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ISDU: integrated smoke detector unit for commercial microwave ovens

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ISDU

Integrated Smoke Detector Unit
For Commercial Microwave Ovens

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April 17, 2007

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1. Abstract

We suggest that smoke detection devices be integrated into range ovens and microwaves, the leading causes of domestic structure fires. There have been various detectors made for microwave ovens, but none have been implemented to detect smoke. Our design will work on the principles that when smoke is detected during microwave operation, the device will temporarily disable microwave operation and let the user know that the food has begun to smoke or even burn.

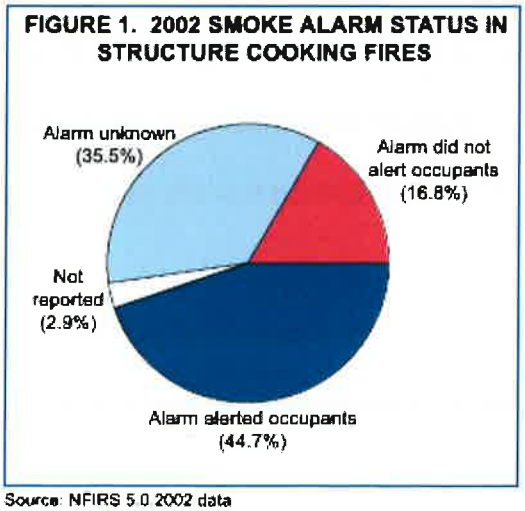
The product, Integrated Smoke Detection Unit (ISDU) for commercial microwave ovens, will work in the following way. The presence of particulate during cooking will trigger our device thus sounding an alarm and halting microwave operations. To allow for flexibility during cooking we will implement a user-adjustable sensitivity control. During our research we have discovered only one patent referring to this concept, however, that patent has since lapsed due to non-payment of maintenance fees.

In our implementation we considered several optional features including integration into infrastructure security systems as well as possible inclusion into the future digital home concept. Our design fits well with the digital home concept because it offers the user full remote access to information and control over the microwave.

We have spoken with numerous consumers of different backgrounds about this subject and in every case all of them agreed with the necessity of the design as well as a curiosity to why this is yet to be produced. Therefore, it is clear that this design will be easily marketable to the general public as an additional safeguard against fires occurring in the kitchen due to user negligence.

2. Introduction

According to a report published by the United States Fire Administration's National Fire Data Center in August of 2005, "cooking is the leading cause of fires and fire injuries in structures." These occurrences comprise about 36% of all reported fires; more than double any other causes. The report based its findings on the 2002 statistics as they were available from NFIRS (National Fire Incident Reporting System) data. Among the data from the NFIRS in 2002 alone, cooking fires caused approximately 185,600 fires in structures, 80 deaths, 3,875 injuries and $481 million in property damage [1]. It was also found that over 80% of cooking fires occurred in residential structures where food was neglected or forgotten. The report also looked into the causes of the fires within residential structures and they found that range ovens and microwaves together accounted for 76% of the equipment at fault. The NFDC report also investigated the relationship between the existence and functionality of smoke alarms in the homes where fires were reported. They found that an alarm was operational and alerted the occupants in only 45% of the incidents [1] as seen below in Figure 1.



Though these numbers are disturbing, a solution is being developed. We suggest that smoke detection devices be integrated into range ovens and microwaves, the leading causes of domestic structure fires. This will ensure that whether or not detectors are present and functioning properly in the kitchen, occupants are alerted in the event of a fire during cooking. Due to the scope of this design project and the time constraints, we have decided to invest our time and effort towards integrating a smoke detection device into a microwave. Based on our findings, we suggest that the same is done with range ovens in the future. We have spoke with numerous consumers of different backgrounds about this subject and in every case all of them agreed with the necessity of the design as well as a curiosity to why this is yet to be produced. We have attempted to contact leading microwave manufacturers to ascertain why this concept has yet to be put into production, however, after extensive attempts no responses were returned.

We intend to not only integrate a smoke detection device but to add a user-friendly feature that will allow the user to change the sensitivity of the detection device depending on what is being cooked. It is known that cooking foods that include oils and sugars generate more non-threatening smoke than other foods and would trigger a standard detection device, thus an adjustable sensitivity control is needed. One design for a detection circuit in a microwave was found during our research, but the patent has since expired due to non-payment of maintenance fees [2]. After extensive patent research using the federal government's patent search site, http://patft.uspto.gov, we were able to determine that this endeavor has yet to be completely undertaken.

Currently the designs of newer microwaves have gone in the direction of integrating steam detection for the purposes of "One Touch" cooking. Using preset buttons a consumer can cook various types of food with the detection circuit in the microwave determining when the

food is properly cooked by the amount of humidity inside the microwave chamber [3]. However, steam detection is not used when the user sets the cooking time manually and it may work improperly if the user selects an incorrect preset button. As a result, consumers may walk away from the microwave believing they have set the correct settings and that their food will be done correctly when they hear the classic microwave 'ding'. This is where problems arise and fires can occur. With the introduction of a smoke detection circuit inside the microwave the consumer will be alerted, by a louder more intense alarm, that they have overcooked their food or that there is another cause of smoke inside the microwave. This alarm will not only save the consumer from having to purchase a new microwave, but could save their home and their life.

Through this design we will also include suggestions for possible future integrations. One suggestion is that this design be incorporated into large apartment buildings where fire alarm networks exist and are able to alert the building's fire detection system. In addition this would alert the local fire department if a serious problem occurs. Also, as the concept of the digital home slowly becomes a reality, this is a design that could easily be incorporated into such a system. As is stated later in this report, using the AC power lines as communication lines would allow for the consumer to monitor the status of food in the microwave, or more importantly the oven, from other rooms in the house where they have computer access.

Once this design is brought to reality and ready for production, we anticipate that the increased estimated cost of $10 per unit will not be a significant decision factor for consumers when purchasing a microwave. It is a feature that is easily marketable as a way to protect the homes and family members of consumers, especially ones where there are young children who may not know how to properly operate a microwave. What will follow in this proposal are the details of how we intend to bring this design to a reality.

2.1. *Previous Work*

Although there has been no physical model has been built for implementation of a smoke detector in a microwave, there has been some interest in detecting particles, such as water vapor and other particulates, during the microwaving process. Additionally there is a patent on a microwave smoke detector, but the patent expired on February 20, 2004 because the originator of the patent failed to pay the renewal fees. We attempted to contact the originators of the patent to determine why the patent was not maintained or pursued, however, after extensive attempts no responses were returned. The lack of maintenance has allowed the idea to become open to the public.

There have been various detectors made for microwave ovens, but none have been implemented to detect smoke. One detector that has been implemented in various microwaves is the steam detector. Usually under the name "Sensor Cook", it has been implemented by many manufacturers such as Samsung [4]. Currently it is in production in most microwaves that are available in most stores such as Wal-Mart and Sears. This sensor monitors the humidity by measuring dew-point, absolute humidity or relative humidity during the microwaving process and will usually adjust cooking time accordingly [3]. This technology is used in various auto-cook features that are found in many microwaves today to aid in the microwaving of foods such as soup, pasta, and popcorn [5]. While it does sense steam coming off of the food, it fails to detect the solid particulates in smoke since the steam detector only detects gaseous state particles. The other problem is that this method of detection only occurs when the auto cooking functions are in use. This means that consumers will be unprotected in the event that they do not use the auto cooking functions.

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While there is no smoke detection implementation, there have been a few methods for monitoring hazards in microwaves. All microwaves are required to have a double stage thermal cutoff. This is essentially a heat detector for the magnetron. If the magnetron overheats, a soft breaker interrupts the power. If a fire occurs, a thermal cutoff permanently disables the microwave. Every microwave has a thermal failsafe system that must be implemented.

One device that has similar problems to the microwave is the range oven. While the method of cooking is different to that of a microwave, it is similar in the fact that the cooking in either leads to byproducts such as smoke and steam. While not currently in production, a smoke detector in the oven seems to have implementation in the works. [6] shows a design for a smoke detector implementation for use in the self cleaning cycle in an oven. While smoke is a definite effect of the self cleaning process in an oven, the potential danger is high since the oven may try to burn off left over fats and oils from meats, which can cause a fire.

2.2. Integration

When smoke is detected during microwave operation, the device will turn off the microwave and let the user know that the food has begun to smoke or even burn. To do this, we plan to have the smoke detector powered by the integrated low-voltage power supply. Once smoke is detected, we will send a signal that lets a circuit interrupt the power to the microwave through the use of a 'soft' power-off function already in use by the microwave logic. This will stop the microwave while simultaneously sounding an alarm. After the alert, the user will be able to reset the microwave, change its sensitivity, or stop microwaving.

Since some foods, mainly liquids and foods with fats and oil, will smoke during microwaving, it is clear that the detector must be of variable sensitivity. As a result, the decision to add a digital dynamically variable adjustment to the detector will be included. By

adjusting a digital display located on the microwave, the user will be able to adjust the sensitivity of the smoke detector to different levels for various foods. Thus the user can prevent the microwave from shutting off if the food being microwaved might emit a fair amount of smoke without actually over cooking the food. If the food begins to trigger a false alarm, the user will also be able to change the sensitivity level while microwaving because the sensitivity adjustment is dynamic. This option will assist in the reduction of false alarms. The change of sensitivity will occur via "+" or "–" buttons that are located somewhere on the microwave. We plan to use a bar graph display located somewhere on the microwave to display the sensitivity level. If the alarm is tripped while microwaving not only will there be an audible alarm, but the LCD will display an error message that lets the user know the microwave has shut off.

The detection method itself can be done in two ways: software or hardware. With software, the detection can be done with a simple algorithm that compares the amount of smoke received to an assigned value. This code will determine, through hardware, what the level is and decide whether or not it will shut off the microwave's power or not. The problem with this, however, is that it will only add to cost since investments in extra ROM chips would have to be made as well as extra parts that the code would write too such as a logic controlled relay. Another more favorable approach is to use the hardware method. With hardware, we intend to have some threshold that the detector must pass in order to have the alarm go off. This threshold, which is weighed against a value through the use of a comparator, will be able to be changed when the sensitivity adjustments have occurred.

3. Design Specification

The product, ISDU for commercial microwave ovens, will work in the following way. As food within the microwave is heated past the smoking point, the particulate released into the

air will be transferred to a secondary housing, via a small fan, containing the smoke detection unit. Using an opto-electric sensor, smoke particulate above a certain threshold density value will create an output function which will be translated into an error prompt and temporarily suspend normal microwave functions. The threshold value will be set by the user and adjustable at any time, both prior to and during operation. Acknowledgement of the alarm condition will require user intervention and normal microwave functions will not be restored until such a time.

A number of considerations arise in relation to the design of an integrated smoke detection and alarm unit. Of greatest concern is the user's ability to estimate the level of sensitivity necessary for food preparation without generating excessive false alarm conditions. To adjust for this problem, the design will incorporate a default sensitivity threshold chosen by cross-sectioning smoke-points versus normal cooking techniques and time. The sensitivity value will reset to the default state with the completion of cooking or the intervention of the alarm. The default threshold will provide ample smoke detection with minimal false alarms. Another concern inherent in the design of this system is the propensity of the smoke detector towards false alarms. Because a photoelectric detector is more prone to isolated particulate triggering, measures must be taken to ensure triggering only when an alarm is merited. To prevent such singular responses, the time averaged output signal from the smoke detector can be evaluated and used to output an alarm trigger only in the event of true danger to the user.

Triggering the smoke detector will output a number of alarm conditions to alert the user. The alarm state will consist of a suspension of normal microwave functions including the cessation of magnetron operation, a visual alert to be displayed on the integrated microwave LCD, and an audible alert. The latter two prompts will repeat at specified intervals to continuously alert the user to the alarm state and do so until such a time as steps are taken to

acknowledge the situation. Acknowledgement of the alarm state will reinstate all normal microwave functions and reset the smoke detector circuit for further use.

Visually, the entire design will be self contained and hidden within the microwave except for the potential sensitivity adjustment device that may be mounted exterior to the main compartment. Because of the limited amount of space available within the microwave housing, smaller solid state components have been chosen rather than larger, higher rated components (e.g. electromechanical motion relays). This substitution should have a negligible affect on the circuit as high wattage switching is not necessary for the design approach. Additionally, power consumption for the entire device is estimated to be low. Power will be drawn from the low voltage power supply integrated into the microwave. Should power consumption exceed available power for the circuitry, an additional low voltage power supply will be installed and integrated into the input AC source.

4. Task Breakdown and Technical Approach

4.1. Smoke Detector Design

Smoke is primarily composed of carbon dioxide, water vapor, and particulates — very small particles of matter suspended in air. Depending on the source being burned a number of other elements can be found in smoke and the particulate matter varies. The other elements that can be found in smoke are carbon monoxide, hydrocarbons and other organic compounds, nitrogen oxides, and trace minerals [7] to name a few. There are two core systems designed for detecting evidence of smoke as a means of fire alarms. These two detectors are commonly known as ionization and photoelectric smoke detectors.

As the name suggests, an ionization detector works on the principle of the ionization of chemical elements present in the air. The source for the ionization is a small amount of a radioactive element known as Americium-241. The presence of Americium-241 is very small, approximately 200 micrograms, or about 0.9 microcurie. A curie is a unit of measurement for nuclear materials which undergoes 37 trillion nuclear transformations per second [8]. The radioactive element Americium-241 has a half-life of 432 years and is a good source of alpha particles [8]. Since the radioactive material is in very small quantity and only releases alpha particles, it is relatively safe. The only potential danger Americum-241 presents in this small dose, is direct contact with skin or if it were to be inhaled. The alpha particles released by the Americium-241 are the source of ionization of chemicals in the air. The ionization chamber of the smoke detector consists of two metal plates of opposite charge via a battery source, and the radioactive material Americium-241 as can be seen below in Figure 2.

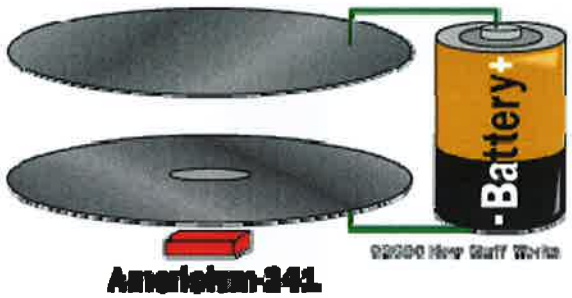

Figure 2

As the alpha particles come radiating out of the Americium-241 they collide with the oxygen and nitrogen atoms in the air inside the chamber. This collision knocks off an electron, thus ionizing the atoms and producing a free electron and a positively charged ion. The free electron is attracted to the positively charged plate, and the positively charge ion is attracted to

the negatively charged plate. This generates a small amount of current that is measured in the detection process. As smoke enters the ionization chamber, the particulates in the air attract the ions and neutralize them. This creates a disturbance in the current due to a decrease in free electrons and positively charged ions. If the current fluctuates past the circuit's set threshold value, a signal will be generated in order to sound an alarm.

A photoelectric smoke detector works on the principle of light variations caused by smoke. The basic design of a photoelectric smoke detector consist of a light source, usually an infrared (IR) light emitting diode (LED), and a light receiver. The light receiver is usually an IR phototransistor. The IR LED and phototransistor are enclosed in a non-reflective casing with two different arrangements. One arrangement is set so that the beam of light from the LED is perpendicular—or offset to avoid direct light contact—to the placement of the phototransistor (see Figure 3). This is to take advantage of the light scatter caused by the particulates in the air.

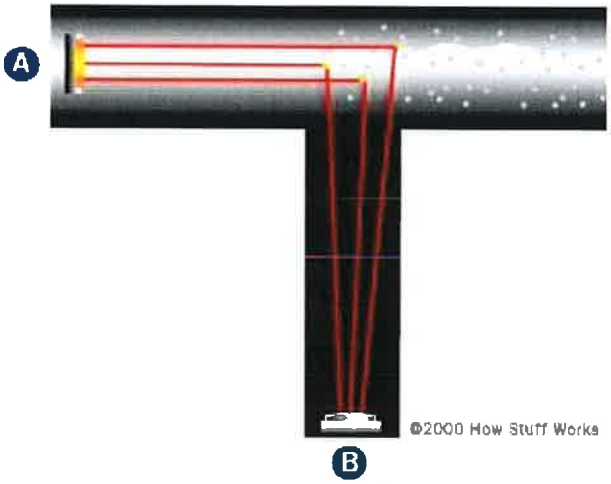

Figure 3

The other arrangement is such that the IR LED is pointed directly at the phototransistor. This arrangement takes advantage of the decrease in light caused by smoke interference. As smoke enters the enclosed chamber, the phototransistor will detect the increase or decrease of light

caused by the smoke particulates. An increase or decrease of the light level to the transistor will increase or decrease the current respectively. This change in current is compared to a set threshold value to determine if an alarm should be triggered. If the threshold is reached, an alarm signal is generated and the smoke detectors alarm is triggered.

Each smoke detector type, ionization and photoelectric, has advantages and disadvantages in their implementations. In controlled experiments, ionization alarms react earlier than photoelectric alarms in fast-flaming fires, such as those involving paper or flammable liquids, while photoelectric alarms tend to react substantially earlier than ionization alarms in smoldering fires, such as those ignited by cigarettes in upholstered furniture, bedding materials, and mattresses [9]. Ionization smoke detectors also use Americium-241. Although it is deemed to be a safe amount of Americium-241, handling a damaged ionization detector can be harmful to ones health. In most microwave fires, the contents smolder before igniting. With this knowledge, and avoiding the handling of radioactive materials, we have decided to implement a photoelectric smoke detector into our design.

Within the system design of photoelectric smoke detectors, there are a few different implementations. The two main designs we will discuss are a system of one light versus two light detectors placed within the detection chamber. In addition to the single light detector system, the configuration of the placement of the light detector to the light emitter can be varied to provide slightly different operation; as discussed earlier. Each of these designs has its own advantages and disadvantages. When the position of the light receiver is placed perpendicular to the emitted light beam, the function is to detect scattering light from particulates in the air. Two main types of particulates can exist in the air during a microwave cooking procedure, water vapor, and particulates from smoke. The water vapor particulates do not scatter light as well as

the more dense opaque smoke particulates. Because of this, an offset light receiver will have a higher light detection when smoke is in the chamber than if water vapor was present. The counter to this arrangement is the direct light receiver, which will have a higher light detection with water vapor and a lower light detection with smoke. Because of the difference between water vapor and smoke particulates, a system of two light receivers provides a more precise and more flexible system for the detection of water vapor or smoke particulates.

The two light detector design incorporates both arrangements of the single light detector design within its enclosure. Thus, one light detector for direct light radiation and one light detector for scattered light radiation. When smoke or water vapor enters the enclosure, the direct light radiation received by the first receiver is decreased, while the scattered radiation received by the second receiver is increased. The output signals from both receivers will change in opposite directions (i.e. one signal will go more positive, while the other will go more negative). To take advantage of this, the signal-processing circuit is preferably designed to generate a signal constituting the difference between a signal derived from the first receiver and a signal derived from the second receiver [2]. Emission of smoke and water vapor during a microwave heating procedure is a dynamic process and the useful information resides in the signal change rather than the absolute signal magnitude [2]. The signal-processing circuit is therefore designed first to differentiate the output of the two receivers and then subtract the two differentiated signals from each other. This difference signal reduces the occurrence of false alarms and is used as an alarm signal. According to [2] "there is a considerable difference, in magnitude and time characteristics, between the signal variations caused by smoke emission and those caused by vapor emission. The signal variations caused by smoke emission are much larger than those caused by water vapor. It is therefore possible to discriminate between smoke and water vapor

by imposing different requirements on the magnitude and the time derivatives of the signal variations." [2] This discrimination provides a level of expandability and flexibility within the system.

In our initial research we determined that a dual light detector design would be more beneficial based on the advantages achieved from a differential circuit design [12, 13]. Advantages that included: Common Mode signal noise rejection, and signal amplification without extra hardware components. After experimentation and testing of such a design, it was determined that our initial assumptions about the particular signal were wrong. Because of this and a time constraint on design plans, we chose a single detector design which resulted in a cleaner and more efficient design that achieves the same, if not a better result.

The concept of the two light detector design originated from patent research [2]. In this particular patent, which has been expired for sometime now, the author(s) detail a dual light detector design for a smoke detector. Their design places a single light emitting diode (LED) inside a chamber with two equivalent light detectors. One detector is placed directly in line of sight of the LED and the other detector is orthogonal. When smoke enters the chamber, the smoke particulate will block light from the direct facing detector and scatter light into the offset detector, thus creating a drop in signal in one detector and a raise in signal in the other detector. We assumed that the implied purpose of such a circuit is to allow the drop in signal to increase negatively, and the raise in signal to increase positively, and after some filtering and amplification of both signals independently, the negative signal would be subtracted from the positive signal and a larger over all signal would result. This filtering, amplification and subtraction are called out in the patent.

The advantage of a differential design lies in equal and opposite signals. When two signals are generated from a single source excitation and equal and opposite signals are generated, these signals can be subtracted from each other to produce an amplified signal without common mode noise. The amplification of the signal is a gain of 2, and the common mode noise refers to the inherent noise that occurs in each independent signal, but yet is equal in amplitude. Because of this property of the common mode noise, the subtraction of the two signals cancels out the common noise factor. The problem with a differential design in the case of a smoke chamber is that there is no way to guarantee equal and opposite signals. This can be easily realized in answering the question of how would equal and opposite signals be achieved? Assuming perfectly equal detectors where the same response curves are given for every photon of light present or absent on the detector, then to insure equal and opposite signals every photon of light that is blocked from one detector must be scattered with equal intensity to the other detector. We also assume that one detector can be biased with a negative voltage supply to generate a negative voltage response or a perfect voltage inversion can be created. This is a very exact and structured requirement, and smoke particulate floating in the air and light scattering is more of a random process than a deterministic one. Thus there is no easy way, if one at all, to insure equal and opposite signals in such an environment. Furthermore in experimentation and testing of particular LED's (QEC122 and QED123) and light detectors (QSD123, OP593A, QSE114, QSC114, OP550C) we where never able to achieve equal and opposite signals in a no smoke environment much less a smoke environment. The problem is that the direct sensor is completely saturated with light and smoke induced in the chamber has little effect on blocking enough photons to bring the sensor out of such a saturated state.

Our initial design with dual detectors assumes that in a clean chamber (i.e. no smoke present) the signal from each detector is zero. When smoke enters the chamber the signal of the direct facing detector will drop towards the negative and the offset facing detector will rise towards the positive. These apposing signals are fed through a differential amplifier because it is not necessarily the raw voltage level of the sensors that matter but the change or the time derivative of each signal. This allows a faster detection response. As smoke enters the chamber at a high rate the signal will change quickly and the response of the differential will be large. If smoke enters more slowly the signal will not change as quickly, but will generate a sharp enough curve to give a decent output from the amplifier. However, as stated before obtaining equal and opposite raw signals is nearly impossible and expecting equal and opposite signals out of a differential amplifier is even more challenging.

We are not proving or stating that such a design called out in the patent is impossible. However due to it's more complex design and rigorous requirements combined with our designing time window, we chose to go with a more simple design using only one indirect light detector fed into a differential amplifier and further into an inverting amplifier. In testing and experimentation such a design produced signal responses that meet our needs.

The output signal from the amplifier is then fed into a comparator to determine if an alarm signal should be generated. For the purpose of later system functionality, we have chosen to produce a digital alarm signal that will be passed on and handled appropriately. Everything before the aforementioned comparator will be analog in nature. The functionality of a digital system is easier to manipulate, and this aspect of the system will be discussed later.

4.2. Sensitivity

Our decision has been to offer the user the ability to adjust the sensitivity of the smoke detector within the microwave. This functionality will offer a chance for the user to control the amount of smoke detected inside of the microwave. The control can be handled one of two ways, analog or digital.

4.2.1. Analog

Analog designs offer a very precise control of the sensitivity of the smoke detector. The basic set up is to use a potentiometer that would control the resistance into the comparator and thus change the threshold value that the smoke detector signal will evaluate against. These two values, the threshold and the detector's signal, would then be input into a comparator. If the comparator's threshold value is less than the signal from the smoke detector, a signal will set off the alarm. The potentiometer would be connected to a knob marked with values from 1 to 10. When the knob is turned, the resistance will increase or decrease. The control obtained with the analog knob provides a wider range of sensitivity. However, if the system were to be reset, the knob would need to be automatically returned to a default position. This is the main flaw with the analog sensitivity system inside the device.

4.2.2. Digital

The digital control of sensitivity offers the flexibility that the system will need. The digital sensitivity control will consist of two buttons, a plus and a minus, for the adjustment of a sensitivity scale of 1 to 10. When either one of the buttons is pressed, using a set of integrated circuit logic chips, the resistance will be adjusted in accordance to its selected sensitivity. The advantage of a digital design is that when the system is reset after the door opens or a stop/reset

button is pressed, the sensitivity adjustment will have the potential to auto-adjust itself back to its default setting. When the user presses the plus or minus buttons, an up/down counter will add or subtract 1 from the previously stored value. The display will be in the form of a bar graph indicator, which will graphically show what the sensitivity is currently set to. The counter will be wired with 4 outputs to a 4-to-16 bit decoder/demultiplexer (demux). The demux will determine the correct output line based on the outputs received from the counter. Each output will be connected to a network of resistors. For each one of these outputs, there will be a different resistance, which corresponds to different thresholds. This connection will then be compared against the value coming from the smoke detector.

The design that we chose for the sensitivity circuit consisted entirely of digital components. Our decision for a digital design was based on the need for a precise comparability against the smoke signal and an easily implemented reset. The digital system was setup using integrated chips obtained from various companies. Each of these chips were connected to optimize performance and also to be soldered to a PC board for easy integration inside the microwave casing.

The main chip was the counter. Although there were many counters out on the market, the 74AC191 Fairchild Up/Down Counter with Preset and Ripple Clock was chosen for three specific design reasons. First, there was a "Preset" function, which would load a preset value to the 4 outputs when a low signal was sent to its "Preset Load" pin. The second reason it was chosen was the counting functionality that it offered. Thirdly the chip counted to a minimum value of ten. The counter however, did not offer any way to stop from counting past ten. It was a four bit counter, thus it counted from zero to fifteen. This problem was originally solved by integrating the counter with an AND gate IC chip discussed later.

The counter's four bits of output controlled the next stage of our design, the decoding multiplexers. The chip chosen for this portion of the design was the Texas Instruments CD54HC451 High-Speed CMOS Logic 4-to-16-Line Decoder/Demultiplexer with Input Latches. The four bit binary output out of the counter was connected to two of these decoders. One decoder was connected to the LED output, which acted as the visual interface between the user and the counter. The second decoder chip was connected to a resistive network. When the number being sent from the counter was decoded, it chose a predetermined resistance by setting one of its sixteen output pins high. These resistances were initially calculated and tested to find ten different voltage (sensitivity) levels. All these resistances were then connected to a bus line which formed a separate voltage divider for each signal output from the multiplexer. This divided voltage was then sent to the comparator. This chip was chosen because it sent a high signal across the channel that was being decoded instead of a low signal, which is standard for most decoders, and it also only turned on one output at a time.

The user's interaction with the sensitivity adjustment is done with the use of plus and minus buttons. The buttons originally chosen were double pole single throw switches. These switches allowed us to send the correct signals to the counter for the purpose of counting up and down, and to be integrated with the AND gate. The AND gate was used to hold the counter from passing ten. However the switches were poorly designed and caused a large amount of noise to propagate through the circuit. This caused errors in the counting up and down functions. Because of these issues we switched our design to use single pole single throw switches. These switches allowed us to send the correct signals to the counter for correct operation but did not allow us to integrate in our original idea of an AND gate. This was a last minute design trade off for our specific prototype. However in complete integration and production the micro controller that is

already implemented in the microwave would be used instead of the counter that we were basing our prototype design on. This kind of implementation would completely elliminate all noise issues that we experienced.

To create, maintain, and repeat an alarm condition and integrate such prompts into the microwave itself, the design will make use of several stages which are diagramed below in Figure 4.

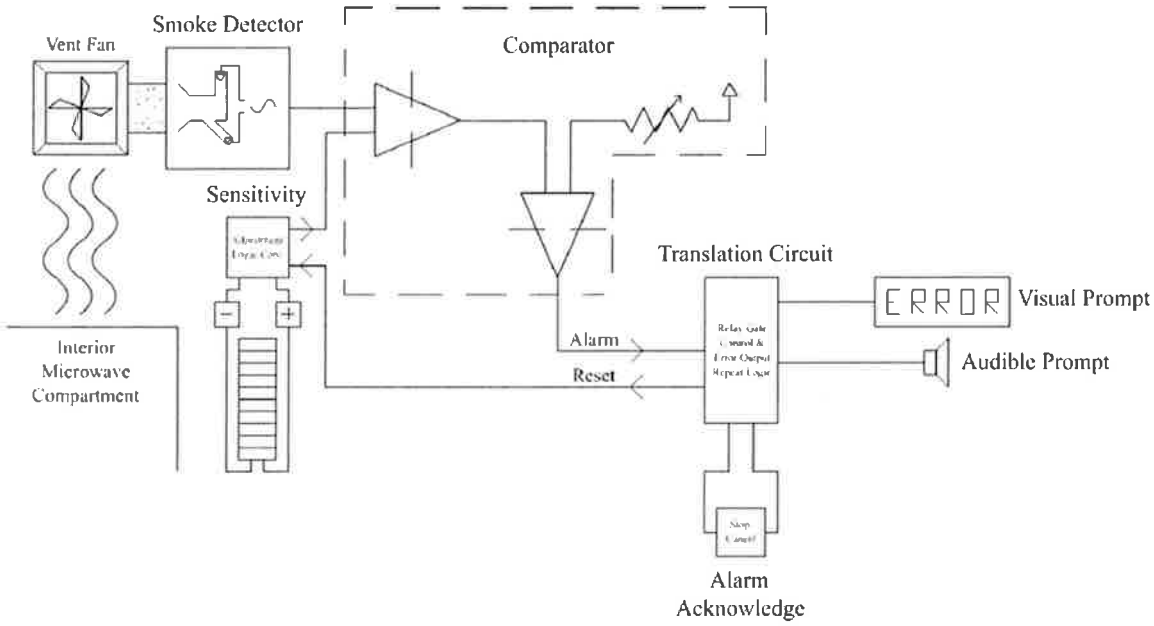

Figure 4

First and foremost will be the smoke detection device that will receive a steady influx of air from the cooking cavity. As discussed, the smoke detection unit operates on the principle of light refraction; therefore any particulate will deflect an optical beam and create an output pulse. Time referencing this output pulse against a set of standard conditions will allow the evaluation of the signal to determine whether an alarm is necessary or not. The variance of the reference threshold will allow for the adjustment of the smoke detector's sensitivity, an important aspect of

the design as well as a preventative measure for instances where smoke would be inherently present.

Sensitivity adjustment will be digitally integrated and will create a reference function which will be compared with the smoke signal to evaluate for alarm conditions. The user interface will be in the form of tactile switches and an ancillary LCD readout. Ideally, sensitivity will automatically reset with the completion of every cook cycle and/or every alarm circumstance.

The verified smoke alarm output signal will then be compared to a designated threshold which will eliminate false alarms due to transient pulses as well as regulate the output voltage to a steady +12VDC. This voltage is vital as it will be the control pulse which activates the alarm prompt and disables microwave function. To allow fine tuning during and after implementation, the comparator circuit will be a simple threshold test of a variable current source versus the signal provided by the smoke detector circuit.

The output pulse of the threshold comparator circuit will trigger the closure of the primary momentary relay. This will suspend the operation of the microwave by triggering the factory designed stop/cancel function. Additionally, this relay will latch a secondary relay providing further error output prompts.

The latching relay will accept two inputs. Primarily, the latch command will be received through the closure of the primary relay. Second, the de-latch command will be provided by the acknowledgement of the alarm state by the user. The output of the latching relay will drive the repeat logic and output prompts.

The repeat logic will consist of an astable oscillator providing time variable output to the integrated LCD and tone transducer. The goal of this system is to alert the user to the smoke

warning and prompt for acknowledgement of the alarm. Of secondary concern is whether acknowledging the alarm will reset the sensitivity adjustment to its default value or if the sensitivity will be statically defined and held as per user discretion. Alarm output will consist of an LCD warning message and an audible alert.

5. Future Uses

5.1. Security System

An idea for future use of this product would be integrating a smoke detection enabled microwave into the security system of a residence. Just as the smoke detectors in homes save millions of dollars a year from possible fire damage, this smoke detector could alert a company such as ADT or Brinks Home Security and, more importantly, the fire department. One problem with connecting it to a home security system would be the sensitivity adjustment. There is a minimum level of smoke that a smoke detector must detect in order to be in proper working order. Adjusting the sensitivity under that level poses a problem. This level is set forth by the National Fire Protection Association. The code states that a smoke detector must be able to detect "0.5- 4.0 % of gray smoke per foot, and 1.5 to 10% of black smoke per foot" [10]. This poses a problem when we wish to adjust sensitivity of smoke detection inside the microwave. The possible resolutions to this problem are to only offer the option of the smoke detector alerting the security service if the percentage is above the recommended value. This would then mean that running the microwave at any other sensitivity below the standard would increase the risk of fire, because it would not meet the correct specifications to be connected to the security system. This raises the issue of having the sensitivity set below the legal percentage. One reason is that a user may want to cook something that will end up smoking, and they have prior

knowledge of this. If they do it's recommended that they watch the cooking process to make sure that excess amounts of smoke or fire do not occur. This could be put into the operator's manual as an important note for operation.

Tying the device into the security system will not be hard. There are two standard wires that connect to the smoke detector and run to the base unit of the security system. Once the smoke detector is triggered it sends a signal to the security system's main box inside the home. From there it would trigger the security system's main office to send out a fire response team. This signal can be sent one of two ways. One option is a wire that must be connected from the microwave to the main system unit or the other option is having data sent over power lines. The latter option leads to the following future consideration.

5.2. Digital Home

With the advent of the computer age, our homes are becoming more wired then our offices. The internet and microelectronics have become normal occurrences in the home. Along with this wave of technology, there is a large amount of research being done to create the digital home. A digital home is an amalgamation of all the utilities in your house, furnace, air conditioning, stove, refrigerator, microwave, etc; all networked together to make the consumer's life easier. Using the idea of the digital home is the next natural progression in technical evolution. Not only would using the digital home allow easy access to the security system, but it also would give the user access to the microwave through a network of computers. One way that this works is over a system called X-10. X-10 was developed in 1975 by Pico Electronics. It "... is a communications "language" that allows compatible products to talk to each other using the existing electrical wiring in the home" [11]. The data is transferred intermittently between pulses in the alternating current (AC) over the existing electrical lines. This allows for data to be

sent to other appliances plugged into the walls as well as, set up a central computer to read these signals. The computer would then give the user access to controlling every appliance and electrical device inside the system.

This system fits in well with the microwave smoke detector concept because it offers the user full access to information and control over the microwave. If the smoke alarm did go off, it would alert the user of the presence of smoke inside the microwave. This data would be sent over a digital home computer network. There are a few systems that are currently being developed that control homes through a central computer system.

One company in the power line communications industry is InTellon. They have created a few products that transfer data over power lines. InTellon offers a faster more efficient way, as opposed to a wireless network or laying network cables around the building, to share broadband, stream HD video, and use VoIP, printer sharing, and security cameras. The product that would best suit our project's needs is the INT6000 HomePlug AV Powerline solution. This chip can be built on a board that would be integrated into the core logic of the microwave. The chip would act just like a network device and would use the power lines as its network cable. On the other end of the power lines would be a separate board that could be inserted inside a computer and would come with Java based software for installation on a server. The Java program would give functionality of starting and stopping the microwave, as well as adding cooking time. The microwave would also send out data across this line and update a timer on the computer as well. The problem with this option is the cost, and amount of work that would be required in building the new board for the microwave.

Another option is a powerline DS-SS Communication Module developed by a small company, SMK, from Japan. This communication module works on the same principles as the

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INT6000 HomePlug AV Powerline, but it has already been integrated into an assembly board. Therefore it's simpler to install in an already existing device. The only problem is the product has not made its way to the US, and may not have been implemented in Japan; whereas, the InTellon products have been tested and are currently being used. The one good thing about the SMK communication module is its use of a standard named ECHONET. This standard was designed to help connect all appliances on a separate power line network rather than a CAT 5 cable based network. The backbone of the ECHONET system connects to central computers of the appliance manufacturers. The manufacturers would be able to sense when products needed service, or a software upgrade. This would make maintenance more easily manageable and less of a hassle for the consumer. Unfortunately these types of additions to appliances take years to develop and lots of money and time to test the devices. Therefore, due to time restrictions we have chosen to not pursue this option at this time.

6. Implementation Issues

One problem we anticipated was noise being emitted during the microwave process. The magnetron produces a 2.4 GHz wave that we thought might interfere with our circuitry as well as having our wires act as unwanted antennas. Under normal circumstances, a simple filter could be used to alleviate this problem, but as [2] states, these conditions are changed by the slightest variation during microwaving. Food that is not placed in the center of the microwave, or different power settings would be examples of variations. The noise we measured tended to be nonlinear in nature. This problem, however, proved to be the least of worries as we moved forward in the project.

The interference from the magnetron was not an issue during steady state operation. Instead, the bigger problem lied in transients. During the beginning of the microwave process, we had

several issues with our sensitivity adjustments; the transients caused by the magnetron forced the reset of our sensitivity. At this time we have not found a direct correlation between magnetron's induced transients and the sensitivity resets. One explanation is that the magnetron's induced transients could cause instability in a portion of our circuit that is involved with keeping track of the sensitivity. Another explanation is that wires connecting different portions of the circuit may have been acting as antennas. The easiest possible issue to rectify was the latter. To alleviate this issue we tried putting a ferrite bead on one of the control signal lines. This proved unhelpful. Due to such a high frequency, we were required to make many turns on the ferrite's core. This resulted in an increased line resistance which in turn periodically disabled our reset function. While troubleshooting line noise we measured a sinusoidal wave on the order of 2 GHz with increasing amplitudes. This line noise equalized during steady state operation. Further investigation must be done to ascertain the exact source of the line noise.

7. Cost and Market Analysis

Due to the simplistic nature of our design the cost of developing our prototype will be low, at approximately $30. A breakdown can be seen in Appendix 1. This breakdown lists the parts required for development and testing. In the event that we require replacements during testing, we will be purchasing two sets of parts. After some research into commercial electronics distributors, we initially estimate that to mass produce this design will add an additional $10 to the current cost of microwaves. This cost estimate is based on quotes from general suppliers of electronic components. Large manufacturers will be able to significantly reduce this additional cost since the components used inside the design are commonly purchased in bulk.

During our research we surveyed approximately 80 homeowners in an attempt to determine what features of a microwave were most important to them. As you can see in the

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graphs in Appendix 3, the most popular responses were the ease of use, features, and, above others, safety. Additionally we asked them if they would be willing to spend more money on a microwave with additional safety features, and if so how much extra they felt was a fair increase. As you can see again in Appendix 3, not only did approximately 80% of those polled say they would spend extra money, but those that indicated that they would spend more responded that they would spend at least $10 or more. Furthermore, 72 of the 80 polled responded that they would purchase a microwave that would prevent food from smoking or catching fire in a microwave. These results clearly indicate that there is a market for our product.

8. Schedule

We were able to begin work on this design immediately. As can be seen in Appendix 2, we set a challenging timeline for ourselves that we were able to successfully complete prior to our deadline. Each name associated with each component indicates the member of the team who is taking lead on that specific component. This does not insinuate that one individual will be working on their assigned component, only that they will be the main contact for the group leader to be in contact with regarding updates and other issues that may arise. Our group was able to work together as a cohesive unit to ensure that everything was completed successfully and efficiently. We had set an ambitious goal of completing our integration by spring break of classes to ensure ample time for testing and completing our final report, as well as compiling our final presentation and as we reported to our adviser, we were able to meet that deadline.

References

[1] Topical Fire Research Series: Structure Cooking Fires, August 2005, Volume 5, Issue 6.

[2] A. Törngren, *Smoke and Vapor Detector for Microwave Oven* US Patent 5493119, Patent and Trademark Office, 1996.

[3] http://humidity-sensors.globalspec.com/LearnMore/Labware_Test_Measurement/Sensing_Measurement_Instruments/Humidity_Measurement

[4] http://www.samsung.com/au/products/microwaveovens/technicalinfo/technicalinfo05.htm

[5] http://www.consumerreports.org/cro/appliances/microwave-ovens/reports/features/important-features/index.htm

[6] A. Kouznetsov, *Self-Cleaning Oven Having Smoke Dtector for Controlling Cleaning Cycle Time*, US Patent 2001/0052853 A1, Patent and Trademark Office, 2001.

[7] http://www.co.missoula.mt.us/envhealth/AirQ/WildFire/Composition%20of%20smoke.pdf

[8] M. Brain, "How Smoke Detectors Work," http://home.howstuffworks.com/smoke.htm

[9] A. Hess, "Smoke Alarms, Photoelectric versus Ionization: The Quest for the Perfect Detection" *Canadian Property Management,* May/June 2000.

[10] NFPA 72 National Fire Alarm Code, Edition 2002, NFPA, July 15 2004, Page 72-189.

[11] http://www.smarthome.com/about_x10.html

[12] Douglas Brooks, "Differential Signals, Rules to Live By"

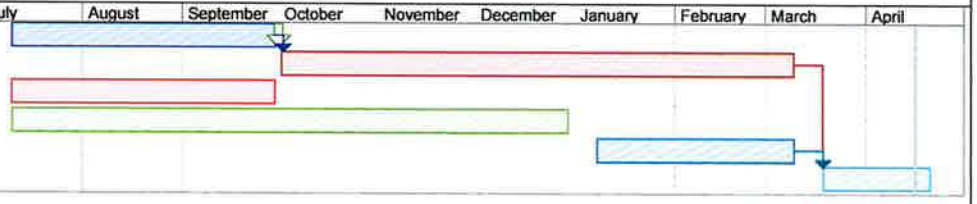
[13] Douglas Brooks. "Differential Signals, The Differential Difference"

Appendix 1

Item Code	Item Description	Qty per Unit	Individual Cost	Cost per 1000		Item Cost	Cost per 1000
QED123	IR LED	1	0.32	0.160		0.32	0.160
QSD123	IR Phototransistor	1	0.32	0.160		0.32	0.160
LM741CN	Op Amp	3	0.29	0.180		0.87	0.540
IN914A	Diode	2	0.01	0.001		0.02	0.002
Misc	Dual PC Board	1	1.79			1.79	
Misc	Chamber	1	2.00			2.00	
	DPST Momentary Sub-miniature EM Relay	4	1.50	0.500		6.00	2.000
	SPDT Latching Sub-miniature EM Relay	1	2.00	0.500		2.00	0.500
	555 Timer	3	0.25	0.010		0.75	0.030
	12V Filtered AC-DC Power Supply	1	6.00			6.00	
	12V Mini Piezo Buzzer	1	1.00			1.00	
	Super Bright Red LED	1	0.35			0.35	
ICL7760S	Voltage Inverter	1	0.97			0.97	
	Quad 2-input AND gate	1	0.37	0.370		0.37	0.370
	Fairchild Fact AC/ACT CMOS Logic Up/Down Counter	1	1.51	1.510		1.51	1.510
	Hi-Spd CMOS 4-16 Ln Decoder/Demultiplexor	2	0.88	0.880		1.76	1.760
	IDC Flat Cable 20 Connectors	1	4.40	4.400		4.40	
	20 Pin onboard Ribbon Connector	1	0.20	0.200		0.20	
Resistors							
82	Ohms	10	0.02	0.002		0.20	0.020
220	Ohms	1	0.02	0.002		0.02	0.002
470	Ohms	1	0.02	0.002		0.02	0.002
1000	Ohms	4	0.02	0.002		0.08	0.008
10000	Ohms	3	0.02	0.002		0.06	0.006
100000	Ohms	1	0.02	0.002		0.02	0.002
Capacitors							
0.01	microfarad 25 V	1	0.05	0.005		0.05	0.005
1	microfarad 25 V	1	0.05	0.005		0.05	0.005
10	microfarad 35 V	3	0.05	0.005		0.15	0.015
100	microfarad 25 V	2	0.05	0.005		0.10	0.010
2200	microfarad 25 V	2	0.05	0.005		0.10	0.010
Totals						$31.48	$7.117

Appendix 2

ID	Task Name	Duration	Start	Finish	Predecessors
1	Design detector circuit	60 days	Mon 7/10/06	Fri 9/29/06	
2	Comparator Component	115 days	Mon 10/2/06	Fri 3/9/07	1
3	Sensitivity Circuit	60 days	Mon 7/10/06	Fri 9/29/06	
4	Translator Circuit	125 days	Mon 7/10/06	Fri 12/29/06	
5	Integration	45 days	Mon 1/8/07	Fri 3/9/07	
6	Testing	25 days	Mon 3/19/07	Fri 4/20/07	5,2



Project: Capstone plan.mpp
Date: Mon 4/16/07

Task | Progress | Summary | External Tasks | Deadline
Split | Milestone | Project Summary | External Milestone

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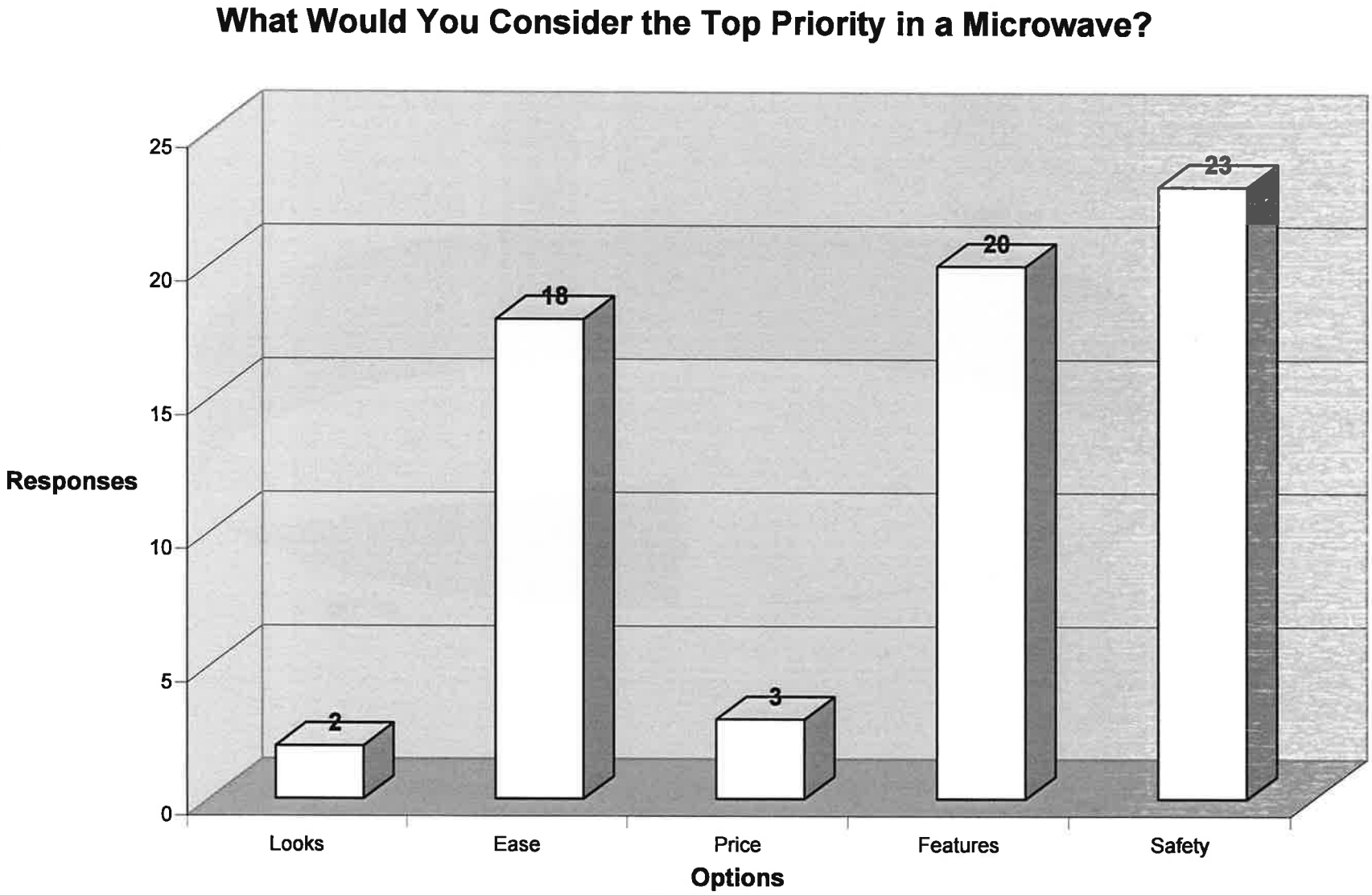
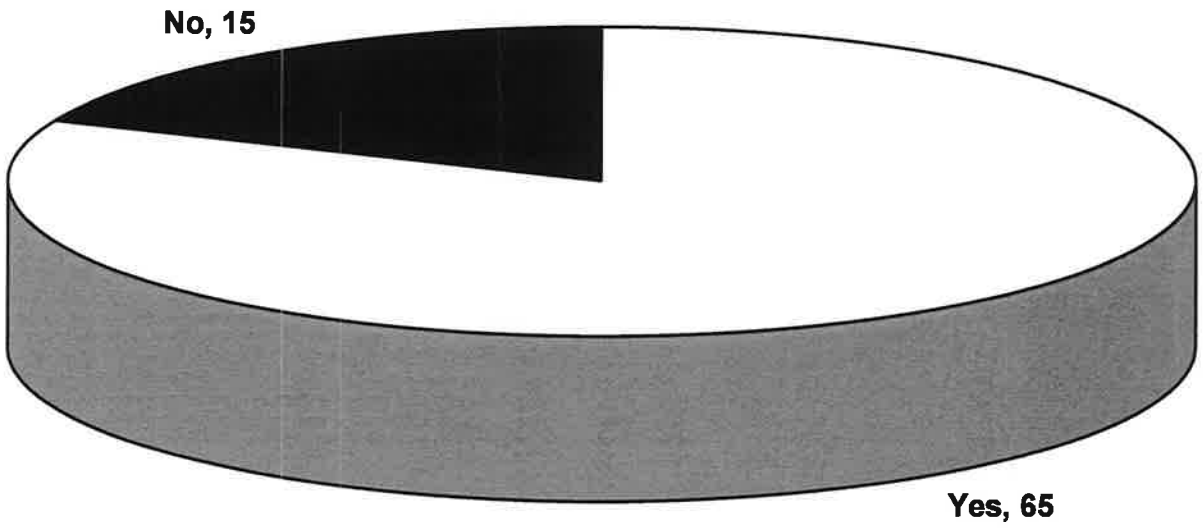
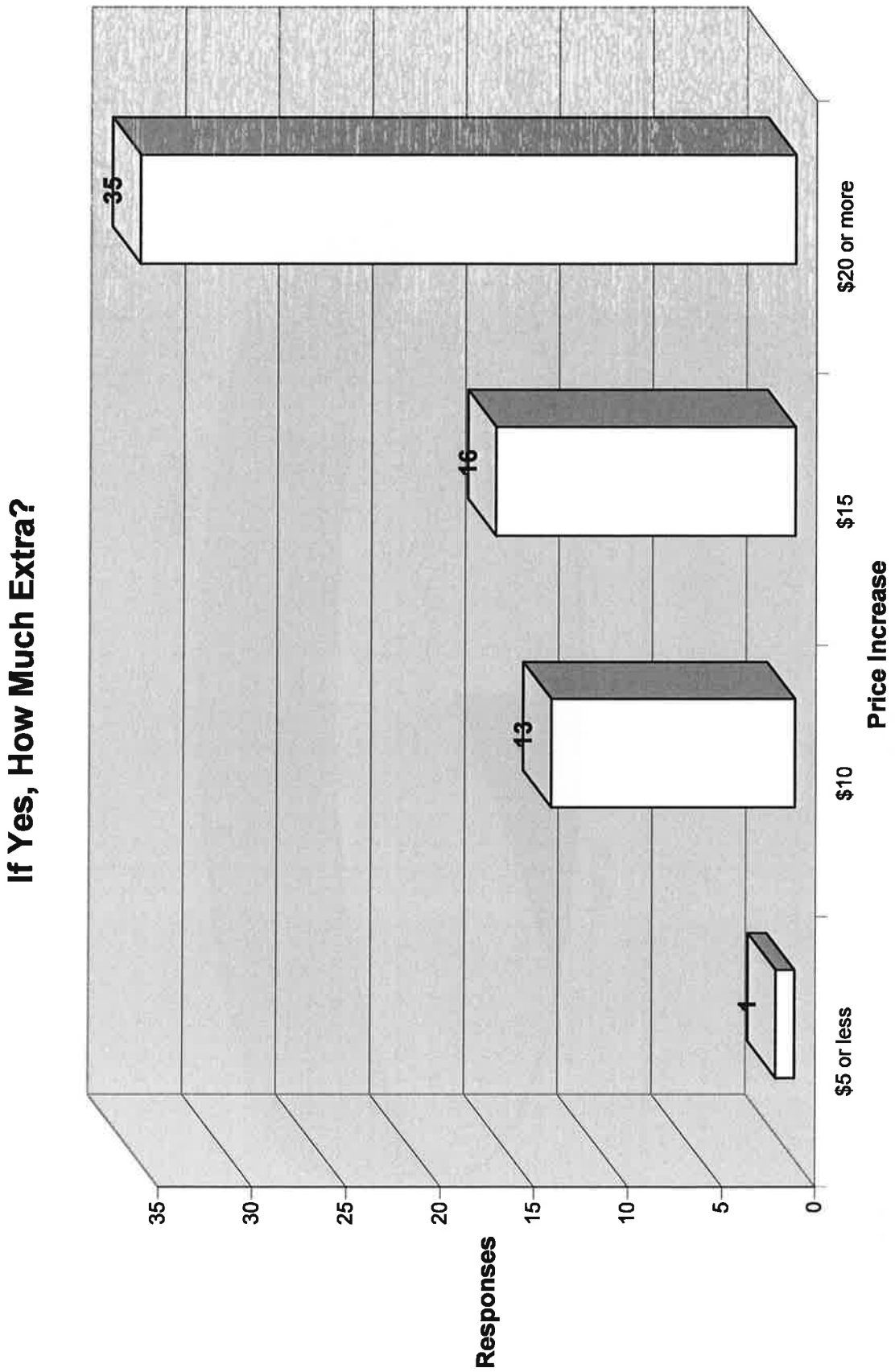
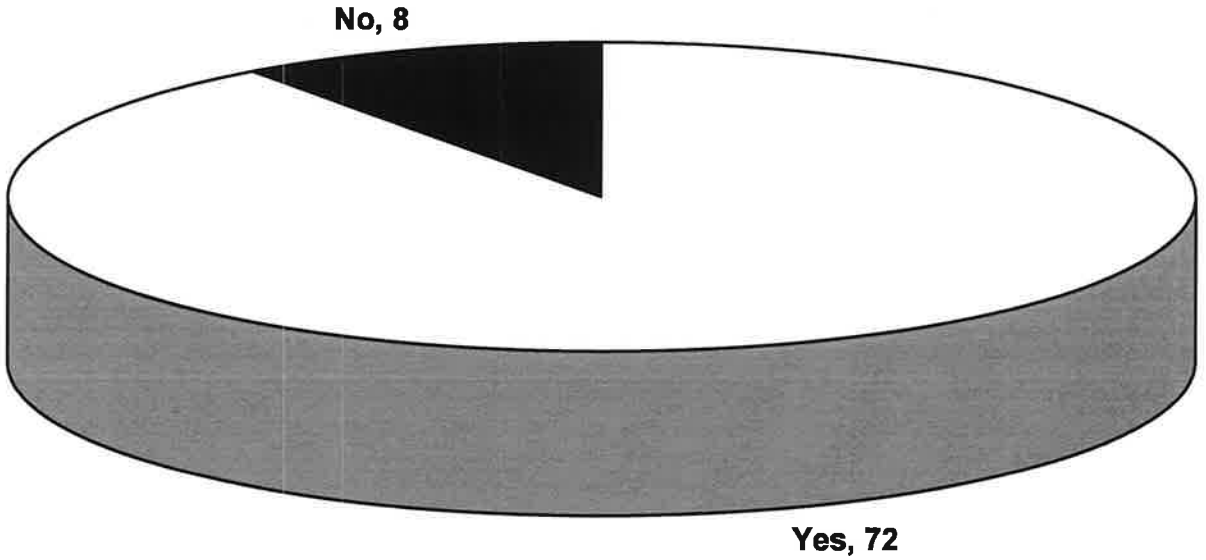
Appendix 3

Survey Results


What Would You Consider the Top Priority in a Microwave?
Responses
25
20
15
10
5
0
2
18
3
20
23
Looks
Ease
Price
Features
Safety
Options

Would You Spend Additional Money for Extra Safety Features?




If Yes, How Much Extra?
Responses
0
5
10
15
20
25
30
35
1
13
16
35
$5 or less
$10
$15
$20 or more
Price Increase

Would You Buy a Microwave That Will Prevent Food From Smoking or Catching Fire?