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# The Implementation and Demonstration of Flame Detection and Wireless Communications in a Consumer Appliance to Improve Fire Detection Capabilities

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# THE IMPLEMENTATION AND DEMONSTRATION OF FLAME DETECTION AND WIRELESS COMMUNICATIONS IN A CONSUMER APPLIANCE TO IMPROVE FIRE DETECTION CAPABILITIES

## 1.0 INTRODUCTION

In the early 1970s, in excess of 8000 Americans were dying in fires annually, 80% of them in residential fires. In 1974, the report of the presidential commission on fire, *America Burning*, recommended that Americans protect themselves from fire at home by installing smoke alarms. According to estimates by the National Fire Protection Association (NFPA) and the U. S. Fire Administration, U. S. home usage of smoke alarms rose from less than 10% in 1975 to at least 95% in 2000, while the number of home fire deaths was cut nearly in half. The home smoke alarm has been credited as one of the greatest success stories in fire safety in the last part of the 20<sup>th</sup> century.

Most homes in the U. S. were constructed before hardwired and interconnected smoke alarms were required by the National Fire Alarm Code (NFPA 72), and single station, battery-only-powered smoke alarms were typically installed in these homes. Depending on the size and layout of the home, if a fire occurs in a remote section of the home – away from the occupants – the smoke alarm closest to the fire may not be sufficiently audible to be heard by some occupants or to awaken sleeping occupants. If the alarms are not interconnected, the delay before a closer smoke alarm notifies the occupants may dramatically reduce the amount of escape time, perhaps leaving the occupants with only seconds to exit the home.

Beginning in 1989, NFPA 74 (later renamed NFPA 72) required interconnected (hardwired) smoke alarms on every level of the home and outside the sleeping area for new construction. NFPA 74 did not require smoke alarms in the bedrooms, nor did it require hardwired smoke alarms to have battery backup. NFPA 72 was later changed in 1993 to require installation of hardwired smoke alarms in bedrooms or sleeping areas. The interconnected smoke alarm in the bedroom provides increased assurance that the alarm sound level will be sufficient to wake sleeping occupants, and it also provides additional protection if the bedroom is the room of fire origin. Hardwired interconnected smoke alarms were not required for existing homes because of the financial burden that it places on homeowners.

The U.S. Consumer Product Safety Commission (CPSC) contracted with the Naval Research Laboratory (NRL) in 2003 [1] to determine the feasibility of incorporating wireless technology into battery-powered smoke alarms. NRL built prototype smoke alarms using a transmitter and receiver circuit in each of the prototype alarms. If any smoke alarm detected smoke, it transmitted a signal to the other smoke alarms. Each receiving smoke alarm also acted like a repeater; thus a smoke alarm that may have been too far away to be activated by the initiating smoke alarm could be activated by a closer smoke alarm that was transmitting an alarm signal. The transmitting range, the receiver power requirement and alarm checking interval for an alarm signal were factors in determining the power requirements. To be an effective system all the smoke alarms in the home would need to include RF receiver/transmitter circuitry. This method would improve audibility by sounding all smoke alarms when any one smoke alarm

detected smoke. Recently stores have begun selling wireless smoke alarms to allow consumers the benefits of interconnected smoke alarms for existing homes and to provide protection in remote areas of the home.

Tests conducted by National Institute of Standards and Technology (NIST) in October 2000 and completed in December 2002 concluded that smoke alarms of either the ionization type or the photoelectric type consistently provided some amount of escape time. NIST released a technical report, Performance of Home Smoke Alarms, Analysis of the Response of Several Available Technology in Residential Fire Settings (NIST Technical Note 1455 of December 2003) detailing their findings. However, the escape times measured were systematically shorter than those found in the “Dunes Tests” conducted by NIST (then the National Bureau of Standards, NBS) in the 1970s. This is attributed to a combination of factors: faster fire development times for today’s products that provide the main fuel sources for fires, different criteria for time to untenable conditions and improved understanding of the speed and range of threats to tenability.

CPSC is continuing to search for advances in fire research that will provide earlier warning to occupants and provide additional escape times. NRL has been tasked to determine if flame detection and wireless fire/smoke alarm signaling can be used in household appliances to further reduce the threat of loss of life in residential fires by allowing increased egress time in a fire scenario. NRL also investigated whether previously developed battery powered, wireless smoke alarms can be incorporated into a fire detection system with a modified small appliance capable of wireless alarm signaling.

## **2.0 OBJECTIVE**

The objective of this project is to determine if wireless fire/smoke alarm technology can be used in homes to further reduce the threat of loss of life in residential fires by alerting consumers to potential fire scenarios as quickly as possible. Early detection at flame ignition can improve smoke alarm signaling and greatly reduce notification times. Project tasks are as follows:

- (a) Investigate various suitable detection technologies and methods to allow earlier detection of flaming fires in a small appliance, such as a toaster oven.
- (b) Investigate whether wireless technology, previously developed by NRL or similar technology used to signal smoke alarms for earlier fire detection of appliance based fires, can be used to decrease the detection time of a fire.
- (c) Demonstrate proof of concept by incorporating flame detection and wireless smoke/fire alarm technology and methods into a home appliance.
- (d) If the integration of a fire/flame detector and wireless alarm signaling capability in a small appliance is successful; use it to form a fire detection system with the previously developed wireless smoke alarms. Flames detected in the appliance

will cause the system to wirelessly transmit a signal to the smoke alarms in the vicinity, initiating an alarm condition in all of the wireless smoke alarms in the system.

### **3.0 DETECTION TECHNOLOGY CHOICES FOR USE IN SMALL APPLIANCES TO DETECT FLAMING FIRES**

A research effort was initiated to identify candidate technologies for the detection of flames in a confined cooking area of a small consumer appliance such as a microwave or toaster oven. The search resulted in identifying devices which can be classified into two major areas; contact and non-contact devices. The contact devices measure temperature via a direct connection to the surface of the device of interest. The non-contact devices infer temperature by measuring the thermal radiation emitted by a material. These devices operate within the frequency range for which they were designed, such as Ultraviolet (UV) and Infrared (IR) sensors.

#### **3.1 Contact Type Sensors (Point Sensors)**

The contact type detection sensors that were identified are: thermocouples, Resistance Temperature Detectors (RTDs), thermistors, bimetallic devices, liquid expansion devices, and change-of-state devices. Liquid expansion, change-of-state and bimetallic devices are not considered suitable for this application due to their inability to generate known temperature data that are easily recorded or transmitted. They are point source temperature measurement devices that do not react quickly to transient temperature spikes, possibly allowing fire conditions in an appliance to get out of hand before signaling an alarm.

Flame detection means the remainder of the contact type devices would consist of thermal rate-of-rise measurements within a limited period of time. The rate-of-rise over a specific period of time would have to be adjusted initially by trial and error because of the different contact and detector types, their mounting requirements and thermal transfer characteristics. These devices would generally be packaged in an array or be configured in an array covering the area to be monitored. The contact devices can come in packages with hefty mounting hardware which could cause severe temperature lag, while the mount comes up to temperature.

Of the contact devices studied thermocouples and RTD devices may have applications in tracking longer term thermal increases, but probably not the transient temperature changes required to detect flaming fires. The RTD devices, in general, do not have a broad enough temperature span (-200 °C to 425 °C) for use in flame detection devices. Initially, thermocouple temperature measurements looked attractive for flame detection, but the cold junction correction (the difference between the actual temperature at the voltage measuring side and 0 °C is usually corrected for electronically) and the necessity of deploying the devices in an array considerably complicate the flame detection implementation using thermocouples and contact type devices.



### **3.2 Non-Contact Type Sensors (Volume Sensors)**

Non-contact type sensors infer temperature by measuring the thermal radiation of materials and when combined with signal processing can detect different types of flame signatures and are the preferred sensor type for this application. UV and IR devices are sold to detect flaming fires and to measure surface temperatures in HVAC systems from a distance. For flaming fires, these devices can monitor large open spaces like warehouses for flame signatures while rejecting common false alarms and can cost thousands of dollars. They can be purchased in IR, UV or a combination UV-IR. The combination models cover a broader spectrum and have enhanced false alarm resistance to radiation sources such as cosmic rays, scattered sunlight, tube fluorescence and halogen lamps. Many of these flame detectors, besides being costly, are too large to be integrated into a small appliance. Flame detector sensors often can require false alarm compensation, stabilized power sources, high voltage power supplies and signal processing capabilities to function; plus they do not operate well in high humidity environments due to electrical leakage in the required high impedance, high voltage power supply.

For this application, a flame detector sensor and support printed circuit (PC) board have been identified which will facilitate the implementation of a flame detection capability in a toaster oven. The support PC board provides a stabilized high voltage source and signal processing for the sensor and provides buffered detection signal sources. This flame detector product was selected for this application to quickly demonstrate a flame detection capability in a small appliance and to minimize design, fabrication and integration expenses. The flame detection product used in this demonstration works for a wide range of applications, but it can be noted that using specifically designed flame detection circuitry that is mass produced for this application may reduce the individual part cost.

### **4.0 NRL'S PREVIOUSLY DEVELOPED WIRELESS ALARM COMMUNICATION HARDWARE**

NRL previously developed and implemented an RF communications capability for use in battery operated smoke alarms. This effort was initiated under an interagency agreement [2] [3] [4] number CPSC-I-02-1290 between NRL and the CPSC. The communications capability was implemented to demonstrate that wireless technologies could be incorporated into battery operated smoke alarms without drastically increasing the cost of the smoke alarm and retaining the primary power source (battery), not increasing the general size of the smoke alarm and providing a reliable wireless interconnection between smoke alarms without false alarming. An RF transmitter and receiver design was implemented and incorporated into several battery powered smoke alarms. Two or more of the modified smoke alarms can be used to form a wireless smoke alarm system which would sound all audible alarm horns when one smoke alarm goes into an alarm condition by wirelessly communicating that alarm to the other smoke alarms in the system. The modified smoke alarms were successfully demonstrated in buildings and residences [4].

In the previous effort two wireless technologies were recommended in the initial effort for testing and implementation; (1) RF communications and (2) sonic communications. Several

sonic communication design approaches were implemented, tested and modified to address problems encountered during development. It was determined that changes and improvements in several areas are needed to produce a refined sonic communications approach. An RF receiver/transmitter (R/T) prototype was also developed and tested favorably in several residences. The RF R/T design was implemented on separate PC boards for the first effort; one for the receiver and one for the transmitter. One receiver and one transmitter board were integrated into standard smoke alarms. The modified smoke alarms were tested to determine their effectiveness in transmitting and receiving alarm signals wirelessly between each other in residential buildings and successfully demonstrated to the CPSC sponsors.

The purpose of this effort (CPSC-I-05-0003) [1] is to investigate whether wireless technology previously developed by NRL or similar technology used to signal smoke alarms for earlier detection of fires, can be used to decrease the detection time of an appliance fire. It has been determined that the R/T designs and implementations are appropriate for use in a small appliance (toaster oven) if space, ventilation, temperature management and flame detection requirements are met. Installing the transmitter board and a smoke/fire/flame detector would be required to transmit detected alarm conditions from a small appliance to the previously modified smoke alarms. In addition, the smoke alarms that were constructed during the initial effort will form a fire detection system that will respond to alarms from the wireless transmitter and UV flame detector equipped toaster oven.

## **5.0 FLAME DETECTION AND WIRELESS ALARM COMMUNICATION FOR CONSUMER APPLIANCES**

A major obstacle for incorporating a flame detection sensor and RF transmission electronics into a microwave or toaster oven is the ability for them to operate in a relatively high temperature environment (70°F – 400°F). Since off-the-shelf electronic products usually are not designed to operate in these temperature extremes an effort was made to isolate them from the hostile temperature environment. A suitable host oven must be one that has enough unused space to accommodate the electronics, insulating materials, and provide free air space and vents for the air circulation necessary to help isolate and mitigate the temperature extremes. A circulation fan was installed to maintain a tolerable operating environment for the added electronics. A target temperature environment for off-the-shelf and industrial electronics that was used in this application is 0°C to 70°C (32°F to 158°F). Teflon ® insulating material is used between the oven and the installed electronics to provide a barrier to heat from within the oven. Teflon was used in this application because of its availability. Other insulating materials can be substituted for the Teflon.

The toaster oven will operate normally and independently of the added electronics that detect flames and transmit RF signals to wireless smoke alarms. Several of the previously developed wireless smoke alarms can be positioned in the general vicinity (same room, adjacent room) of the ovens operating and use location to form a smoke/fire detection system. Added electrical wiring, within the oven, meets or exceeds temperature requirements for ovens of the type selected. It is possible that electrical fires may occur in toaster ovens or other appliances. Reacting to that type of fire by interrupting the power source could also disable any detection

and alarm transmission capabilities. No attempt will be made to disconnect the oven from 120 VAC power when flames are detected and an alarm is transmitted to adjacent smoke alarms. Electrical connections to primary 120 VAC made inside of the oven are fused. Good mechanical and electrical fabrication standards are employed for modifications, and meeting any known electrical standards. All improvements will be self-contained within the oven enclosure. The only external connection is the original 120 VAC input power plug. Openings for emissions from the RF transmitter are covered with a non-metallic cover that is permanently attached and shall shield and direct emissions outward from the oven enclosure.

### **5.1 Selection of a Small Consumer Appliance to Demonstrate Improvements**

The main selection criteria for a small appliance to modify with flame detection and RF transmission capabilities for this effort, is its availability and that it has available space within the cabinet to facilitate the installation of circuitry and support hardware. A toaster oven meeting the space requirements needed for this implementation was selected, see Figure 1. There were many other toaster ovens meeting this requirement that could have been used in this demonstration.

### **5.2 Flame Detection Implementation in a Toaster Oven**

An inexpensive (relative to other flame detector assemblies studied), compact, light weight UV flame sensor with a spectral response at 185 to 260 nm and a supporting electronics PC board were identified. This detector is manufactured by Hamamatsu, and uses the UV Tron® C3704 Series driving circuit. The sensor is a UV Tron® R2868 compact UV sensor. Tests on the sensor/PC board combination (shown in Figure 2) showed to be extremely responsive to flaming fires. The flame detector PC board has settings to compensate for various UV background noise levels (depending on various environmental factors), a means for adjusting the length of the alarm signal for a detected flame, various output signal polarities and an open collector output for driving up to a 100 mA load. Modifications to the hardware were made to automate the selection of the background noise cancellation level in the signal processing circuitry. The flame detector pulse width (which controls the RF transmitter) was modified from the original 10 mS to 10 seconds to allow a repeated RF transmission sequence to the wireless smoke alarms during flame detection. As long as detections are sensed, the transmit pulse width will be extended until flaming is no longer detected. The flame sensor was mounted inside a black anodized, machined aluminum block and positioned with the sensor looking through a rectangular opening on one side of the toaster oven interior. The rectangular opening in the aluminum block is positioned and mounted on the side of the toaster oven with the sensor monitoring the entire interior of the oven through an opening cut in the oven wall. The aluminum block is positioned back from the opening in the oven wall to limit the UV sensor's viewing area to the oven interior only, to minimize false alarms from exterior radiation sources.

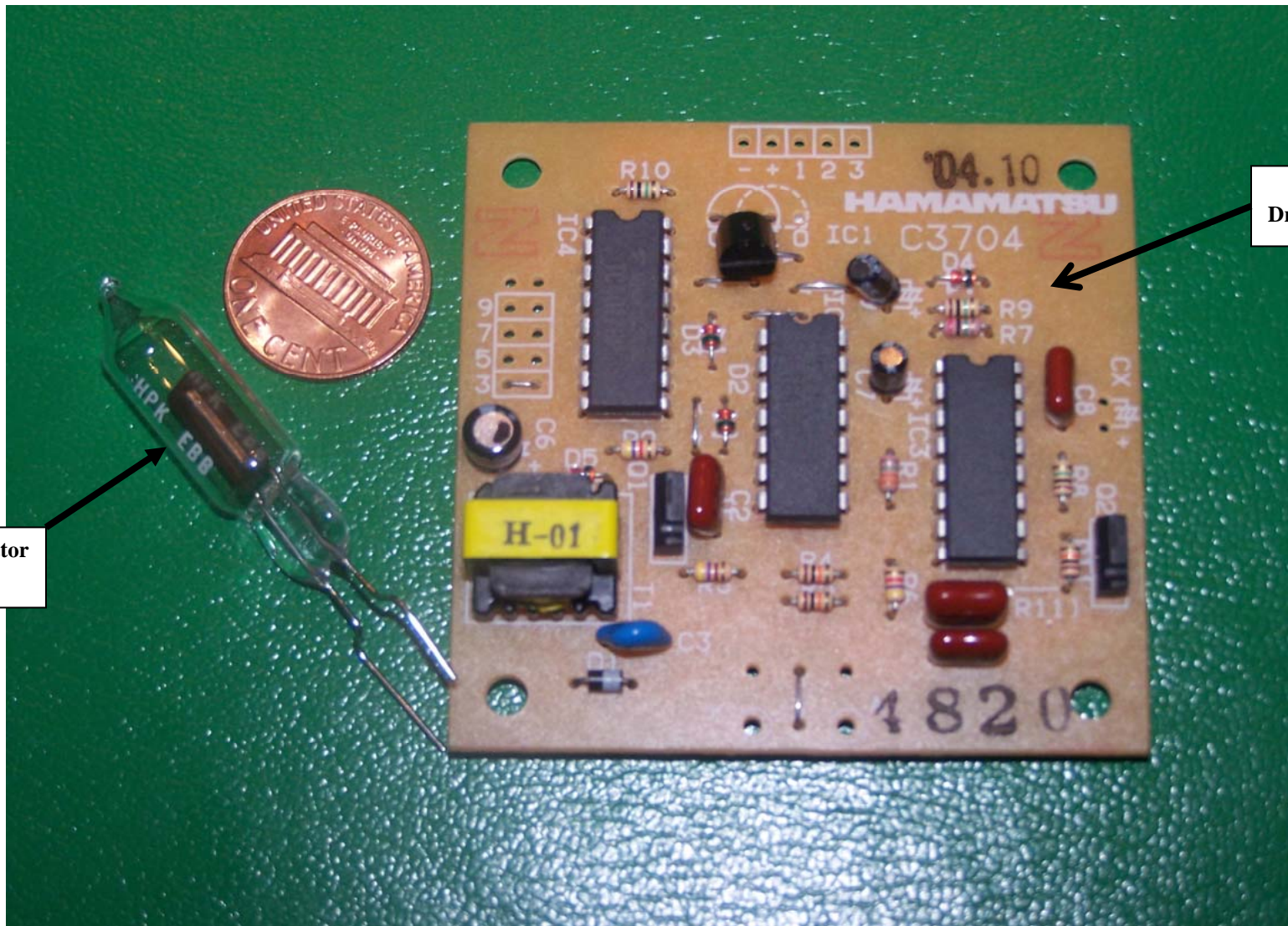
### **5.3 False Alarm Prevention Implementation**

Flame detectors can false alarm to radiation sources which are present in the environment. Some of these sources are mercury lamps, sterilization lamps, halogen lamps, direct or reflected sunlight on the sensor, electrical or welding sparks, radiation sources and high



**Figure 1, Standard Toaster Oven**





Flame Detector  
Sensor

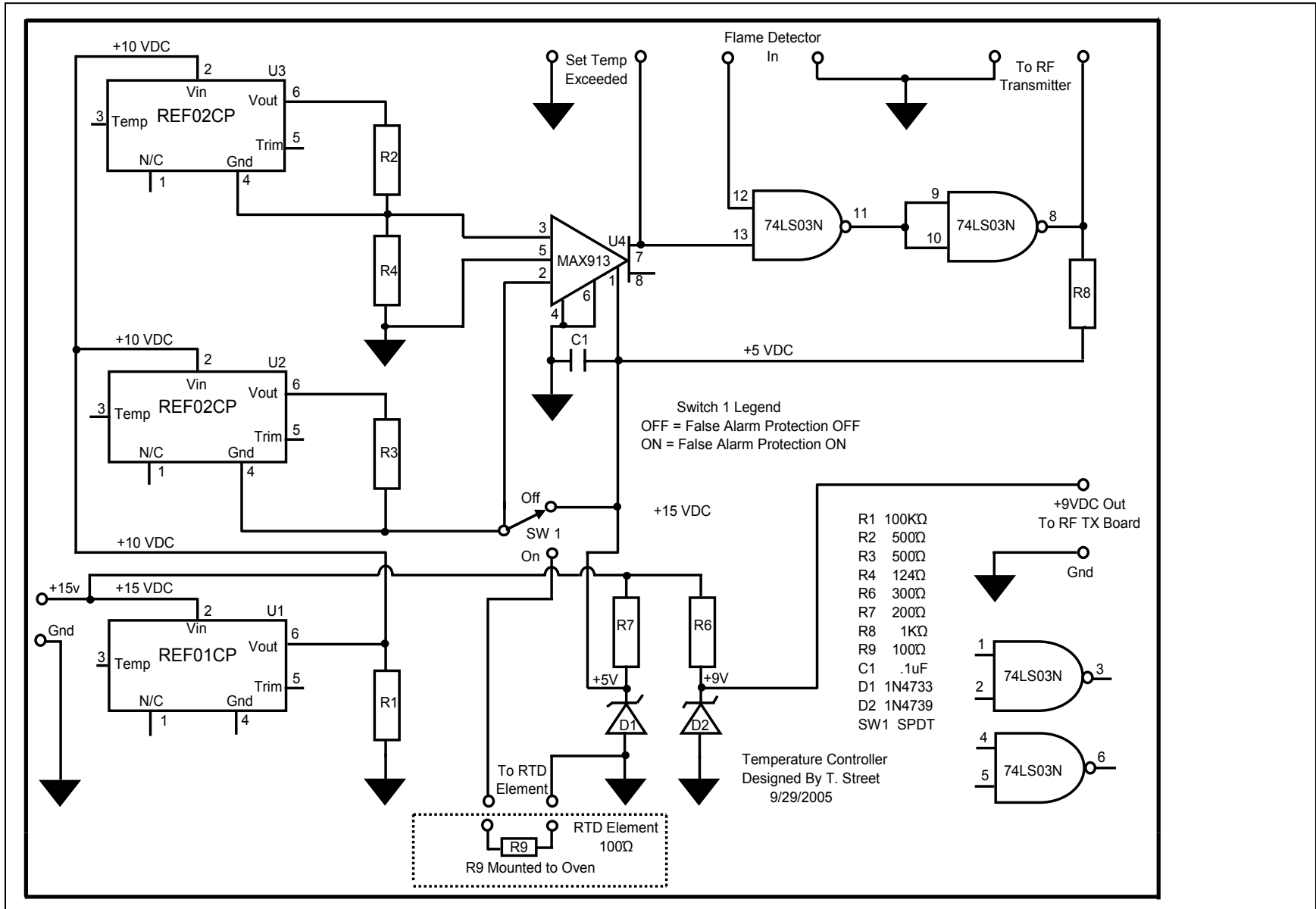
PC Board  
Driving Circuit

Figure 2, UV Tron Flame Detector Sensor and PC Board Driving Circuit

electric or static fields that are present near the sensor. Many radiation sources were exposed to the flame detector without incurring false alarming. This implementation is designed to react to flaming fires caused by food, containers or oven contents exposed to the oven's heating elements. A reasonable assumption is that fires generally do not occur in cold ovens. It could also be assumed that if a substantial fire were to occur in a cold oven the oven temperature should raise sharply. Flame detectors can and do react to radiation sources and could have the propensity to false alarm in their presence. In order to reduce false alarms to environmental radiation sources, a temperature monitoring circuit has been implemented that will disable the flame detection capability if the oven is below 90°C (194°F). Since the modified toaster oven will be tested to determine the degree this implementation will improve alarm and egress times for detected fires, it was felt that a built-in false alarm prevention mechanism could be useful and/or necessary. Shown in Figure 3 this mechanism would turn off the flame detector unless the toaster oven was above a specified temperature that would indicate it was in use. This effectively would disconnect the flame detector when the oven was not in use.

For testing purposes, the false alarm prevention mechanism can be turned on or off by a toggle switch SW 1, located in a user non-accessible area of the toaster oven. When enabled and the preset threshold temperature is exceeded, it allows the flame detection circuitry to operate; and when the temperature threshold is not exceeded it disables the flame detection circuitry providing false alarm prevention when the oven is not in use. The threshold temperature is set by selecting a resistance value on the temperature controller board that corresponds to a threshold temperature. A 124  $\Omega$  resistor was selected that corresponded to approximately 90°C (194°F) in the toaster oven to activate the flame detector.

A resistance temperature detector (RTD) sensor was selected to measure the oven temperature to help prevent false alarms by the flame detector. The temperature controller was designed to monitor and detect when the oven temperature exceeds a preset temperature. A 100  $\Omega$  @ 0°C (RTD) was installed in the space between the oven's interior and exterior surfaces just above one of the heating elements used during all the toaster oven functions (bake, broil and toasting). Two voltage references provide constant voltages for the reference and RTD voltage inputs to a voltage comparator. As the monitored oven temperature increases, the RTD's resistance rises causing the voltage drop across the RTD to rise. When its temperature exceeds 90°C (194°F) the resistance value exceeds the resistance installed on the temperature controller reference side and the flame detector is activated. When the resistance value of the reference is not exceeded the flame detector is not activated. This allows the flame detector to operate only when the toaster oven is in use and above 90°C (194°F) providing false alarm protection against environmental radiation sources when it is not in use. When the switch is turned "ON" flame detection alarms are transmitted via RF any time the flame detector detects flames and the threshold temperature has been exceeded. As the temperature of the RTD is exposed to increases and decreases in temperature, its resistance increases and decreases proportionally.



**Figure 3, Temperature Control and False Alarm Prevention**

### **False Alarm Protection With the Switch in the “ON” Position**

When this switch is turned “ON” the flame detector would function only after the oven reached a predetermined temperature.

### **False Alarm Protection With the Switch in the “OFF” Position**

When the switch is turned “OFF” the flame detector operates any time a flame is detected, without regard to the oven’s temperature and an alarm will be transmitted via RF.

## **5.4 Wireless Alarm Communication Implementation**

Since smoke alarms were previously modified by NRL with RF receivers and transmitters to form a fire/smoke detection system, only the transmitter design previously developed would be required for the wireless portion of the toaster oven implementation to signal the modified smoke alarms in the system, Figure 4. The physical size of the RF transmitter’s PC board is 2 ¼” X 1 ¼” (57.15 mm X 31.75 mm) which can easily be integrated into the toaster oven and many other appliances. Since a 9 VDC power source is required for the transmitter, a 9 VDC zener diode was used. The zener diode was mounted on the temperature control PC board.

Consideration must be given to the fact that the antenna for this design is an integral part of the PC board and must be unshielded by metal components of the appliance in order to radiate its RF signal. When a flame is detected inside the toaster oven, the RF transmitter is activated signaling the wireless smoke/fire detectors in the area to sound an alarm. A rectangular hole was cut in the right side of the toaster oven where a mount was installed for the RF transmitter PC board. The rectangular access hole is covered by a removable cover. Mounted on the removable cover are a circulation fan and a piece of non-metallic material from a welder’s helmet covering the opening for the RF transmitter’s PC board and antenna. Using the same RF transmitter as the battery powered wireless smoke alarms provides the toaster oven with identical communications capabilities for alarm transmissions to the battery-powered wireless smoke alarms. Detected fires in the toaster oven would transmit a signal directly to wireless smoke alarms in the system.

The wireless smoke alarm system when coupled with improved sensors for flaming fire detection in an appliance could greatly reduce alarm time to fires and decrease egress times. Without a flame detector in the appliance, smoke emitted from a fire in the appliance would have to migrate to the closest smoke alarm, before alarming. This design allows any wireless smoke alarm to sound if the modified toaster oven detects a fire condition, without waiting for the smoke to propagate to the nearest smoke alarm.

## **5.5 Temperature Stabilization of Flame Detection and RF Transmission Circuitry**

The toaster oven is capable of temperatures in excess of 232°C (450°F) and if maintained for extended periods of time while baking and broiling could exceed the operating temperature range for the added electronic components, even though they are located outside the cooking



area of the oven. A thermal barrier has been installed between the oven and the electronic components to limit the direct temperature effects from the oven. Even with the barrier, air within the area where the additional electronics are installed can reach extreme temperatures because the area is adjacent to the oven. To prevent the electronics from overheating, a circulation fan has been installed to moderate the temperature extremes in this area, as shown in Figure 5. In addition, an Airpax<sup>®</sup> thermostatic sensor, shown in Figure 6, is mounted to the aluminum block, holding the flame sensor, to monitor the sensor operating temperature and to control the circulation fan, when the temperature of the block exceeds 65°C (149°F). The circulation fan directs the airflow directly onto the sensor mounting block and sensor support PC board to stabilize the temperature then exhausts it through the oven vents at the top, side and bottom of the oven. Figure 7 is an overall diagram of the toaster oven modifications necessary to integrate flame detection, reduced false alarming circuitry and wireless alarm communication for this effort.

## **6.0 DEMONSTRATION OF THE MODIFIED TOASTER OVEN**

The modifications to the toaster oven incorporating a flame detector, wireless alarm transmission capability and a false alarm protection scheme have been completed and tested in a laboratory environment. In the first series of tests, the flame detector has been tested using flames produced by a match with the oven door opened. The flame detector responded accurately to the flame and activated the RF transmitter which activated the wireless smoke alarm. In a second series of tests, an unlit match was placed on the heating element on the bottom of the toaster oven, the oven door closed and the bake cycle initiated. The heating element ignited the match and the flame was immediately detected by the flame detector which immediately set off the smoke alarm via the wireless alarm communication. During these tests there was never an occasion that the flame detector didn't respond to the flame and initiate the wireless alarm. No tests were conducted for smoldering fires or flame detection capabilities in smoky environments.

The toaster oven was placed in a residential home environment to verify its resistance to false alarms. A wireless smoke alarm was set up nearby to monitor the RF emissions of the toaster oven under test. No false alarms were initiated by the toaster oven alarming to ignition sources outside of the toaster oven cabinet (false alarm switch turned "OFF" for this test) during this week long experiment. In the laboratory environment the flame detector has not alarmed to any external ignition source with the oven door closed. The glass oven door prevented over 90% transmission of UV radiation below 300 nm, which is an advantage for false alarm prevention for external flames, such as gas stoves, candles and matches. It appears that the 185 to 260 nm frequency of operation of the UV sensor helps prevent false alarms from external sources.

The Naval Research Laboratory does not have the capability of testing this modified toaster oven in a residential environment over a long period of time for operational, false alarm and wireless alarm transmission reliability in the changing environmental stresses presented in a residential kitchen under varying conditions. However, the toaster oven was false alarm free with reliable flame detection and alarm signal transmissions in the laboratory for the limited operational testing that was performed.

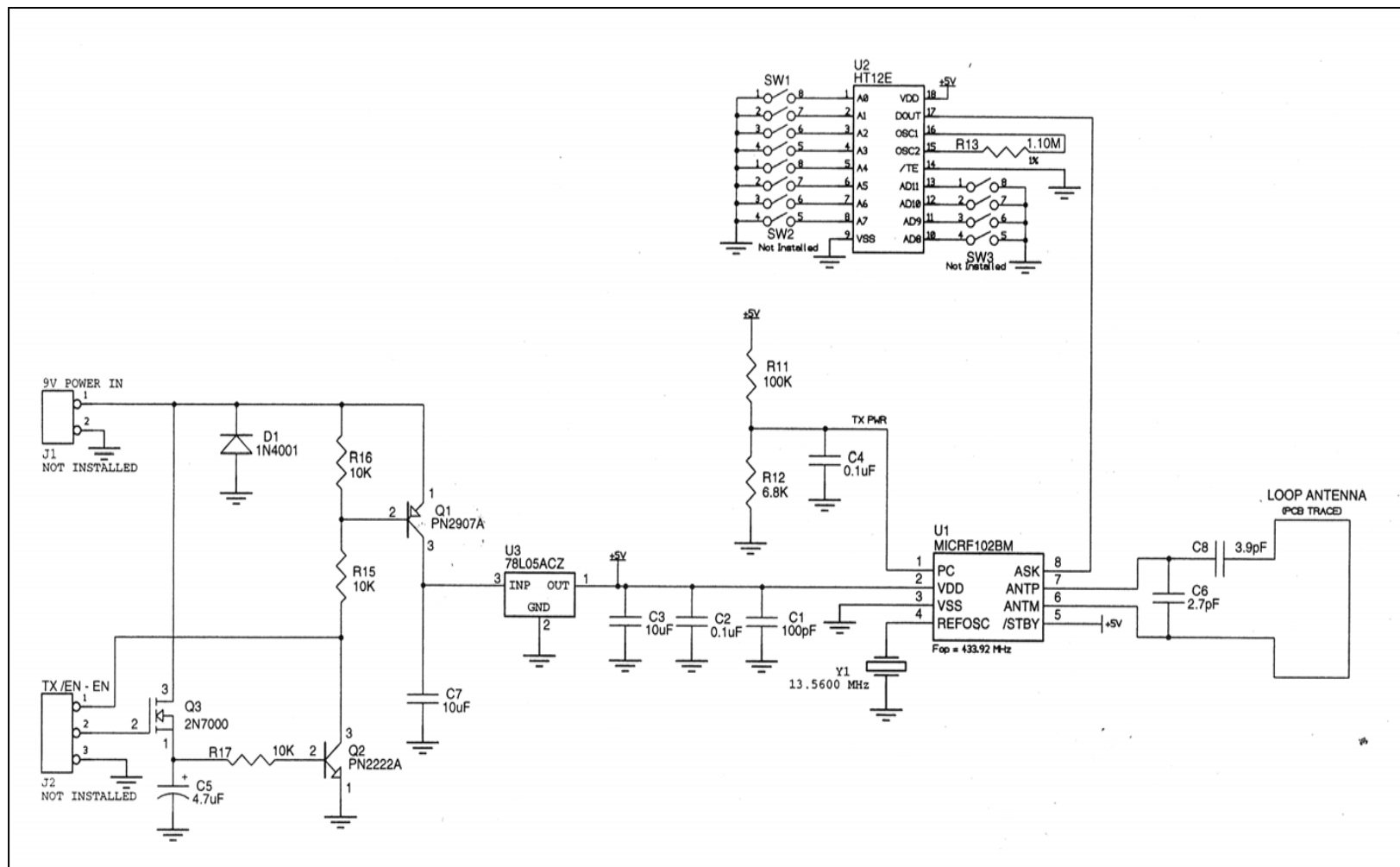
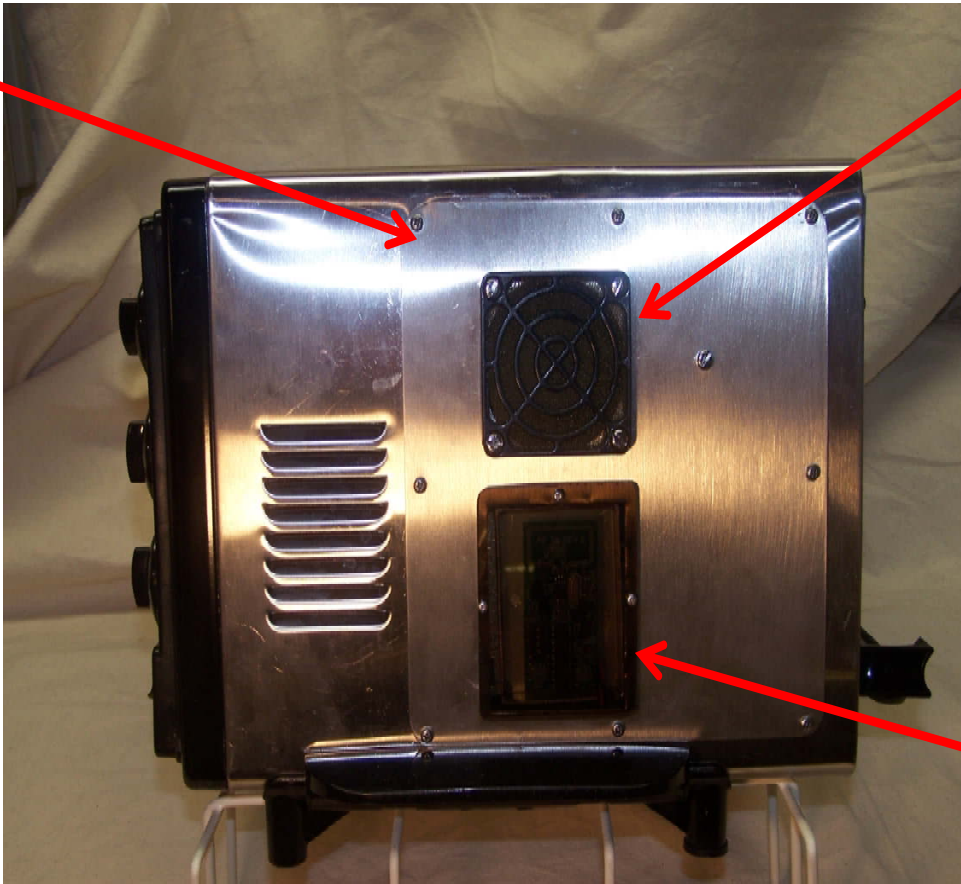


Figure 4, RF Transmitter Schematic

Toaster Oven  
Component  
Cover

Temperature  
Control Fan



RF Transmitter  
Cover

Figure 5, Modified Toaster Oven - Side View



Figure 6, Modified Toaster Oven Component Identification & Location

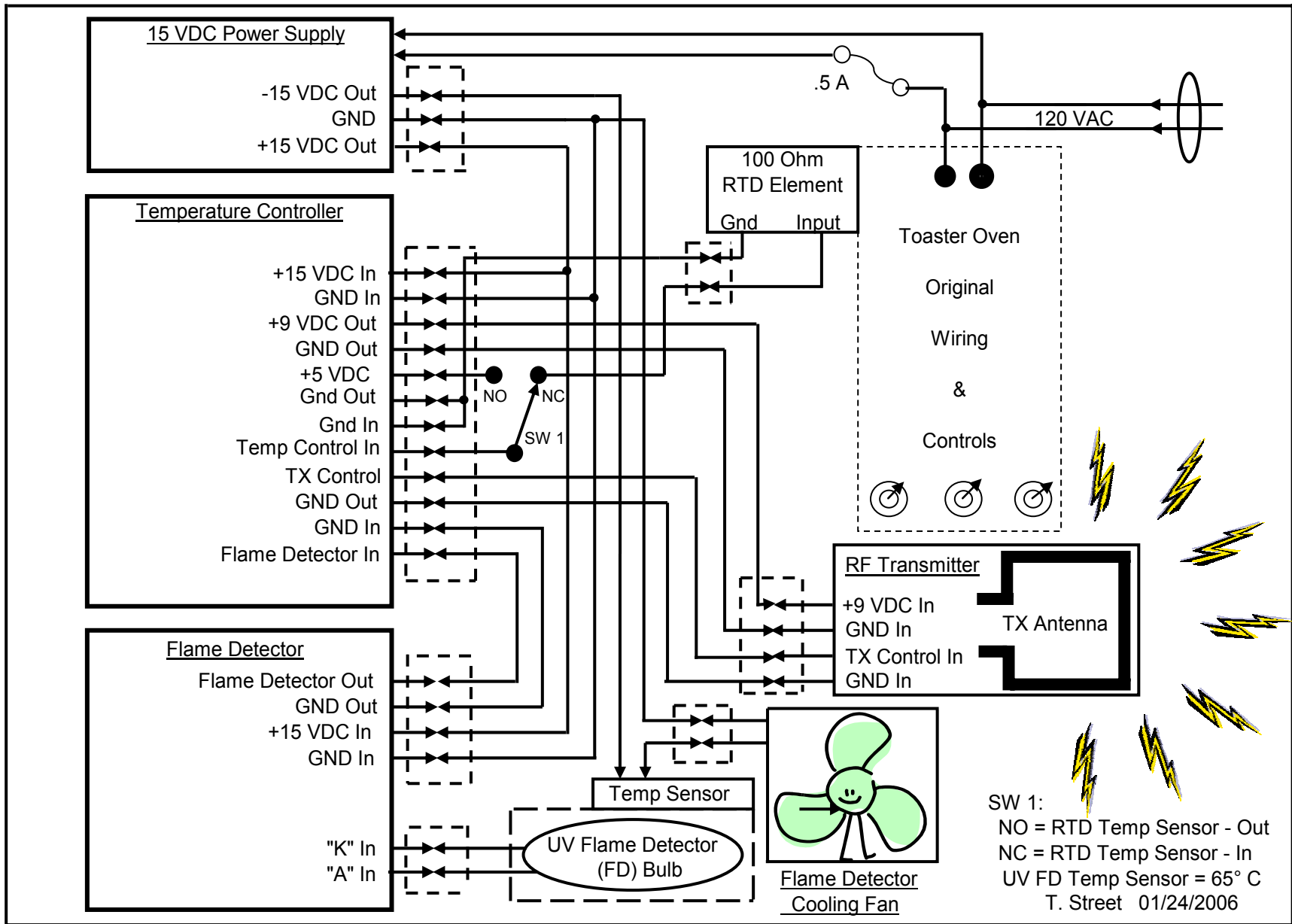


Figure 7, Toaster Oven Wiring

## **7.0 COSTS OF PARTS**

The cost of parts listed in Section 7.1 to 7.3 reflect what a manufacturer might pay if purchased in large quantities. The cost of parts for the flame detection, wireless alarm transmission and false alarm scheme is presented below:

### **7.1 Cost of Parts to Implement a Flame Detection Capability**

See Table 1.

### **7.2 Cost of Parts to Implement a Wireless Communication Capability**

See Table 2.

### **7.3 Cost of Parts to Implement a False Alarm Protection Scheme**

See Table 3.

## **8.0 CONCLUSIONS AND RECOMMENDATIONS**

This effort has shown that incorporating a flame detection system in an appliance will cause a wireless smoke alarm to sound almost immediately to a flaming fire in the appliance. The reduction in alarm times due to the wireless smoke alarm and the flame detection system should increase reaction times to fires of this nature and allow additional egress time for building occupants. Additional testing to compare the smoke alarm times with and without the flame detection system in the appliance should be conducted.

An extended operational and false alarm monitoring test series is highly recommended to quantify the actual improved capabilities of these modifications. This concept can be expanded to other heat producing appliances to detect fires within the appliance and transmit an RF signal to a wireless smoke alarm

## **9.0 ACKNOWLEDGEMENTS**

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Item Number	Part Name	Part Number	Value	Schematic Designation	Quantity	Cost Each	Cost Total
1	Voltage Regulator	78L05ACZ		U3	1	\$0.13	\$0.13
2	Capacitor	ECS-F1AE475K	4.7 uF	C5	1	\$0.23	\$0.23
3	Capacitor	ECJ-2VC1H101J	100 pF	C1	1	\$0.02	\$0.02
4	Capacitor	ECJ-4YB1C106K	0.1 uF	C2,C4	2	\$0.06	\$0.12
5	Capacitor	ECJ-4YB1C106K	10 uF	C3,C7	2	\$0.31	\$0.62
6	Capacitor	1206CG279C9B200	2.7 pF	C6	1	\$0.03	\$0.03
7	Capacitor	1206CG399C9B200	3.9 pF	C8	1	\$0.03	\$0.03
8	Diode	1N4001		D1	1	\$0.02	\$0.02
9	2^12 Dncoder	HT12E-18		U2	1	\$0.40	\$0.40
10	UHF RX	MICRF002BM		U1	1	\$1.25	\$1.25
11	NPN Transistor	PN2222A		Q2	1	\$0.07	\$0.07
12	PNP Transistor	PN2907A		Q1	1	\$0.06	\$0.06
13	N CH MOSFET	2N7000		Q3	1	\$0.07	\$0.07
14	Resistor	ERJ-3GEYJ104V	100K	R11	1	\$0.01	\$0.01
15	Resistor	ERJ-3GEYJ682V	6.8K	R12	1	\$0.01	\$0.01
16	Resistor	ERJ-3EKF1104V	1.1M	R13	1	\$0.01	\$0.01
17	Resistor	ERJ-3GEYJ103V	10K	R15-R17	3	\$0.01	\$0.03
18	DIP Switch	209-4MS		SW1	1	\$0.41	\$0.41
19	Quartz Crystal	AB-6.7459MHZ-20-D	13.560 MHz	Y1	1	\$0.32	\$0.32
20	Circuit Board	RF Transmitter			1	\$0.68	\$0.68
					<b>Total</b>	<b>\$ 4.13</b>	<b>\$ 4.52</b>

Table 1, RF Transmitter Parts List

Number	Name	Number	Value	Designation	Quantity	Each	Total
1	Voltage Reference	REF01CP		U1	1	\$0.38	\$0.38
2	Voltage Reference	REF02CP		U2, U3	2	\$0.38	\$0.76
3	NAND Gate (OC)	74LS03N		U5	1	\$0.23	\$0.23
4	Comparator	MAX 913 CP		U4	1	\$0.06	\$0.12
5	Capacitor	1109PHCT-ND	.1 uF	C1	1	\$0.12	\$0.12
6	Zener Diode	1N4733	5V	D1	1	\$0.03	\$0.03
7	Zener Diode	1N4739	9V	D2	1	\$0.03	\$0.03
8	Toggle Switch	CKN1071-ND	SPDT	SW1	1	\$0.02	\$0.02
9	RTD Element	HRTS-61-T-100V	100Ω	R9	1	\$2.72	\$2.72
10	Resistor	100KH-ND	100K	R1	1	\$0.01	\$0.01
11	Resistor	510H-ND	510Ω	R2, R3	2	\$0.32	\$0.64
12	Resistor	BC124ZCT-ND	124Ω	R4	1	\$0.01	\$0.01
13	Resistor	300H-ND	300Ω	R6	1	\$0.22	\$0.22
14	Resistor	200H-ND	200Ω	R7	1	\$0.41	\$0.41
15	Resistor	1000H-ND	1KΩ	R8	1	\$0.32	\$0.32
16	Circuit Board	Temp Controller			1	\$1.27	\$1.27
					<b>Total</b>	<b>\$ 6.53</b>	<b>\$ 7.29</b>

Table 2, Temperature Controller Parts List





## 10.0 REFERENCES

1. Interagency Agreement Number CPSC-I-05-0003 between the Naval Research Laboratory (NRL) and the Consumer Product Safety Commission (CPSC).
2. Interagency Agreement Number CPSC-I-02-1290 between the Naval Research Laboratory (NRL) and the Consumer Product Safety Commission (CPSC).
3. Street, T. T., Williams, F. W. and Pitas, F. R., “Smoke Alarms, Low-Cost Batteries, and Wireless Technology Technical Report: Phase I–Preparatory Study and Literature Search”, NRL Memorandum Report 6180-03-8664 of 11 July 2003.
4. Street, T. T., Williams, F. W. and Pitas, F. R., “The Implementation and Demonstration of Wireless Communications Capabilities in Off-The-Shelf, Battery Powered Smoke Alarms Phase II Report”, NRL Memorandum Report 6180—04-8712 of 23 February 2004.

