receiver unit.

ESFS staff anticipates that certain use scenarios will present challenges and that the GPS-receiver based concept will have limitations. Notwithstanding the above, ESFS staff believes that the GPS receiver technology may prove useful as an adjunct to CO emission reduction technologies to extend protection into enclosed spaces. Therefore, the use of GPS receiver technology merits investigation.

The graphic below shows how GPS receiver technology can be integrated into a portable generator to detect indoor operation and shut down the generator. The concept is rather simple: once the GPS receiver cannot track the required number of satellites (from which one can infer that the generator may be operating indoors), an actuation circuit will disable the engine from running. Otherwise, the indoor-outdoor detection system concludes that the generator is running outdoors and the generator will run as intended.

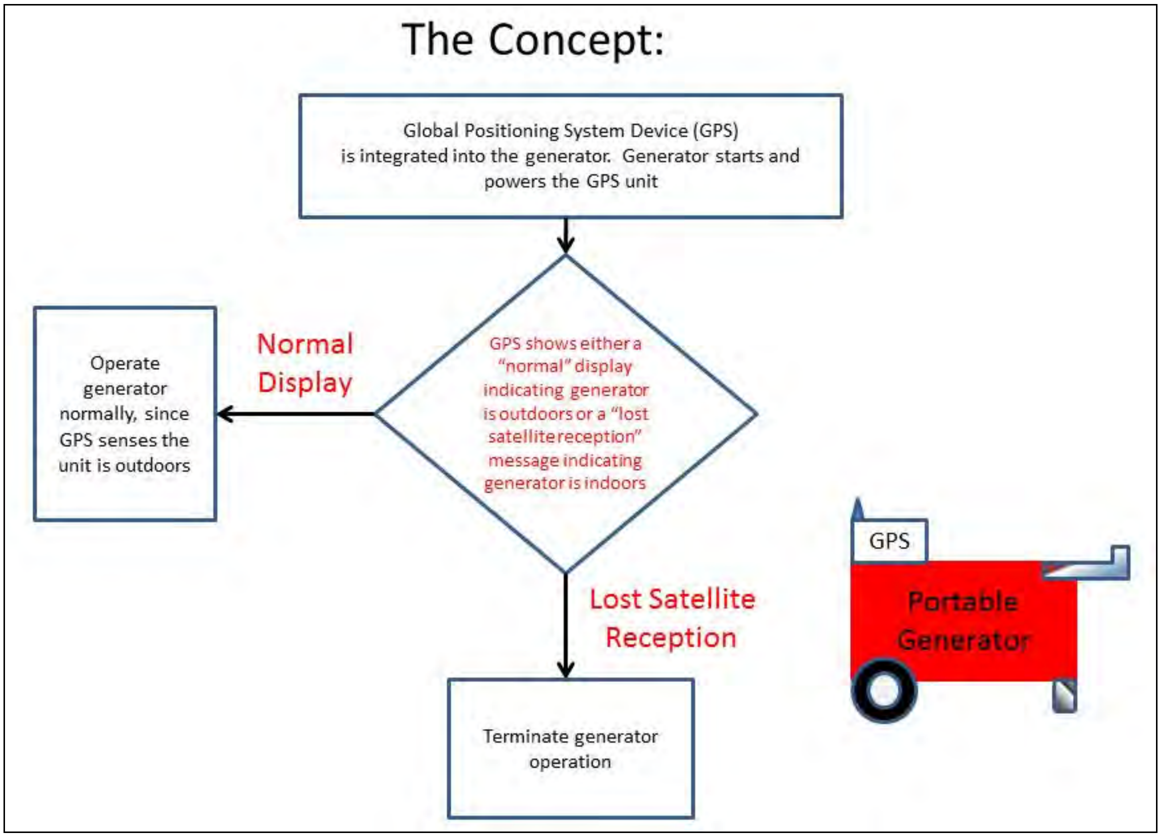

Figure 1 - Concept of GPS-Based Generator Shutdown System

IMPLEMENTATION

The Candidate GPS Receiver Unit

The worldwide GPS uses a system of 24 satellites that orbit the earth twice a day sending data to earth. A GPS signal contains three components of information–a pseudorandom code, time data, and date data. These components of information identify the satellite, its current status, date, and time, as well as pinpoint where it is located at any given time.

ESFS staff initially evaluated two GPS receiver units that were commercially available. ESFS staff compared the relative strengths of a 2005 GPS receiver and a 1998 receiver selected by ESFS staff for the exploratory exercise. The 2005 GPS unit, without an external antenna, was readily able to receive clear reception in every room of a detached, single family home. ESFS staff acquired a 1998 model GPS receiver equipped with an external antenna that could be modified to obtain the optimal "balance" to discriminate between indoor and outdoor environments.

The 1998 GPS receiver used in this study must continuously receive signals from at least three satellites to calculate the GPS receiver's location and track the receiver's movement [2]. At times, additional satellites may be needed to determine its location. The GPS receiver can only process radio signals from satellites that are above the horizon and provide adequate radio signal strength to the GPS receiver's antenna. Once the GPS receiver is initialized to a location, it will compute a position in a few minutes. Shortly after the 1998 GPS receiver is turned on, a flashing triangle with a question mark first appears, indicating that it is locating the required satellites to determine its location. After several minutes, the GPS receiver will either display its location, complete with longitudinal, latitudinal, and elevation coordinates, or display an error message, depending on whether the GPS receiver unit has adequate reception.

The GPS receiver requires an unobstructed view of the sky for optimal performance because GPS satellite signals are generally weak and cannot travel through rock materials, metal, or heavy tree cover. If the GPS receiver does not detect the required number of satellite signals, it will display the error message, "Poor Satellite Reception" [2].

To improve the receiver's ability to discriminate between indoor and outdoor locations, it was necessary to make the receiver less sensitive to satellite reception. ESFS staff chose to use the receiver intact as a "black box," rather than attempt to modify the proprietary internal components of the 1998 GPS receiver unit. Using the above approach greatly simplified concept evaluation. For example, if a new method or adjustment was made to attenuate the GPS receiver signal by partially shielding the antenna, the only output for evaluation was either the presence or absence of an error signal on the GPS receiver's screen displaying "Poor Satellite Reception."

Various signal attenuation approaches using metal shields on the receiver's antenna were evaluated: mesh steel wire cage, aluminum foil, and copper tubing. The above three materials are known for attenuating radio frequency signals. A fixed length of copper tubing gave promising results during the initial screening evaluations and was chosen as a shield.

As mentioned in the background section, there may be instances where the location, nearby structures, and terrain, for example, may impede the reception of satellite radio frequency signals. To understand some of these effects, ESFS staff evaluated the 1998 GPS receiver unit in various homes and surrounding spaces, such as the front yard and back yard.

According to the owner's manual [2], the 1998 GPS receiver unit determines in approximately 5 minutes whether the required number of satellites is not detected. If the appropriate number of satellites is not detected, the unit displays a "Poor Satellite Reception" message. The decision time of 5 minutes *is particular to this 1998 receiver*, and a shutoff system could be designed to make the decision more quickly. However, it would be at the risk of shutting the generator down while it is properly being operated outdoors. Deaths have occurred where generators were operated outdoors, near the home, near open windows, doors, or vents [1]. This tradeoff would have to be carefully considered because the utility of a generator and, possibly, acceptance of the GPS receiver controlled shutoff system by the consumer could be negatively impacted by a system that shuts the generator off when used properly outdoors.

A section of copper tube was used to reduce the sensitivity of the 1998 GPS receiver antenna strength to obtain the optimum balance of “strong enough to detect outdoors” and “weak enough not to detect indoors.” While the copper tube was a somewhat better alternative to aluminum foil or mesh steel wire cage, the copper tubing had limitations. ESFS staff tried several lengths of tubing to fine-tune the amount of attenuation. Various evaluations were done using 17 mm and 15 mm long copper tubes. As noted previously, the only output for evaluation was either the presence or absence of an error signal on the GPS receiver’s screen displaying “Poor Satellite Reception.” After conducting many trials in various indoor and outdoor environments, such as an ESFS staff’s house and parks with heavy tree cover, it appeared that the 15 mm copper tube did not provide sufficient shielding. Ultimately, ESFS used the 17 mm copper tube. Further fine-tuning was attempted by positioning the 17 mm copper tube on different locations of the antenna (held in place with a set screw). After several trials (approximately five to six different positions on the antenna), the optimum position was obtained. Figure 2 shows the GPS receiver with the 17 mm copper tube in its optimum position. The GPS receiver shows an error message indicating “Poor Satellite Reception”, as illustrated in the right-side photograph of Figure 2 when the GPS receiver cannot track the required number of satellites. The change in luminosity (from light to dark) in the area inside the “optical sensor target” box (illustrated in Figure 2) is what is detected by the optical sensor to trigger the shutdown function.

Figure 2 - GPS Receiver with External Antenna and Copper Tube for Signal Attenuation; (Left): LCD Screen Does **Not** Show Error Message in this view (Right): LCD Screen Shows Error Message

<u>Preliminary Considerations and Experiments</u>

Stray electromagnetic interference (EMI) can disrupt the proper operation of the GPS-based shutoff circuit. Current GPS designs effectively shield interference from many sources, such as radio and television antennae, garage door operators, and more. One source that may pose a particular challenge for a GPS receiver unit mounted onto a generator is the EMI that is radiated from the alternator in the generator. A few limited evaluations were conducted to gauge if such sources could have an adverse effect (interference) on the GPS receiver’s ability to sense indoor versus outdoor environments.

ESFS staff deemed that interference did not exist if the "Poor Satellite Reception" error message did not display on the LCD screen when positioned near the alternator of an operating engine. Evaluating for interference was done by tests with the GPS receiver inches away from a parked car alternator and an unloaded[1] portable generator alternator. There did not appear to be interference in these two trials. However, it is unknown whether trials with a generator supplying an electrical load (a configuration that was not tested in this study) may give different results. A third trial consisted of placing a television antenna with a booster amplifier a few inches from the 1998 GPS receiver; again, no interference was observed. Although adverse EMI effects were not observed with this limited testing, further investigation may be needed to determine whether these effects will ever pose a problem.

<u>Generator Shutdown System Demonstration Package</u>

The demonstration system consists of three main components: the GPS receiver, the photo sensor activation circuit, and a portable generator. The generator, which was used in emissions testing for the CPSC staff study in reference [1], is hereafter referred to as "SO1" (short for shutoff generator 1). While the GPS receiver determined indoor or outdoor status, an actuation system was developed by Engineering Sciences, Division of Electrical Engineering (ESEE) staff that would interface the generator to the GPS receiver. A circuit that would recognize a change in state from normal GPS receiver operation (with satellite reception) to poor satellite reception was developed. This circuit was not integrated into the actual GPS receiver unit; rather a separate external circuit box was constructed. An error message that appears on the LCD screen was the trigger source. A relatively simple circuit was employed to sense the "Poor Satellite Reception" error signal on the GPS receiver's screen and deactivate the generator as shown schematically in Figure 3. Figure 4 shows the fully assembled physical circuit layout.

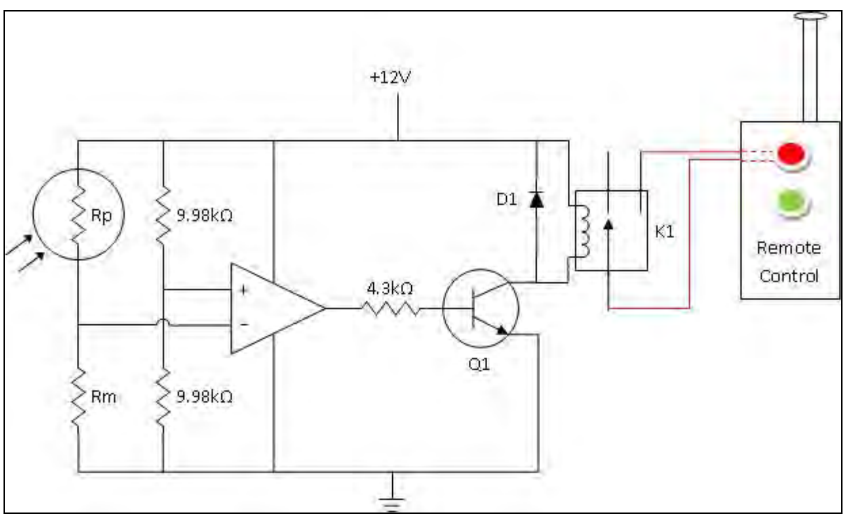

Figure 3 - Schematic Diagram for Photo Sensor Activation Circuit for Shutdown System

[1] An electrical receptacle panel was not connected to the generator, so the generator was not electrically loaded, although the alternator was being energized.

The SO1 prototype generator already had a remote engine shutoff switch installed, and it was activated by a remote controller. This feature was used quite often for the testing conducted at the National Institute for Standards and Technology (NIST) [1] to shut off the generator safely using the remote control feature. ESEE staff decided to make use of this existing generator shutoff feature. Figure 5 shows the components that comprise the shutdown system: modified GPS receiver, actuation circuit box, and remote controller.

The photo resistor, Rp, senses the change in the brightness of the LCD panel when the "Poor Satellite Reception" message is displayed. This signal is sent to the operation amplifier (triangular shaped symbol in Figure 3) turning on transistor Q1, which, in turn, activates relay K1. The relay contacts of K1 were connected to the "lock" button on the remote control, and when activated, the remote control sends a signal to shut off the generator's engine. Shutting off the generator is achieved by grounding the engine's spark plug.

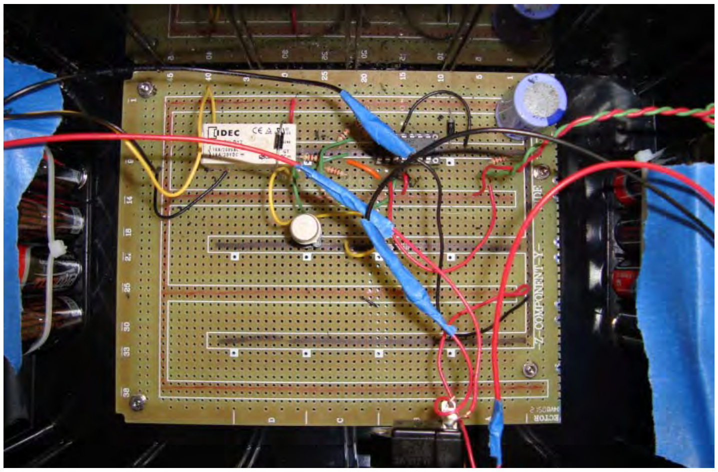

Figure 4 - Top View of Photo Sensor Activation Circuit

Figure 5 - Components of the Shutdown System, from Left to Right: Remote Controller, Photo Sensor Activation Circuit Box, and GPS Receiver

Plan for Evaluation of the Demonstration Package

As mentioned in the background section, the GPS receiver is not immune to external influences. Varying tree cover is a potential issue. ESFS staff investigated to what degree trees may affect the GPS reception of the particular 1998 GPS receiver used in this exploratory exercise. Originally, ESFS planned to test the demonstration system (generator plus shutdown system) in many different indoor and outdoor locations, such as homes, buildings, front yards, and back yards. However, since generator shutdown system depends upon the generation of the "Poor Satellite Reception" message on the GPS receiver's LCD screen, only the GPS receiver was used for these evaluations.

As presented in the results and discussion section, a variety of home types, with and without garages, and with and without basements, were evaluated.

RESULTS AND DISCUSSION

The data and discussions are presented in the chronological order that the evaluations were conducted. The 1998 modified GPS receiver is hereafter referred to as GPS receiver.

Preliminary Test Data

To test the feasibility of using the GPS receiver unit, ESFS staff initially evaluated the effectiveness of the GPS's ability to differentiate indoor and outdoor environments. During these initial steps, the exact locations of the GPS receiver unit (*e.g.*, middle of the room, near a window) were not noted. While these exact locations are important, ESFS staff conducted these limited, estimated experiments to determine if the GPS's ability to differentiate indoor and outdoor environments would work. Table 1 below shows the results.

The evaluations, as indicated in Table 1, led to further investigation of the feasibility of using GPS receiver technology for differentiating indoor and outdoor environments. The data shown in Table 1 did not specify particular locations in the various rooms, but rather, they were merely collected to determine if further study should commence. Therefore, a detailed evaluation was conducted on more homes, and the GPS receiver was placed in a variety of specific locations (see Tables 2 and 3). The office building indicated in Table 1 is CPSC's National Product Testing and Evaluation Center (NPTEC), 5 Research Place, Rockville, Maryland 20850.

Table 1 – Preliminary Data from Two Homes and a CPSC Office Building

Location	Room	Does the GPS Receiver Get Satellite Reception Using the Modified Antenna?
Single Family Home with 2-Car Garage	office room	NO
	2-car garage, near garage door	NO
	2-car garage, near back wall	NO
	Basement	NO
	back yard deck	YES
	front yard	YES
Single Family Home with 1-Car Garage	living room	NO
	1-car garage	NO
	2nd floor bedroom	NO
	sunroom	NO
	back yard deck	YES
	front yard	YES
CPSC Office Building (NPTEC)	cubicle	NO
	parking lot	YES

<u>Test Data from Seven Indoor and Outdoor Environments</u>

Seven homes of CPSC Engineering Sciences and Laboratory Sciences personnel were evaluated to help characterize the reception qualities of the selected GPS receiver. There were a variety of home types, with all but one having garages of various types and one home was a townhome. Homes with garages were of particular interest, as some fatalities occurred when the generators were run in the garage and CO infiltrated into the homes [1]. It should be noted that this list of homes is not intended to represent any particular cross-section of homes in the United States; rather, it is a limited list of homes that were available at the time of this study.

Table 2 – Detailed Evaluation of the Modified 1998 GPS Receiver in Seven Homes

Home	Indoor Detection	Front Yard (Outdoor) Detection	Back Yard (Outdoor) Detection
Single family detached home with 2-car garage (HOME A)	YES	YES	YES
Townhouse with 1-car garage (HOME B)	YES	YES	YES
Single family detached home with 4-car garage (HOME C)	YES	NO*	YES
Single family detached home with 1-car garage (HOME D)	YES	YES	YES
Single family, one level detached home with detached garage (2-car garage) (HOME E)	YES	YES	YES
Single family detached home with 1-car garage (HOME F)	YES	YES	NO*
Single family, detached one-level home, no garage (HOME G)	YES	NO*	NO*

* GPS receiver failed to properly detect outdoor status, possibly due to dense tree canopies. However, the following observations were made:
HOME C detected outdoor status in the back yard 18 ft from the sunroom
HOME F detected outdoor status 9 ft from the front yard stoop
HOME G detected outdoor status 27 ft from front yard stoop [side walk], which is not considered part of homeowner's property
<u>Additional notes</u>:
One-level homes were indicated as such. Other homes listed either had a full second floor or split-level foyer type of second level.

Table 3 – Specific Areas of the Seven Homes That Were Evaluated

Indoor Rooms Tested:	garage, basement, bedrooms, living room, kitchen, sunroom/enclosed porch, dining room – all near windows to maximize the opportunity for the GPS receiver to obtain satellite signals
Outdoor Areas Tested:	decks, open grassy fields, varying distances from the front yard stoop

For indoor detection, a "YES" indicates that the GPS receiver generated a "Poor Satellite Reception" error message, which means that the GPS receiver correctly sensed indoor status. For outdoor detection, a "YES" indicates that the GPS receiver was able to obtain its location coordinates and did not generate an error signal, which means the GPS receiver correctly detected outdoor status. For outdoor detection, a "NO" indicates that the "Poor Satellite Reception" error signal appeared which means the GPS receiver incorrectly detected indoor status. As the data tables show, the GPS receiver unit did not have any problems detecting indoor status. However, the 1998 modified GPS receiver had difficulty detecting outdoor areas in three homes with dense tree cover. See Figure 6.

In contrast, homes with fewer trees did not exhibit problems obtaining a clear satellite signal outdoors. See Figure 7.

Figure 6 – Three homes that had difficulty receiving a satellite signal outdoors; left (Single family, detached one-level home, no garage); middle (4-car garage home–only had difficulty in the front yard); and right (1-car garage home–only had difficulty in the back yard).

Figure 7 – Three homes that did not have difficulty receiving a satellite signal outdoors; left (townhouse); middle (1-car garage home); and right (2-car garage home).

ESFS staff observed that if the GPS receiver was located where a roof-type structure was over it, even a clear, tempered glass sunroom (of Home C) provided sufficient shielding to detect that the GPS receiver was located indoors. One caveat to this observation is that it is not clear whether the indoor detection was due solely to the glass ceiling, or if surrounding trees or other obstructions played a role.

<u>Verification of the Shutdown System Functionality</u>

ESFS and ESEE staff verified the physical functionality of the shutdown system after installing the GPS receiver-photo sensor activation shutdown system onto the SO1 generator. This verification was independent of the indoor and outdoor GPS receiver evaluations. Using the GPS receiver-based shutdown circuit, ESFS and ESEE staff demonstrated successful shutdown of a generator within 2 minutes after having started the engine. This demonstration was conducted in the all-terrain vehicle (ATV) laboratory at NPTEC. All safety checks were conducted prior to running the verification, such as securing the generator to the floor and connecting the engine exhaust pipe to the exhaust snorkel. Figure 8 shows the generator fitted with the shutdown system. The successful shutdown system operation was captured on video.

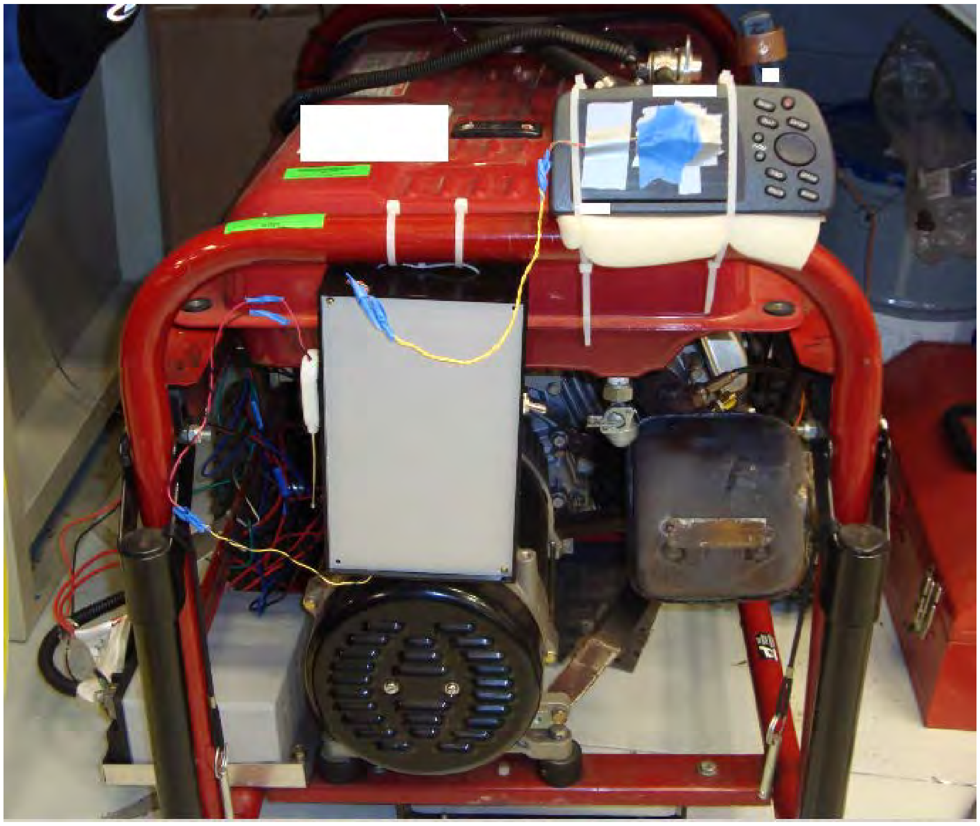

Figure 8 - Shutdown System Fitted onto SO1 Generator at NPTEC

Testing at NIST Test Home

While evaluations of the seven houses provide a rough sketch of how the GPS receiver performed in those scenarios, ESFS staff also evaluated the GPS receiver at the National Institute for Standards and Technology (NIST) test home (Building 423 - NIST Indoor Air Quality House, see Figures 9 and 10). This building was designed for testing indoor air quality of a single story home. This test home is furnished like a residential home complete with bedrooms, bathrooms, fireplace, window curtains, kitchen appliances, such as a range, and the building has been used for a multitude of indoor air quality related projects, including recent emission testing programs for the Prototype Generator testing [1].

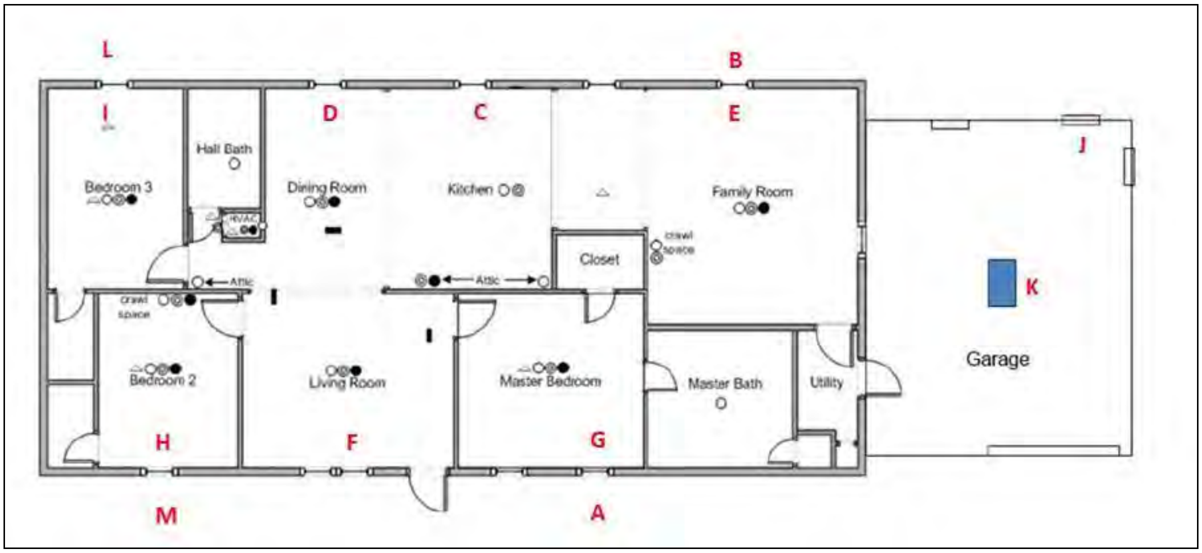

Figure 9 - Floor Plan of NIST Indoor Air Quality Building 423


Figure 10 – Aerial View of NIST Building 423

Table 4 – GPS Receiver Evaluations Conducted at NIST Indoor Air Quality House Building 423, July 23, 2012

INDOORS	
Room	Approximate Times (MM:SS) for "Poor Satellite Reception" Error Message to Display
Location K* – Middle of the Garage	5:13
Location J** – Window of the Garage	1:48 // 1:52 // 1:48 // 5:05 // 1:56
Family Room	1:42
Kitchen	1:09
Dining Room	1:34
Living Room	1:55
Master Bedroom	1:54
Bedroom 2	1:30
Bedroom 3	5:30
OUTDOORS	
Location	Approximate Times (MM:SS) for Indicating GPS Acquired All Necessary Satellites
Location A* – Grass field 15 ft from window	1:58
Location B* – Grass field 15 ft from window	3:09
Location L* – Grass field 15 ft from window	3:12
Location M* – Grass field 15 ft from window	1:42
NOTES: * Refer to the specific lettered locations in Figure 9 ** Since the garage area was of interest and with time permitting at the NIST facility, five trials were conducted at Location J	

The results in Table 4 show that the GPS receiver unit was capable of distinguishing indoor from outdoor environments. The "indoor" times in Table 4 represent the time from the moment the GPS receiver unit was powered on, to when the "Poor Satellite Reception" error message appeared. The "outdoor" times represent the time from the moment the GPS unit is powered on, to indicating that the GPS receiver has acquired the minimum number of satellites for proper operation. The GPS receiver then displays its exact location, complete with longitude, latitude, and elevation coordinates. When the GPS receiver unit is powered on, a triangle with a question mark flashes continuously until either a location is determined or an error occurs ("Poor Satellite Reception" message appears). One caveat is that Building 423 had only a few surrounding trees. The perimeter of the building has grassy fields and open spaces.

ESFS staff observed that, on occasion, the GPS required somewhat longer times to detect the indoor environment status.[2] This observation regarding longer times is believed to be

[2] The times were approximate, as the staff's reaction times to the start and stop events were performed with an electronic stopwatch.

due to the complicated attenuation of the GPS radio signal from the satellites because of the interaction of varying terrain, tree cover, building materials, building structure, and location within the building, among other variables. The above-mentioned factors make GPS shutdown time challenging to predict.

It is necessary to keep in mind that the GPS receiver was treated like a "black box," and staff was only monitoring the output (error "Poor Satellite Reception" signal or no error signal). Also, the selected GPS receiver unit was manufactured in the 1998 timeframe, and there have been many improvements and refinements in GPS circuitry and software since then. Additionally, the shutdown times are somewhat irrelevant because GPS technology is evolving. These times only reflect how <u>this particular</u> GPS receiver performed, and they are not necessarily indicative of how a future GPS receiver, designed specifically for the generator shutdown feature, could function. However, it was more important to discover whether the GPS receiver was capable of correctly identifying whether it was operating indoors or outdoors.

The demonstration supplements the work performed on the reduced-CO generator by University of Alabama (UA), and it is not in place of the UA work. ESFS staff recommends that GPS technology experts and generator manufacturers creatively explore the feasibility of possible solutions (on the indoor-outdoor detection aspect).

<u>**POSSIBLE FUTURE PROTOTYPE**</u>

ESFS staff envisions an efficient "black box" that uses GPS receiver technology with a specifically designed antenna (internal or external) to detect indoor or outdoor status only. This simple detection scenario means that there is no need for populating maps, generating complex algorithms to log routes, or any of the other auxiliary computation-demanding tasks found in common consumer GPS receivers, thereby, minimizing demands on the chip processing power, circuit complexity, and costs. These design parameters would enable the ease of a GPS receiver-based shutdown solution for integration into the generator.

A true production model would have a fully integrated design. GPS receiver circuitry could be housed safely in a weather-resistant enclosure, with only the antenna exposed; or, the manufacturer could opt to design an internal antenna. It should also be designed to be tamper-resistant so that a consumer is unlikely to defeat this safety feature. This safety feature could be used in conjunction with mandatory labeling/packaging to the effect: "This product will not operate indoors." This feature may actually help consumers heed the warning: "do not use indoors." Depending on how the power configuration is designed, the GPS receiver unit could be powered by a battery or super capacitor that is internal to, and charged by, the alternator. The options are limitless, but quite achievable, given the ubiquitous nature of GPS receiver technology found in everyday electronics, such as cellular phones and tablet computers.

Looking ahead, CPSC staff envisions a robust test method that will ensure the shutoff system performance has the following characteristics: (a) produce repeatable performance in the variety of indoor environments that generators have been reported to be operated in; (b) tamperproof (the generator will not start if the shut off system has been removed or bypassed); (c) durable after prolonged exposure to a generator's typical storage and operating environments; and (d) features a fail-safe mechanism (prevents the generator from starting) when the shutoff system is not functioning for some reason or its battery/supercapacitor is discharged or does not sustain charge.

CONCLUSION

ESFS staff has conducted a limited, exploratory exercise to demonstrate the feasibility of using GPS receiver technology to distinguish indoor and outdoor environments, with the intent of shutting down portable generator operation when used indoors. ESFS staff demonstrated that a modified off-the-shelf, commercially available GPS receiver unit can distinguish indoor and outdoor environments, with some exceptions where there were dense tree cover scenarios. The issue of dense tree cover requires further exploration by GPS technology experts. The above scenarios can be addressed as the GPS receiver technology continues to evolve and become more sophisticated.

ACKNOWLEDGEMENTS

Don Switzer (ESFS) provided oversight and his breadth of knowledge to help facilitate this exploratory exercise. Mark Gill (ESEE) developed the photo sensor activation circuit system and was instrumental in demonstrating the concept of this exploratory exercise.

The author thanks the numerous staff who have contributed and provided support:

CPSC Staff:
Patricia Adair, Director for Division of Combustion and Fire Sciences (ESFS)
Janet Buyer, ESFS, Project Manager for Portable Generators
Susan Bathalon, Directorate for Hazard Identification and Reduction (EXHR)
Brian Baker, Laboratory Sciences staff for his assistance in the ATV laboratory
Stephen Patterson, Laboratory Sciences staff for fabricating the GPS receiver antenna modification components
Andrew Trotta, Director for Division of Electrical Engineering (ESEE)
CPSC staff who have volunteered their homes for the various GPS experiments

NIST Staff:
Steve Emmerich (Energy and Environment Division, Engineering Laboratory)
Dan Greb (Energy and Environment Division, Engineering Laboratory)

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