# Protecting Electrical Equipment From Red Imported Fire Ants

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# REPORT SUMMARY


A behavioral characteristic of fire ants may lead to a means to control their inhabitation of electrical equipment. Initial tests suggest that the method can prevent or reduce fire ant infestation in utility pad-mounted transformer cabinets.

### Background

Fire ants have been a problem in electrical equipment since their introduction into the United States in the 1940s. By invading electrical equipment, fire ants cause short circuits and also introduce damage-causing food, soil, and debris. When their nest is in a pad-mounted transformer, the lineman opening the enclosure must deal with the ants before working on the original problem. This can lead to greatly extended outage duration. To solve the problem, EPRI, TU Electric, and Houston Lighting & Power (HL&P) have cosponsored this project.

### Objectives

To investigate alternative methods to control or prevent fire ant infestation of electrical equipment enclosures.

### Approach

Researchers trapped a series of fire ant colonies to establish a laboratory test case to experiment with various methods of disrupting the ant colony. Several different methods were tried before one method appeared most promising. To test that method and the devices they designed to exploit the fire ants' characteristic weaknesses, the research team trapped more ant colonies. Those designs that proved effective in the laboratory were then field-tested. To gauge the relative effectiveness of the various methods, an observer counted the number of ants crossing a given area, before and after device installation. The most promising device had evolved through four generations by the time this report was prepared.

### Results

The study found a characteristic of fire ant behavior to exploit that either reduced their vitality or encouraged the ant colony to move its nest away from the device. In initial laboratory experiments, the device successfully attracted and killed a substantial number of fire ants. Many of those that were not killed outright by the device became

deranged and started attacking other ants in the colony. The device also caused ants to gaster-flag, releasing a chemical scent into the air as an alarm response. The scents increase the general level of activity in the colony, reducing the colony's long-term vitality.

In a field trial on the HL&P distribution system, results were not as conclusive as in the laboratory. In one case, ants were able to overcome the device by burying it. These field results, however, did show the device will either cause the colony to move out of the pad-mounted transformer enclosure or reduce the remaining colony's vitality.

### EPRI Perspective

It appears that a new method has been discovered to control fire ants. The method has been found to reduce the ants infestation of pad-mounted transformer enclosures. More tests are necessary, however, before the method is conclusively proven. At the time of this report's publication, testing continues.

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# EXECUTIVE SUMMARY

Red imported fire ants (RIFAs) have been a problem in electrical equipment for over fifty years. The RIFAs invade the electrical equipment causing short circuits and introduce food, soil, and other debris to the electrical equipment that could cause additional damage. Some ants are electrocuted by the short circuits, and the corpses remain on and around the circuitry. The electrical equipment that is not damaged by short circuits can be impaired by the large number of RIFAs accumulating on the equipment.

The RIFAs are not attracted to the electric fields. The ants, instead, gather at an electrical site where they are able to contact the exposed conductive material. When the ants come into contact with the exposed conductive material, they are usually electrocuted. If the RIFAs do not die, they are electrified and display aggravated behaviors such as immobility, attacking nest mates and live wires, accelerated movement, and involuntarily releasing chemicals from their abdomen.

Expected exploring of the environment accidentally leads the RIFAs to come into contact with the conductive material. These ants are affected in the various ways and attract other ants to the site of the conductive material. Other ants are, in turn, affected by the conductive material. One integrated pest management approach is to deny RIFAs access to electrical equipment by covering all equipment or completely sealing equipment containers. But a more viable solution is to establish a device that will rid the RIFAs in and around the electrical equipment.

Texas Tech University and the Electric Power Research Institute agreed to study methods to protect electrical equipment from red imported fire ants. Researchers constructed ant-accessible boxes that contained 16 sets of copper plates with alternating current (AC) and direct current (DC) distributed to wires connected to the plates. Different species of ants were introduced to the boxes, and all were attracted to the AC- and DC- powered plates with at least 50-60 volts of current.

Researchers wanted to develop an electronic device that took advantage of certain RIFA behaviors and prevented the ants from destroying the electrical equipment. A device that would best meet EPRI needs could be installed near the electrical equipment and maintained with little or no upkeep. This device would either kill the ants or drive

them away from the electrical equipment and reduce the amount of damage the ants cause to the equipment.

The laboratory tests and field trials were divided into three phases.  Phase one was the development of a static electric device.  Phase two involved the development of a second-generation, smaller, and more economical static electric device.  The second-generation device was designed from the first static electric device's field trials.  Phase three focused on the development of a third-generation static electric device.  The third-generation static electric device was built using information from the first two generations.  This device was self-cleaning and more effective against the RIFAs.

Research is ongoing.  Other methods to keep the RIFAs off electrical equipment is being tested including flashes of UV light, exposure to multiple static electric devices, and incorporation of integrated pest management tactics to make the static electric devices more effective.

# 1

# INTRODUCTION AND REVIEW OF PREVIOUS WORK

## Introduction of the Red Imported Fire Ant into North America.

The red imported fire ant (RIFA), *Solenopsis invicta* Buren (Hymenoptera: Formicidae), has been an important economic pest in North America since its accidental introduction near Mobile, Alabama, between 1933 and 1945 (Buren et al. 1974, Vinson and Sorensen 1986). Although native to the floodplains of the Paraguay River and its tributaries in Brazil and Paraguay, *S. invicta* rapidly invaded the southern and southeastern states of the USA (Lofgren 1986).

The RIFA causes human medical problems (Adams and Lofgren 1982, Clemmer and Serfling 1975, Rhoades et al. 1977), threatens domestic animals (Hunt 1976, Wilson and Eads 1949), endangers wildlife (Mount 1981, Sikes and Arnold 1986), and damages agricultural crops such as maize, soybeans, potatoes, cabbage, and citrus (Adams et al. 1983, 1988, Apperson and Powell 1983, Banks et al. 1991, Eden and Arant 1949, Lyle and Fortune 1948). The RIFA tends aphids and harvests honeydew whereby increasing aphid populations and disease transmission to plants (Nielson et al. 1971, Reilly and Sterling 1983). In contrast, the RIFA is considered a beneficial insect by reducing populations of the sugar cane borer (Reagan et al. 1972), the lone star tick (Harris and Burns 1972), whiteflies (Morrill 1977), alfalfa weevils, and green pea aphids (Morrill 1978).

## RIFA Invasion of Electrical Equipment

### *Economic impact*

RIFAs cause economic damage by invading electrical circuitry and equipment. The earliest reports of RIFAs accumulating in and damaging such equipment came from Southwestern Bell Telephone in Galveston, Texas. In September 1939 alone, 83 of 446 subscriber's residential telephone failures were caused by ants (Eagleson 1940). Surveys from June 1985 to August 1988 in Bryan and College Station, Texas, revealed RIFA presence in 75% of Texas Highway Department's signal cabinets (Vinson and MacKay 1990) and damage to 20% of the cabinets (MacKay and Vinson 1990). In the same Texas area, air conditioner service companies reported that nearly 33% of their repair calls were due to RIFAs "shorting" residential and commercial units (Vinson and

MacKay 1990). A 1986 survey of state departments of transportation in Alabama, Florida, Georgia, Louisana, Mississippi, and Texas confirmed the RIFAs status as an economic and maintenance nuisance (MacKay et al. 1989).

Ants accumulate in such large numbers that they often prevent proper movement of the mechanical portions of electrical devices (Little 1984, MacKay et al. 1989, Vinson and MacKay 1990) such as telephone ringers (Eagleson 1940) and contact connections in signal cabinets (Vinson and MacKay 1990). Ants remove insulation material from wires (Eagleson 1940, Galli and Fernandes 1988, MacKay et al. 1990, MacKay and Vinson 1990) and cause shorts in apparatuses by physically bridging electrical contacts with their bodies which results in electrocution by excessive internal current flow (Little 1984, MacKay et al. 1989, Vinson and MacKay 1990). The electrocution of ants during the short circuit creates large numbers of ant corpses that remain in and around circuitry. Ants often nest inside electrical equipment (MacKay et al. 1989, Vinson and MacKay 1990) and introduce large quantities of soil, food particles, and other debris that may cause damage to equipment through increased humidity and corrosion (Eagelson 1940). In addition to highway and electrical company equipment, RIFAs have destroyed household light sockets, televisions, electric fences, well pumps, and airport landing light systems (Jolivet 1986, Little 1984, Vinson and MacKay 1990).

### *Attraction to electrically charged metal disks and AC and DC current*

MacKay et al. (1992a) constructed ant-accessible boxes which contained 16 sets of 1-cm diameter, copper plates located one mm apart. Both alternating current (AC) and direct current (DC) voltage were randomly distributed to copper wires connected to the plates. Workers of ten species of ants, including *Solenopsis geminata* Fabricius and *S. invicta*, were strongly attracted to both AC- and DC-powered plates, and responses were directly proportional to increased voltage. Most species had lower response thresholds of approximately 50-60 volts, below which ants exhibited little or no attraction. No differences were noted in responses to AC- or to DC-powered plates; however, when voltages were turned off, RIFAs departed much slower from AC-powered plates than from DC-powered equipment (MacKay et al. 1992b). Ants habituated to electrical fields after several hours of exposure. Also, a thin layer of plastic insulation prevented RIFA responses to powered apparatuses. The RIFA was not attracted to electromagnetic fields, magnetic fields, ozone, wire insulation materials, or heat (MacKay et al. 1989).

### *Response to current and conductive material*

Electric fields do not attract RIFAs and do not directly cause the massive accumulations responsible for equipment disruption and malfunction. Rather, ants congregate and aggregate at an active electrical site if they are able to simultaneously contact the exposed or bare conductive material (Slowik et al. 1996). The lowest threshold of response was approximately 5.0 V, or 0.83 milliamperes.

At high voltage, ants are often electrocuted, instantly killed, and left on the live wires as part of the active circuit. At 197, 75, 50, 20, and 10V DC, some ants are momentarily shocked and rendered disabled. These permanently incapacitated ants die slower and usually remain on or very close to live wires. Many ants are briefly electrified, are seemingly "deranged", and exhibit peculiar behaviors such as highly accelerated movement, extended immobility, mandible clamping on nestmates and single wires, and prolonged, almost involuntary gaster-flagging (an alarm response in which the ant raises its abdomen to spray chemicals) (Slowik et al. 1996).

The following scenario of events may illuminate the phenomenon of RIFA accumulations in active electrical equipment (Slowik et al. 1996). Normal ant exploration of the environment may result in incidental contact with the electrically active conductive material in accessible equipment. This electrification results in ant death, incapacitation, or altered behavior. These activities may excite and attract other ants to the site where they, in turn, meet a similar fate. Dead ants may then affect investigating ants in other ways. The amassing ant aggregations increase the total conductive area of the circuit, thereby increasing the chance of contact and electrification of approaching ants. Ants deposit colony debris on top of and near developing accumulations (bone piles), often with lethal results. Lastly, prolonged gaster-flagging by both healthy and shocked ants has been observed, and odors and pheromones affect ant behavior and attraction. Denial of ant access to circuitry, whether by covering all exposed conductive material or sealing equipment containers, may be one integrated pest management approach to preventing electrical damage by ants.

### *Insect attraction to magnetic fields.*

Insect behavior associated with magnetism has been most extensively studied in the honey bee, *Apis mellifera* L. Magnetism affects worker motility (Hepworth et al. 1980), local field detection (Walker and Bitterman 1989), spatial and temporal orientation (Lindauer and Martin 1972), and general activity and aging (Martin et al. 1989). The honey bee has magnetite ($Fe_3O_4$) in the abdomen (Gould et al. 1978), and iron oxide granules are localized in trophocytes of the subcuticular fat body of the abdomen (Kuterback et al. 1982; Kuterbach and Walcott 1986a,b). Hsu and Li (1993, 1994) claimed to have found innervated and cytoskeletally attached superparamagnetic magnetite in honey bees, but their findings have been disputed (Kirschvink and Walker 1995, Nesson 1995, Nichol and Locke 1995).

The RIFA may have geomagnetic orientation capabilities (Anderson and Vander Meer 1993). In nocturnal experiments with RIFA colonies foraging in a Heimholtz coil-enclosed arena, the time required for trail development from a newly introduced bait to the nest was measured. Ants were acclimated to either a normal or artificially reversed (180 change) magnetic field (MF), then forced to find new bait and establish a trail in an environment of opposite MF polarity. Ants in these circumstances always took significantly longer to create a return trail than in a control environment where the acclimation stage MF did not change. Because the RIFA accumulates in active electrical equipment which have electromagnetic fields associated, the ants may have MF responses.

### *Detection of magnetite-containing tissues in the red imported fire ant.*

Slowik and Thorvilson (1996) located subcuticular ferric material in the abdomens of major, media, and minor RIFA workers by using iron-specific staining confirmed by X-ray spectroscopy. Granular, iron-staining patterns were located just beneath the abdominal cuticle near other cells of subcuticular fat and in short "rods" running anterior to posterior, along anterior abdominal segments. However, no association with nerve cells was detected. Tissues of worker heads and thoraces did not consistently contain areas of localized iron. Queens and alates also did not consistently stain for concentrated iron in body tissues. Gut and ommatidial tissues of all ants occasionally revealed iron-containing areas.

Magnetic resonance imaging (MRI) of RIFA workers, queens, and alates exhibited images similar to those of the honey bee and the monarch butterfly, both of which possess ferromagnetic material (Slowik et al. 1997). This magnetism may arise from internal ferromagnetic material, either in the form of biogenically concentrated iron oxides or iron accumulated through diet. Magnetism was not located in a particular body region of the RIFA, which may be a result of lack of resolution by a clinical MRI on such small specimens. Before a hypothesis of internal compass orientation is accepted, more MF impact, including that of electrical equipment, on ant behavior and navigation must be determined (Slowik and Thorvilson 1996).

## Statement of the Problem and Objectives

### *Relationship with the Electric Power Research Institute*

Beginning in March 1996, the Electric Power Research Institute (EPRI) and Texas Tech University (TTU) Department of Engineering Technology and Department of Plant and Soil Science agreed to study methods to protect electrical equipment from infestation by red imported fire ants (RIFA). The basic purpose of the contract was to develop an electronic device which exploited certain aspects of RIFA behavior and prevented RIFAs from infesting electrical equipment. Initial analysis showed that development of a device that could be installed and required no maintenance would meet EPRI needs for this effort.

### Three phases of research

Laboratory tests and field trials were divided into three phases. Phase 1 entailed the development of a static electrical device (SED1) that would have an optimum size, voltage, and configuration for field application. Financial aspects of the ultimate pest management system are extremely important; therefore, continuous life cycle economic analyses have been maintained at each step of research.

Phase 2 consisted of designing and constructing a second generation of SEDs (SED2). The SED2's optimum size and configuration were constructed based on the results of SED1 field trials. The SED2 design was smaller, more economical, and consisted of one solid sheet of stainless steel and one sheet of perforated stainless steel. In laboratory tests of the SED2, ant colonies were given the choice to relocate to a distant chamber that did not contain an SED2 or to stay in the chamber with the SED2. Behaviors were observed and recorded, and percent mortality was calculated.

Phase 3 consisted of modifying and constructing a third generation of SEDs (SED3) that was self cleaning and more dependable against ants and environmental conditions. The charged surface of the SED3 consisted of two stainless steel strips without perforations. A single SED3 was placed into each of ten infested transformer boxes in Houston, Texas, and two SED3s were placed in five transformer boxes to test whether two devices were more effective in repelling RIFAs than just one device. A second, factorial treatment (physical disturbance of mounds) was administered to colonies in one-half of the treated transformers. Replications of laboratory trials with SED3s of different charged surface areas were completed.

Exploratory research phases have continued. Laboratory colonies have been exposed to brief, intense flashes of light to measure any disruption of foraging behavior, mortalilty, or brood production. Electrical devices with multiple areas of charged surface are being tested against laboratory colonies. Incorporation of integrated pest management tactics to reinforce SED effectiveness in the field are being studied.

# 2

# LABORATORY TRIALS OF ELECTRICAL DEVICES

## Phase 1. Three Technologies

Phase 1 involved designing a device from three different technologies, testing them in the laboratory to identify which technology performed best, and then taking the first generation device to the field for further testing. The three technologies studied are listed below.

1. Microwave Radiation (MRD)

2. Ultraviolet Radiation (UVD)

3. Static Electric Device (SED)

### *Ultraviolet Light (UV) Exposure*

As an extension of EPRI research, RIFA exposure to UV was tested. The purpose was to determine if constant UV exposure increased RIFA mortality. The experiment began on 23 April 1996 and is ongoing. Three colonies of similar size (number of ants), each with brood and dealated reproductives, were transferred to plastic trays. The top three inches of each tray was painted with Fluon to contain the ants. After providing food and water, these colonies were allowed to acclimate for 22 hours. After acclimation, all dead ants were removed from trays, and the colonies were each placed inside specially prepared cardboard boxes to limit light from overhead. Constant UV radiation at 254 nm is applied. One box without UV exposure (total darkness) served as a control. All three colonies are provided liberal amounts of food and water. Observations of activity are made frequently, and dead ants are collected.

Results indicated that ant colonies have increased mortality when exposed to constant UV. The control colony consistently had fewer dead ants than did the two colonies under exposure to UV as shown in Figure 2-1. The number of dead ants collected from each colony showed a peak after sixty-five days. Replications of this experiment will be needed for statistical analysis.

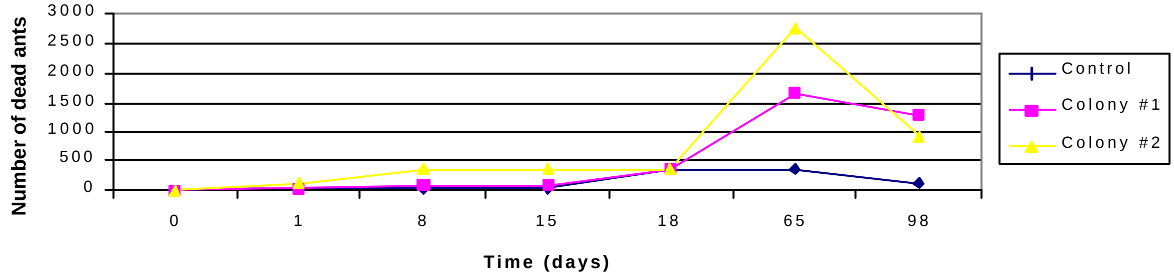



**Figure 2-1**
**Mortality of RIFAs when Exposed to UV Radiation**

### *Repellence Potential of UV*

Each of two RIFA colonies was placed into a foraging tray divided into two separate portions using UV-opaque materials suspended over each tray. The ants had free access to move from one tray side to the other. Water, food, and a brood box were provided on both sides of the divided tray. The colonies were acclimated for 8-10 hours, and individuals dispersed in the tray without constraints. Foraging ants, ants inside each brood box, alates, and dealated reproductives were counted before UV exposure and then each hour during a six hour exposure period. Colony trays were placed in a dark room where a randomly selected side of each tray was illuminated by UV light at 254 nm, and the other side was in darkness. The experiment was replicated five times.

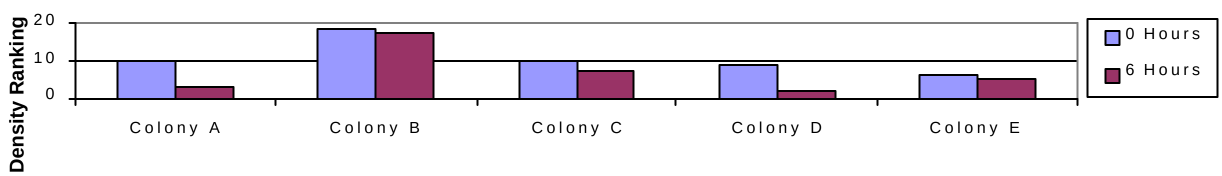



**Figure 2-2**
**RIFA Population Density when Exposed to UV Radiation**

A ranking system was devised to compare the population densities of the brood boxes before exposure to UV. In the ranking system, a ten ranking indicated that ants were equally distributed within a tray. A ranking greater than ten indicated greater number of ants in tray halves that were exposed to UV radiation, and a ranking less than ten indicated a greater number of ants in shaded tray halves. Pre-treated rankings of Colony A and Colony C showed even distribution within a tray. Colonies D and E had the dominant number of ants in the shaded areas of the tray. Colony B was aggregated in the unshaded half of the tray. After six hours of UV exposure four out of five colonies were more aggregated in shaded portions of a tray. Colony B was the only tray that had ants remain in the UV exposed portion of the tray. When a colony is exposed to UV-radiation, ants move away from the area of radiation and transport their brood out of such areas. Reproductive forms also moved from areas of UV exposure and into areas shaded from UV radiation.

### Engineering Development of SED

Prior to March 1996, several tests had been performed to determine RIFA response to the following gradients: thermal, acoustical, magnetic field, and electric field. These studies indicated the RIFA was relatively indifferent to thermal, acoustical, and electric field gradients. The studies also indicated a slight response to magnetic field gradients. The most interesting phenomenon was the accumulation of RIFA in electrical contacts. Dead ants were found accumulated around bare electrical contacts. The cluster of dead ants around contacts is not a new phenomenon; however, the ants attracted to the contact points and not to the thermal, acoustical, magnetic, or electric field gradients was surprising. A search began for ant behavior responsible for accumulations around electrical contacts. There had been conjecture about ant response to magnetic fields, and research verified an ant response to electric fields. Ant response to electric fields seemed to be a more productive area of work than magnetic fields, so electric field response work was begun.

The initial electric field laboratory tests were made using carefully spaced bare-stranded, 14-gauge, copper wire. The spacing between the copper wires could be adjusted to produce a varying electric field from a few hundred volts per meter to several thousand volts per meter. The ants seemed to respond to the highest electric field region corresponding to the closest spacing of the wire. Further investigation determined the ants were simultaneously contacting both bare wires at the closest wire spacing and getting an electrical shock. Modifications were made to the experiment. One of the wires was insulated, and the experiment was performed again. With one wire insulated, the ants lost all interest in the electric field experiment. When the ants contacted both of the energized bare conductors, they exhibited very agitated behaviors including gaster-flagging, fighting and killing their nestmates, and death. The goal in the experiment was exploiting these agitated behaviors to disrupt the RIFA colonies.

With the bare copper wires, research was initiated to investigate the voltage thresholds that caused agitated behaviors. The minimum voltage to cause any response was 10 VAC. Any voltage above 90 VAC would cause violent contractions rupturing the ants' abdomen and causing immediate death. After determining the maximum and minimum voltages for stimulating ant behavior, the research team designed four devices. The first device was bare copper conductors arranged in rows spaced 1 mm apart, close enough for a small worker to bridge the gap. The bare wire exploited the

RIFA behavior and attracted and killed ants confined in the colony tray. The second device was a three-dimensional, aluminum grid. The aluminum grid failed. Aluminum has a thin oxide film coating, and the film is an insulator. Due to the insulating film, the ants were making poor contact with the conductors. After buffing the oxide layer off the surface of the aluminum, the ants could make good contact with the conductor. The aluminum grid worked well after cleaning but would slowly oxidize again over time. The third device was a printed circuit board. The printed circuit board failed. The team designed the circuit board and sent the specifications to an etcher for fabrication. The etcher fabricated the circuit board and then tinned the circuit board with lead solder, as customary in the industry. The lead solder forms an oxide insulating boundary as did the aluminum. The lead oxide layer was cleaned. The circuit board worked, but not well. The surfaces of the lead-coated circuit board or a non-coated board were very smooth. The ants could walk on the surface but did not make as good electrical contact with the circuit board as they did with the wires or the rough aluminum surface. The fourth device was constructed of brass. Copper and brass do not have thick insulating oxide layers so both the materials work well for causing the agitated behavior. The brass, however, was very well polished when received, and it did not provide the ants with a good gripping surface. The brass plates were sandblasted to provide a roughened surface giving the ants very good purchase of the surface. The research team machined the brass to provide ants with contact surface areas and energized the fourth device. The fourth device worked very well.

The fourth device was tested from February 1996 through March 1996. The team then designed a fifth and sixth electrical device. The fifth and sixth electrical devices were designed in April 1996. Twenty of the fifth iteration devices (termed the SED1 in the body of this report) were constructed and deployed into the field, and three of the sixth iteration devices were deployed into the field. The SED1s are sandblasted brass plates forming an energized electrical grid. The potential between the grid is current-limited, and voltage-adjustable from approximately 30 to 50 VAC. The field devices were adjusted to 40 VAC, and current-limited to a maximum of 20 mA. The fifth iteration worked well in the laboratory and appears to be working well in the field. The fifth iteration device has a surface area of approximately 11.5cm x 23.5cm = 270.25 $cm^2$. The sixth iteration electrical devices are a variation on the SED1 and are sandblasted brass plates forming an energized electrical grid. The sixth iteration device active surface area is 11.5cm x 23.5cm = 270.25 $cm^2$. The potential between the grid is current-limited and voltage-adjustable from approximately 20 to 40 VAC. The field devices are adjusted to 40 VAC and current-limited to a maximum of 20 mA. The seventh iteration electrical devices are sandblasted brass plates forming an energized electrical grid. The seventh iteration device's active surface area is 5.75cm x 11.75cm = 67.6 $cm^2$. The potential between the grid is current-limited and is not voltage-adjustable. The output is approximately 65 VAC. The field devices are current-limited to a maximum of 30 mA.

The eighth iteration electrical device (SED2) was tested in the laboratory in October and November of 1996. The eighth iteration device is constructed of sandblasted and perforated stainless steel plates. The grid voltage is approximately 65 VAC. Stainless steel does not have an electrical insulating surface oxide layer and is cheaper than brass plating. Stainless steel is readily available in perforated sheets with several perforation shapes and perforation grid areas from which to choose. The eighth iteration device is current-limited to 100 mA.

Some of the fifth iteration devices (SED1 ) were redesigned as electrically dynamic devices (DED). The DEDs were fitted with electrical timers to periodically turn the device on and off. Part of the ant behavior is to remove dead bodies to the ant graveyard. If the device is turned off periodically, then the ants will clean the device. In the field, ant bodies have not accumulated on the fifth iteration static device, and the ants have generally left the space surrounding the devices. Since there are no accumulations of ant bodies on or around the static devices, and dynamic devices require additional hardware, there has been no further development of the dynamic devices. The cost benefit of the dynamic device was not large when compared to the static devices.

### *Sandblasted, brass device (SED1)*

Trials were completed in the controlled temperature, light, and humidity of the Insectary in the Texas Tech University Agricultural Sciences Building. Individual RIFA colonies were maintained separately in 39 x 51 x 5 cm plastic trays (colony tray). Within each, a plastic brood box (11 x 11 x 3.5 cm with dental plaster bottom) provided a humid habitat for queen(s), brood, and nurses. Foraging ants were presented daily with food, and water was available at all times.

### *Experimental Devices: 40V AC device with 24 square inch grid*

The mean number of foraging ants (95% confidence interval) over a 24-square inch, non-electrical target area in colony trays was between 17.2 and 41.4 during a four-hour period and 12.8 - 21.1 during an eight-hour period. Electrical devices were added to colony trays, and activity of ants was recorded every 30 minutes.

**Table 2-1**
**Mean ant numbers (95% CI) on device**

| | four-hour period | | eight-hour period | |
|---|---|---|---|---|
| | uncharged | charged | uncharged | charged |
| Foraging ants | 25.2 - 63.4 | 76.3 - 254.5 | 15.9 - 41.9 | 112.7 - 175.5 |
| Dead ants | -- | 44.1 - 87.1 | -- | 43.5 - 69.1 |

RIFAs used the SED1 as a new object in their habitat. In addition, ants tend to be more interested in a charged device (Table 2-1). Foraging activity on a charged device was significantly greater ($P$<0.001) than on an uncharged device. In general, ants respond "massively" to a charged device within 30 minutes. The number of foraging ants on an SED can be described by a third-order polynomial equation (Figure 2-3).

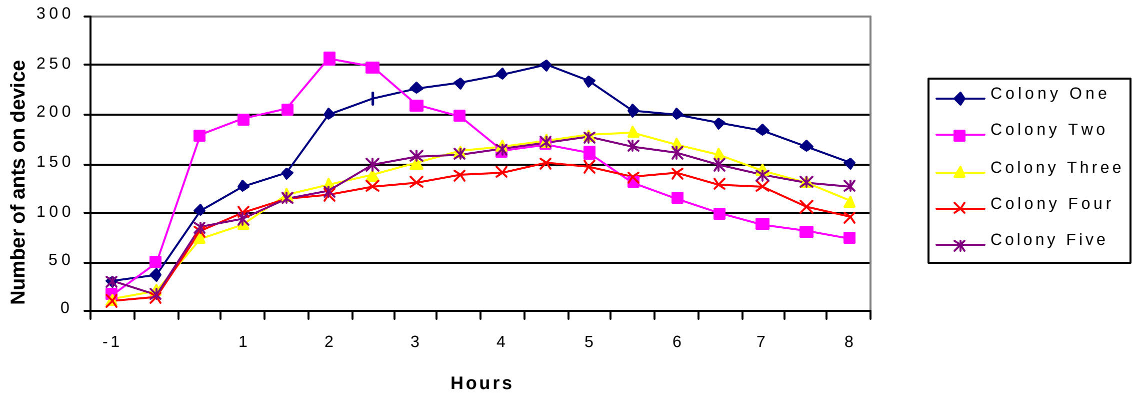



**Figure 2-3**
**The Effect of SED (40 VAC; 24 sq. in.) on RIFA Foraging**

Peak numbers occurred 2.5 to 5 hours after activation, as did peak ant death caused by SED1s (Figure 2-4).

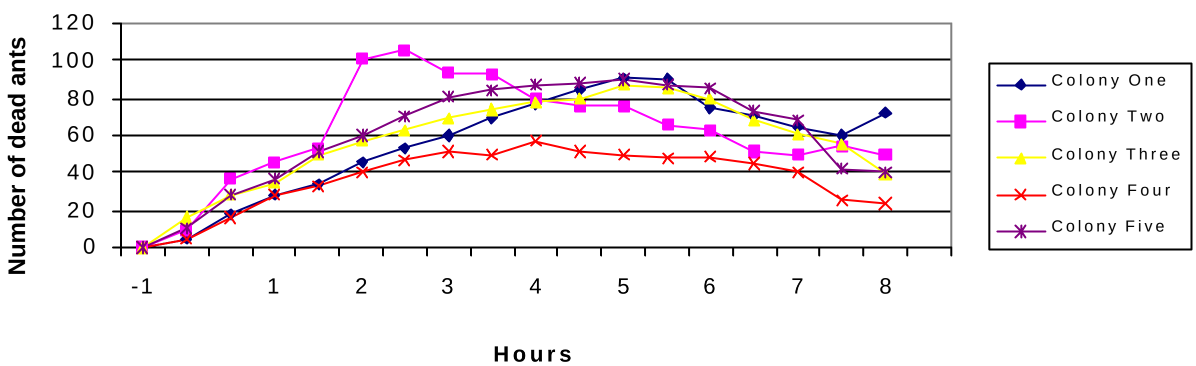



**Figure 2-4**
**The Effect of SED (40 VAC; 24 sq. in.) on RIFA Death**

Ants began cleaning dead ants from devices 2 - 3.5 hours after power-up, and ants began piling debris on the SED within 7 hours after power-up.

### *Comparisons of 40V AC device with 12-, 24-, and 48- square inch grids*

Numbers of ants were recorded at approximately 30-minute intervals for an 8-hour period. Baseline average foraging activity (95% CI) of ants at each recording time over inert targets without an electrical device was 9.0 - 17.2, 12.8 - 21.1, and 17.2 - 28.2 for 12-, 24-, and 48-square inch targets, respectively.

**Table 2-2**
**Mean ant numbers (95% CI) on device**

| Device | | Foraging ants | Dead ants |
|---|---|---|---|
| 12-square inch | | | |
| | uncharged | 12.0 -20.2 | -- |
| | charged | 55.3 - 74.3 | 24.2 - 47.2 |
| 24-square inch | | | |
| | uncharged | 15.9 - 41.9 | -- |
| | charged | 112.7 - 175.5 | 43.5 - 69.1 |
| 48-square inch | | | |
| | uncharged | 52.5 - 71.3 | -- |
| | charged | 90.1 - 207.5 | 29.7 - 54.1 |

Significantly more ants crawled on the charged devices as compared to uncharged devices (*P*<0.01) (Table 2-2).

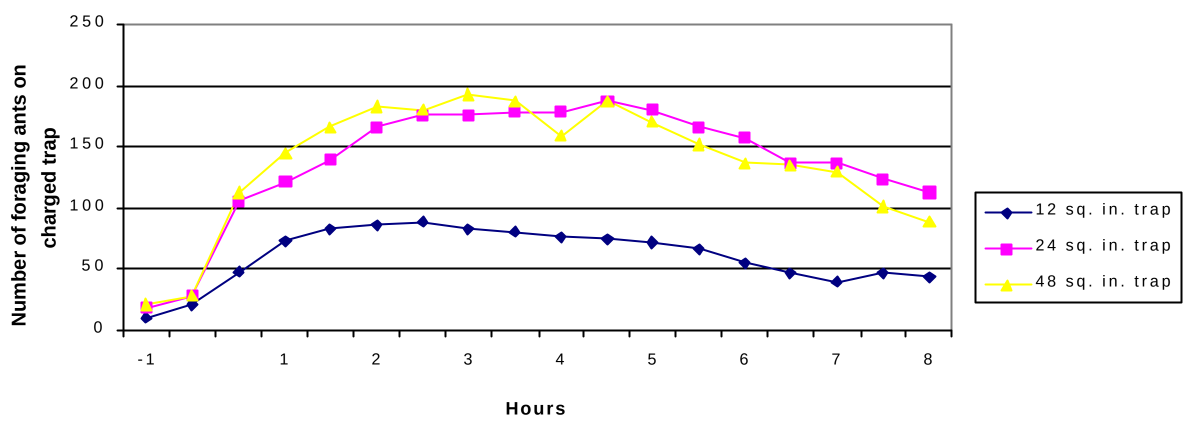



**Figure 2-5**
**The Average Effect of SED on RIFA Foraging**

Analysis of variance (ANOVA) detected significant differences among grid sizes in numbers of ants crawling along the surface ($P<0.005$) and in numbers of dead ants ($P<0.025$). Mean separation by least significant difference (LSD) detected that 12-square inch grid attracted fewer ants than did the other grid sizes, and that 24- and 48-square inch grids were not different as shown in Figure 2-5. The 24-square inch grid killed more ants than the other two sizes (Figure 2-6). Therefore, 24-square inch grid devices may be optimal for field trials.

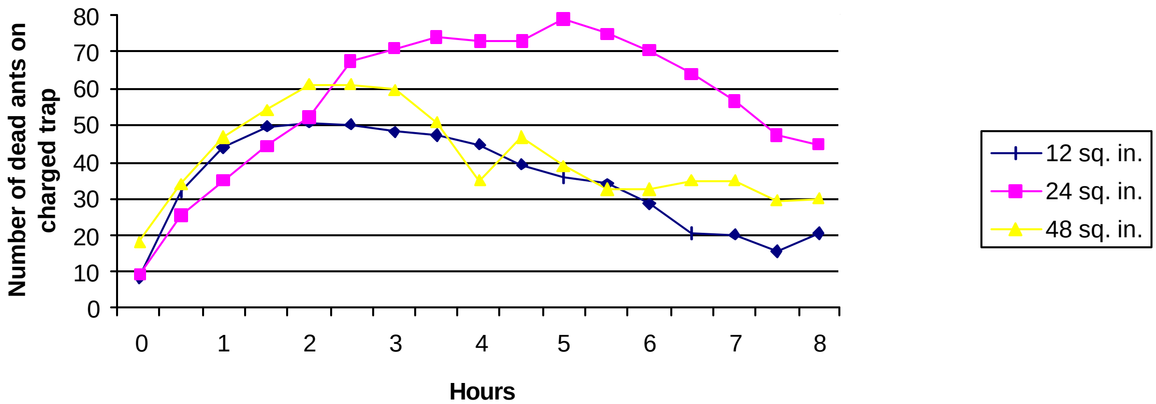



**Figure 2-6**
**The Average Effect of SED on RIFA Death**

### *Dynamic electrical device (DED)*

Due to the destructive behavior of RIFAs in electrical transformers, a research plan was conceived to replicate conditions inside a transformer case. A static electric device (SED1) and a dynamic electric device (DED), which was turned on for two hours and turned off for one hour, were built using 40 VAC (48 sq. in. grid) and 60 VAC (24 sq. in. grid) of current, respectively. Four RIFA colonies were collected from the Abilene, Texas, area and were used in these experiments. One colony was randomly assigned the SED1 treatment, and another was treated with the DED device. The two remaining colonies were untreated controls, and the SED1s were not electrified. Colony behavior, size, bone piles, and level of activity were observed.

Although the charged SED1 increased general activity and agitation, it produced less activity and agitation than on the DED. The peak foraging activity was 2.5 - 5.0 hours after power up, and peak death was 2.5 - 3.5 hours after power up. In comparison, ANOVA detected a significant difference between devices in number of ants dead ($P=0.025$), and foraging on trap surface ($P<0.005$). Experiments with the DED (on/off device) showed a significant increase in ant activity.

Initial observations on 27 May, 1996 revealed all colonies had little brood in brood boxes. By late July, no brood was present in SED1 and DED colonies, and in one control colony. The second control colony had a medium to high density of large brood. Each colony had two brood boxes, and the activity of the DED colony and control was significantly greater than the other colonies. The SED1 colony and control had minimum activity between brood boxes. The SED1 colony used only one brood box, possibly because the large electrical device restricted access to other boxes. By late July, bone piles appeared on the DED within a 24 hr. period, but none were present on the SED1. Bone piles were counted on two separate dates (6/27/96 & 7/30/96), numerically showing differences as shown in Figures 2-7 and 2-8.

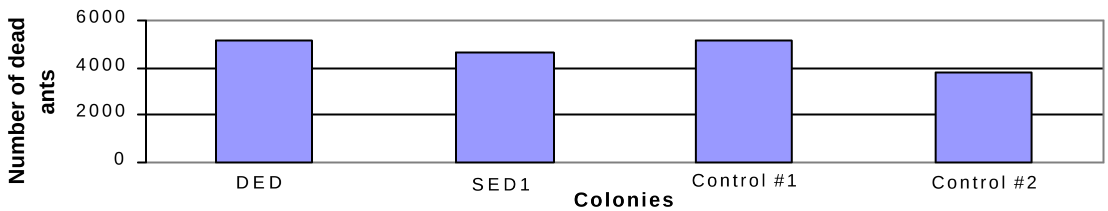



**Figure 2-7**
**Number of Dead Ants from Bone Piles 6/27/96**

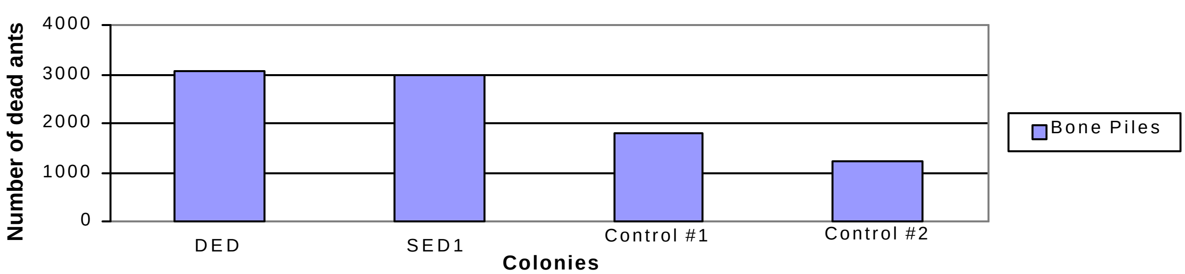



**Figure 2-8**
**Number of Dead Ants from Bone Piles 7/30/96**

All colonies were of approximately equal size in the beginning month of March, yet near the end of July the SED1 colony and one control colony showed a smaller colony size. Colony size was determined by ranking colonies 1-5 (low to high) (Figure 2-9).

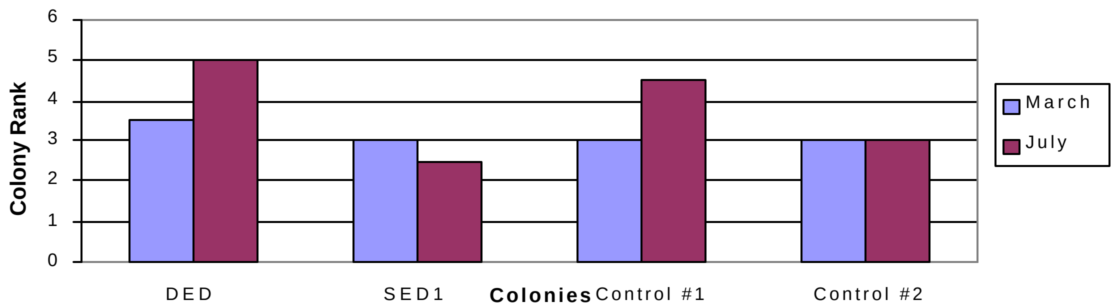



**Figure 2-9**
**Ranking of Colony Size March through July**

The SED1 colony also showed a high death rate in conjunction with lower colony size, which is the opposite of the DED colony which had a high mortality rate with large colony size. Though this initial experiment did not have the statistical support to draw any other conclusions, further experimentation would produce the necessary results and conclusions.

During laboratory tests, it was found that shortly after the power to the DED was cut off, the surviving ants would begin cleaning the dead ants off the device. A cycle of two hours with the DED on followed by one hour with the DED off produced the greatest mortality among the ants and allowed the survivors time to remove the dead ants.

Design of an electronically dynamic low-voltage device (DED) for field application began. A life cycle cost analysis was conducted which compared the expected life cycle cost of the SED1 to the DED. The results of this study showed that the DED's life cycle cost was 600 times that of the SED1. Most of this difference was accounted for by the increased power demand of the electronic timer. The SED1 uses only one kilowatt hour of energy per year. After discussion with Harry Ng, the project manager, a change in the contract was requested to allow the research team to focus the remainder of the effort on fully utilizing the SED as the best technology, lowest life cycle cost option. The DED was too expensive to maintain, so it was canceled from the laboratory tests due to the Net Present Value (NPV). The problem of keeping the device clean for extended periods of time will be addressed by optimizing the geometry of the device with respect to the transformer.

### *Perforated, Stainless Steel Devices (SED2)*

The second generation SED (SED2) consisted of one solid sheet of stainless steel and one sheet of perforated stainless steel. These material changes were made to reduce the oxidation potential inherent to the brass plates used in the SED1 which will increase the ultimate service life of the device. Additionally, the perforated steel was used to reduce the manufacturing cost from the milling used in the SED1. A layer of latex paint was used on one side of the perforated piece of stainless steel to insure that the only circuit that can be made on the SED2 is by the ants themselves when they come in contact with the base plate and the perforated sheet of stainless steel. The SED2 is 12.7 cm by 17.8 cm and uses a 2 to 1, center-tapped transformer. The SED2 was considerably smaller and more compact, and it could be manufactured for about one-half the cost of the SED1. As previously stated, it draws about one kilowatt hour of power per year.

## Laboratory Experiments

### *Single-Chamber Experiments with SED2*

RIFA colonies in plastic trays (55 cm x 13 cm) were subjected to a 50 VAC, 60 VAC, 70 VAC, or a control treatment without a device. Each colony was given equal amounts of food and water and was held in the same environmental conditions of temperature (21-27 $^{\circ}$C), humidity (70-80%), and photo period (12:12).

Bone piles of dead ants were collected once each week, and observations were conducted on behaviors such as number of ants gaster-flagging on electrical devices, number of individuals around a 2.5 cm zone in a brood box, and number of individuals around a 2.5 cm zone from an electrical device. Each observation of a specific behavior for each colony was conducted two times in five-minute intervals daily.

Because ants rear brood throughout time, calculating percent mortality for each colony is not possible without counting newly reared individuals. Notwithstanding, a "death rate index" can be constructed by dividing the total number of dead ants into the whole colony size at the end of each experiment. Thus, comparisons between treated and untreated colonies may detect a difference in mortality with colonies exposed to electrical devices. An unpaired t-test will be used to determine differences among the SEDs.

### *Choice-Chamber Experiments with SED2.*

Initial experiments of choice-chamber experiments began on 6 September 1996 and were terminated on 26 November 1996. Replication (in time) of choice-chamber experiments were initiated on 25 January and terminated on 4 April 1997.

In the second experiment, two plastic chambers measuring 37 x 26 x 18 cm were connected together by a passageway of a 20.5 cm piece of clear tygon tubing (id. 2.5 cm). White card rampways allowed direct access from the tray floors to the tubing. Treatments consisted of one 35 VAC, two 70 VAC (SED2), and a control without a device. The electrical devices were positioned with the grid plate touching the trya floor. Each colony was given equal amounts of food and water and was subjected to the same environmental conditions of temperature, humidity, and photoperiod as in the single-chamber experiment. Food and water for each colony was divided equally between the two chambers, and each chamber had one brood box. This arrangement allowed colonies to move into or choose a chamber distant from the chamber with an electrical device. Measurements of activity, mortality rate, and disturbance were recorded and conducted in the same manner as the single-chamber experiments. Results were compared to the results of the single-chamber experiments. Unpaired t-tests were used to dete t differences among colonies exposed to treatments.

### Results

ANOVA of the SED2 single-chamber experiments detected significant differences ($P$=0.05). In the first replication (Table 2-3), more activity occurred ≤ 2.5 cm from the device in the 70 VAC treatment, the 60 VAC treatment, the 50 VAC treatment, and the control, respectively. The mean number of gaster-flagging ants followed the same pattern, but the majority of the gaster-flagging ants were the ones exposed to the 70 VAC device.

In the second replication of the experiment (Table 2-4), all of the device treatments caused more activity than the control treatment. However, the 50 VAC device caused significantly more activity than either the 60 VAC or 70 VAC devices.

Gaster-flagging was greatest in the ants exposed to the 70 VAC device, followed by the 50 VAC device and the 60 VAC devices. There were no ants observed gaster-flagging in the control treatment.

**Table 2-3**
**Mean numbers of ants, accumulated number of dead ants, and colony size at termination of single-chamber, SED2 experiment (replication 1, 22 August to 4 December)**

| | Mean number [a] | | Accumulation | Colony size |
|---|---|---|---|---|
| Treatment | ≤2.5 cm from device | gaster-flagging ants | of bone pile | after termination |
| 50 VAC | 1.00a | 0.0a | 1560 | 583 |
| 60 VAC | 2.46b | 2.9b | 4510 | 15,111 |
| 69 VAC | 2.92c | 3.6c | 5650 | 11,140 |
| Control | 1.00a | 0.0a | 3350 | 6900 |

[a] Means followed by the same letter within a column are not significantly different (t-test, $P \leq 0.05$, df= 64)

**Table 2-4**
**Mean numbers of ants, accumulated number of dead ants, and colony size at termination of single-chamber, SED2 experiment (replication 2, January to 5 April 1997)**

| Treatment | Mean number [a] ≤2.5 cm from device | gaster-flagging ants | Accumulation of bone pile | Colony size after termination |
|---|---|---|---|---|
| 50 VAC | 4.7b | 2.5a | 6375 | 10450 |
| 60 VAC | 2.9a | 1.8a | 3500 | 6310 |
| 69 VAC | 3.3a | 4.4b | 6287 | 8410 |
| Control | 1.00c | 0.0c | 1550 | 8040 |

[a] Means followed by the same letter within a column are not significantly different (t-test, $P \leq 0.05$, df= 60)

In the first replication of choice-chamber experiments (Table 2-5), only ants in the #2 70 VAC were significantly more active in the ≤ 2.5 cm zone than were the ants in the control treatment.  Not surprisingly, the most active colony (exposed to the #2 70 VAC) also had a significant number of ants that gaster-flagged during observational periods (Table 2-5).  Although accurate estimations of colony size during the trials could not be made, mortality, expressed by bone pile counts, was numerically less in the control colony.

In the second replication (Table 2-6), significantly more ants were active around, and gaster-flagged upon, the #1 70 VAC device.  All SED2s caused greater gaster-flagging than did the control treatment.  Only the RIFA colony exposed to the #1 70 VAC device moved sizable numbers of brood away from the device and into the “escape” tray.

**Table 2-5**
**Mean numbers of ants, accumulated number of dead ants, and colony size at termination of choice-chamber, SED2 experiment (replication 1, 22 August to 4 December)**

| Treatment | Mean number [a] ≤2.5 cm from device | gaster-flagging ants | Accumulation of bone pile | Colony size after termination |
|---|---|---|---|---|
| 35 VAC | 1.45ab | 0.21b | 2345 | 4401 |
| 70#1 VAC | 1.81a | 0.75ab | 6390 | 8000 |
| 70#2 VAC | 1.45ab | 0.95a | 2740 | 5500 |
| Control | 1.0b | 0.0bc | 715 | 9040 |

[a] Means followed by the same letter within a column are not significantly different (t-test, $P \leq 0.05$, df= 45)

**Table 2-6**
**Mean numbers of ants, accumulated number of dead ants, and colony size at termination of choice-chamber, SED2 experiment (replication 2, January to 5 April 1997)**

| Treatment | Mean number [a] ≤2.5 cm from device | gaster-flagging ants | Accumulation bone pile | Colony size after termination |
|---|---|---|---|---|
| 35 VAC | 1.2a | 1.7a | 1542 | 1260 |
| 70#1 VAC | 1.8b | 2.4b | 2354 | 2880 |
| 70#2 VAC | 1.2a | 0.8a | 3507 | 317 |
| Control | 1.0a | 0.0c | 3185 | 1120 |

[a] Means followed by the same letter within a column are not significantly different (t-test, $P \leq 0.05$, df= 34)

The schematics, drawings, and parts lists of the SED1 and SED2 are detailed in Appendix C.

## Stainless Steel Device with Stainless Steel Strips (SED3)

### *Single-Chamber Experiments with SED3.*

Five RIFA colonies were subjected to two 70 VAC electrical devices, and two colonies were introduced to two non-electrical SED3s. Also two RIFA colonies were subjected to one SED3. An additional device, (SED4) which has five times the amount of charged surface area was also implemented. Two RIFA colonies were introduced to one of these devices and one colony introduced to one non-electrical device. Each experiment was conducted for a two-week period. Bone piles were collected once each week, and observations were conducted in the same manner as in the SED2 experiments.

The mean number of ants in 2.5-cm zones was calculated using the mean rating index, and comparisons were made among treatments using ANOVA ($P$<0.05). The mean rating index is explained below.

0 = 0 RIFAs around the 2.5 cm zone

1 = 1-25 RIFAs around the 2.5 cm zone

2 = 25-50 RIFAs around the 2.5 cm zone

3 = 50-75 RIFAs around the 2.5 cm zone

4 = 75-100 RIFAs around the 2.5 cm zone

5 = 100 + RIFAs around the 2.5 cm zone

Differences in mean number of gaster-flagging individuals on SEDs among treatments were tested using ANOVA. Mean mortality index was calculated by dividing the number of ants in the whole colony after being sacrificed into bone pile numbers. Indices were each compared to the control by students' t-test ($P\leq$ 0.05).

### *Results*

Significant differences were detected for mean rating of ant numbers around a 2.5 cm zone (Table 2-7). All three SED treatments were greater than the control. No significant differences were detected for the mean mortality index at a $P$=0.05 level (Table 2-8). The two SED3 treatments had the least probability of being similar to the control, but the SED4, numerically, had the highest average mortality index. The SED4 produced a high average number of RIFAs that gaster-flagged (Figure 2-10), possibly because the SED4 had a large charged surface area. Research leads to believe that large charged surface area is correlated with greater gasster-flagging, colony activity, and mortality.

**Table 2-7**
**Mean Rating of Ant Numbers in ≤ 2.5 cm zone around SED3 Treatments**

| Device | Mean Rating[a] | t-statistic | P>t |
|---|---|---|---|
| One SED3 | 3.8 | 29.6 | 0.0 |
| Two SED3s | 5.0 | 79.0 | 0.0 |
| SED4 | 5.0 | 79.0 | 0.0 |
| Control | 1.0 | | |

[a]SED treatments compared to control (students' t-test, *P*>0.05)

**Table 2-8**
**Mean Mortality Index of Colonies Compared to Control**

| Device | Mean Mortality Index[a] | t-statistic | P>t |
|---|---|---|---|
| One SED3 | 17.0 | 1.2 | .430 |
| Two SED3s | 35.0 | 4.6 | .136 |
| SED4 | 36.8 | 2.3 | .262 |
| Control | 12.0 | | |

[a]Mean mortality index=mean bone pile numbers/colony numbers at completion of experiment

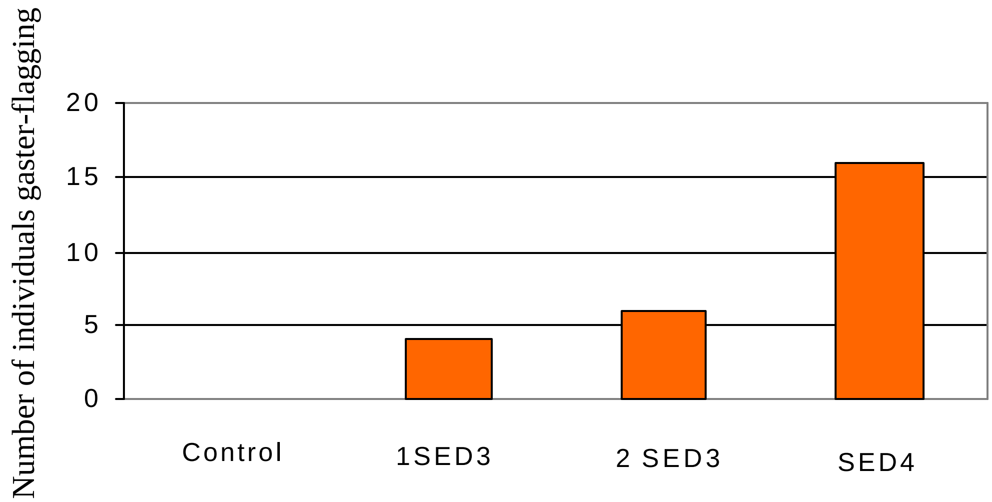



**Figure 2-10**
**Average number of gaster-flagging individuals in a five-minute observational period**

## Strobe Flash Experiment

Brief, intense flashes of light may disrupt the natural circadian rhythm of RIFAs. This hypothesis was tested in the laboratory with the idea of implementation into the field to protect transformers from RIFA infestation.

Laboratory studies have consisted of RIFA colonies in single-chamber trays subjected to a flashing strobe light. Half of each colony tray was covered with opaque cardboard to provide shade from the strobe light. At initiation, brood boxes that housed the reproductive queen and brood were placed in the UV exposed portion of the trays. The shaded and unshaded sides of the tray had identical configurations with brood boxes, water tubes, and equal amounts of food. A flashing strobe light was set to flash five minutes every hour. Four colonies were exposed to the flashing strobe light, and three control colonies were not exposed to the strobe light. These experiments were conducted in two-week intervals. Observations were made for five-minutes twice daily. The percent of the RIFA colony that moved from exposed to shaded areas was recorded, reduction in brood numbers was determined, and comparisons were made with non-flashed control colonies using t-tests ($P \leq 0.05$).

A student's t-test indicated differences in exposed areas between treatments at the beginning of the experiment. Differences also existed between shaded areas and UV exposed areas for the separate treatments at the beginning of the experiment. No significant differences in the number of RIFAs in brood boxes ($\leq$ 2.5) between the shaded areas at the end of the two-week experiment.

- Flashed colonies: mean rating - 0.5
- Un-flashed colonies: mean rating - 0.3
- $t = 1.3$
- $P > 0.192$

Due to these results, the research team believes the experimental design was flawed. This preliminary work indicates that better measures need to be taken to prevent excessive experimental error.  Steps are being taken to refine the experimental design in order for proper conclusions to be drawn from future work.

# 3

# HOUSTON FIELD TRIALS OF ELECTRICAL DEVICES

## SED1

With the decision made to use low-voltage electricity as the base technology for the static electrical device, design of an SED began in earnest. Several models and configurations were tried in the laboratory with varying degrees of engineering success. Virtually every version of SEDs had similar results when used to attract and kill RIFA. Thus the heart of the engineering work became the development of a system which was optimized for size, voltage, and configuration. It was substantially proven that the presence of an SED1 in the vicinity of an active RIFA colony both attracted the ants and caused them to emit pheromones. When the pheromone concentration of the RIFAs on the SED1 became thick, the ants attacked and killed each other. This phenomenon was observable in many replications to a statistical confidence level of in excess of 98%. Therefore, it was determined that the SED1 was indeed a viable technology and the decision was made to take it to field testing.

### *Materials and methods*

The first field trial of the SED1 for RIFA repellence was conducted in Houston, Texas. Mr. David Visconti (Houston Power and Light) located RIFA-infested, pad-mounted transformers in a residential neighborhood served by HP&L. On 20 May 1996, transformers were opened, and a randomized treatment was applied to each transformer (Table 3-1).

**Table 3-1**
**SED1 Treatments Applied to RIFA Colonies in Transformers (20 May 1996)**

| SED1 | RIFA Colony | Number of transformers |
|---|---|---|
| present | intact | 10 |
| present | removed | 10 |
| absent | intact | 5 |
| absent | removed | 5 |
| | | Total 30 |

The colonies in all of the transformers were large and active, and they were not significantly different among treatments. SED1s required 40V AC, were constantly electrified, and had an electrified grid surface of 48-square inches. RIFA colonies were either removed from transformers with a shovel or were left intact. Control treatments did not have an SED, but colonies were either removed or left intact. After twenty-four hours, all transformers were again opened and inspected. All electrical devices were functioning, and no changes in RIFA colony status were noted. Fourteen days (3 June 1996) after initiation of the field experiment, all transformers were opened again, and the presence or absence of active RIFA colonies were recorded.

### Results

Thirteen of twenty transformers in which SEDs had been installed had no RIFA activity, and six transformers had a trivial amount of RIFA activity. In contrast, 80% of transformers without SEDs had active colonies, regardless of initial colony disturbance (Table 3-2).

**Table 3-2**
**Percent Active RIFA Infestations (3 June 1996)**

| Colony Treatment | SED1 | |
|---|---|---|
| | present | absent |
| removed | 30% | 80% |
| intact | 40% | 80% |

Data from the fourteenth day was analyzed as a factorial treatment design with 2-way analysis of variance (ANOVA) and a level of significance set at $P$=0.05. No significant difference ($P$=0.71) was detected in the colony disturbance treatment (removed or retained in transformers). However, the presence of an SED significantly ($P$=0.02) affected colonies. Significantly fewer active colonies were found in transformers with an electrical device. The interaction between treatment factors was not significant ($P$=0.79). The placement of an SED in RIFA-infested transformers had a significantly negative impact on ant activity after fourteen days with a confidence level of 98%. This data was particularly satisfying because the devices were placed in the "worst case" scenario of affecting large, well-established RIFA colonies in transformers.

Colonies in transformers were checked again on 21 October 1996 and were rated on activity level as follows:

1 = 0 RIFAs, no activity

2 = 1 to 100 RIFAs, little activity

3 = 101 to 1000 RIFAs, medium activity

4 = 1001 to 10000 RIFAs, high activity

5 = over 10000 RIFAs, extremely high activity

Only 50% of RIFA colonies in transformers with installed SED1s were active on 21 October 1996 (Table 3-3). Two-way ANOVA of mean mound ratings detected, with 88% confidence ($P$ =0.119), that true differences existed between the presence or absence of SED1s in the trial. Also, the level of disturbance is important. With 89% confidence ($P$ = 0.112), removal of the RIFA colony by shoveling adversely affected treated colony mounds. Interaction between device treatment and shoveling existed at a 88% confidence level ($P$ = 0.119).

**Table 3-3**
**Percent Active Mounds (index >2) in Transformers Treated with SED1 (Houston, TX, 21 October 1996)**

| Colony Treatment | SED1 | |
|---|---|---|
| | present | absent |
| removed | 50% | 60% |
| intact | 50% | 80% |

## SED2

### *Materials and methods*

Twenty SED2s were manufactured for use in Task 3 field testing, which was initiated in September of 1996.

The SED2 was tested in the laboratory to optimize voltage and configuration. Introduction of the 70 VAC SED2 and the first observational measurements began in September and October of 1996. In September, twenty new transformers were treated with an SED2. Of the twenty new transformers, RIFA colonies were removed from ten of the transformers, and the RIFA colonies in the remaining ten transformers were left undisturbed. Through observation, an estimated number of RIFAs in the transformers was determined.

### Results

Fourteen days later, all transformers were opened again and vitality of colonies was measured. Several devices were non-functional and were brought back for diagnostic tests. The complication with the SED2s was due to resistors and other parts that were initially bad. There was little visual difference in colony vitality before and after introduction of SED2s. Because of these results, new construction designs were developed for optimal application. The third generation SED (SED 3) was constructed for introduction in the spring of 1997.

After analyzing the results of the SED2 experiments and field trials, the positioning of the SED2 was a major factor in designing the SED3. Several behaviors directly related to RIFA colony disturbance and relocation were the cause of the failure of some of the SED2s. This has led to the determination of the best way to position the SED2, which was important for transformer protection. To achieve optimum performance, two SED2s may be necessary. The size of the transformers in Houston may be large enough where the RIFAs could keep enough distance from one SED2 not to be disturbed. A certain threshold must be breached to induce the RIFAs to the particular behavior of vacating the transformer. Large amounts of debris were piled on the SED2s, and in some instances the electrical device was almost buried. This caused corrosion of the device, inevitably making it non-functional. Through observation, these colonies had the ability to completely bury the transformer which, at the very least, caused a buffer zone. The burying of SED2s by ants was the main cause for electrical device failure. Unfortunately, ants have unlimited access in the field, so positioning the device right side up in the transformer helped prevent this problem. It was also possible that the environmental conditions in the transformers were excellent for RIFA survival and colony reproduction. It was uncertain, but probable, that these conditions over rode the disturbances caused by the SED2s.

A question arose as to whether two SEDs placed in RIFA-infested transformers would be more effective in repelling RIFAs than one SED. Therefore, a 2x2 factorial experiment of four treatments was initiated on 18 March 1997.

| Number of SED2s | RIFA Colony | No. of Transformers |
|---|---|---|
| Two | Disturbed | 2 |
| Two | Undisturbed | 3 |
| Absent | Disturbed | 5 |
| Absent | Undisturbed | 5 |

**Figure 3-1**
**Treatments of SED2 Field Tests Initiated 18 March 1997 in Transformers in Houston, TX.**

Five RIFA-infested transformers were treated with two SED2s, two of which had RIFA mounds shoveled out. The transformers with two SED2s did not show enough of a difference in RIFA colonies from the transformers with only one SED2 to make use of the second SED2 in the transformers. Some SEDs were left in the field for long-term viability studies.

## SED3

The SED3's design called for more effective insulation between energized plates and more effective self-cleaning so ants could not pile up debris. Gaster-flagging occurs most around the perimeter of the charged surface, so the SED3 was designed without perforations and several stainless steel strips to increase the perimeter in relation to the charged surface area. Charged surface area was another characteristic for consideration for optimizing future SEDs. Construction of the SED3 was finished and tested in the spring of 1997. Particular attention was again paid to certain behaviors such as gaster-flagging, ants defeating the SED by piling debris on it, the number of individual ants around the SED, and mortality indexes.

### *Materials and methods*

Field tests for the SED3 began in the spring of 1997. In addition to the ten transformers receiving one SED3, five transformers received two SED2s, and five transformers received two SED3s (Appendix C). Two weeks after introduction, all of the transformers were checked for RIFA activity and working conditions of the SEDs. Periodic checks were conducted throughout the spring and summer of 1997 for the condition of SEDs and RIFA activity. Two-way ANOVA was applied to all of the data.

Two-way analysis of variance of March 1997 mean activity data indicated that no significant difference among RIFA colonies in transformers existed ($P > 0.05$) before the experiment began (Table 3-4). Installation of devices and distribution treatments were then applied.

**Table 3-4**
**Two-way, factorial analysis of variance of mean activity ratings of RIFA mounds in transformers in Houston, TX, March 1997 (pre-treatment ratings).**

| Source | Sum of Squares | Deg. of Freedom | Mean Squares | F-ratio | Prob>F |
|---|---|---|---|---|---|
| Among Devices | 4.4 | 3 | 1.5 | 1.8 | 0.186 |
| Between Disturbance | 2.1 | 1 | 2.1 | 2.5 | 0.108 |
| Interaction | 0.9 | 3 | 0.3 | 0.3 | 0.792 |
| Error | 17.6 | 21 | 0.8 | | |
| Total | 25.0 | 28 | | | |

### *Results*

Several problems were revealed during the 15 April observations (Appendix C). In one SED3 (an undisturbed transformer), RIFAs had responded by completely burying the device which caused it to short out. That devices was replaced by a functioning device on the same day. Four out of the five two SED2 treatments had some sort of technical problem. One device was shorted out by a large snail on the device. Three of the devices were not functioning at all, most likely due to faulty resistors. Because of all the SED2 defects, these devices were deleted from further analysis.

Analysis of viability rankings of colonies on 15 April failed to detect significant differences among treatments (Table 3-5). However, disturbance may have had the effect at 89% certainty ($P = 0.115$). Percent rating changes between March and April ranged between -24.3% and -42.1% (Table 3-5). April mean activity ratings of the control colonies were significantly less ($P < 0.05$) than in March (Table 3-6), and with 94% certainty, differences existed in the two SED3 treatments ($P = 0.058$). Disturbance by shoveling was important in the April data (Table 3-7). In each treatment activity ratings were numerically less in the disturbed and the control ($P$=0.008) colonies. Encouraging results of SED3 treatment combined with RIFA disturbance were present (Table 3-6).

Unusually dry, hot conditions were prevalent in Houston during summer 1997. Only seven colonies remained in the experimental transformers when observations were made in August (Appendix C), and all of the colonies ranked a very low 2 rating.

Colonies had apparently vacated the transformers, dug deeply into the soil to escape the heat of the transformer interior, or died during the summer. As a consequence, statistical analysis of the data was not possible. These observations emphasize the importance of climatic factors in the survival of RIFA colonies. Future research must include environmental factors of an integrated program of RIFA population management in electrical equipment.

**Table 3-5**
**Two-way, factorial analysis of variance of mean activity ratings of RIFA mounds in transformers in Houston, TX April 1997.**

| Source | Sum of Squares | Deg. of Freedom | Mean Squares | F-ratio | Prob>F |
|---|---|---|---|---|---|
| Among Devices | 0.31 | 2 | 0.1 | 0.1 | 0.871 |
| Between Disturbance | 2.3 | 1 | 2.3 | 2.5 | 0.115 |
| Interaction | 1.2 | 2 | 0.6 | 0.6 | 0.543 |
| Error | 16.1 | 17 | 0.9 | | |
| Total | 19.9 | 22 | | | |

**Table 3-6**
**Mean activity ratings, regardless of disturbance treatment, of RIFA mounds in transformers in Houston, TX, 1997**

| Device | Mean rating (±SD)[a] | | Percent | | |
|---|---|---|---|---|---|
| Treatment | March (pre-trt) | April | change | t-statistic | *P*>t |
| 1 SED3 | 3.7 (0.8) | 2.8 (1.4) | -24.3 | 1.8 | 0.108 |
| 2 SED3 | 3.8 (1.0) | 2.2 (0.5) | -42.1 | 3.0 | 0.058 |
| Control | 3.9 (1.1) a | 2.7 (1.3) b | -30.8 | 2.7 | 0.024 |

[a] Mean ratings within a row followed by different letters are significantly different (Unpaired t-test, critical $P$ =0.05)

**Table 3-7**
**Mean activity ratings of RIFA mounds in transformers in Houston, TX, 1997**

| Device Treatment | Disturbance Treatment | Mean rating (±SD)[a] March (pre-trt) | April | Percent change | t-statistic | *P*>t |
|---|---|---|---|---|---|---|
| 1 SED3 | disturbed | 4.2 (0.8) | 2.6 (1.7) | -38.1 | 1.9 | 0.092 |
| | undisturbed | 3.2 (0.4) | 3.0 (1.2) | -6.3 | 0.3 | 0.740 |
| 2 SED3 | disturbed | 4.0 (2.0) | 2.0 (0.0) | -50.0 | 2.0 | 0.184 |
| | undisturbed | 3.5 (0.7) | 2.5 (0.7) | -28.6 | 1.4 | 0.293 |
| control | disturbed | 4.0 (1.4) a | 1.6 (0.5) b | -75.0 | 3.5 | 0.008 |
| | undisturbed | 3.8 (0.8) | 3.8 (0.8) | 0.0 | 0.0 | 1.000 |

[a] Mean ratings within a row followed by different letters are significantly different (Unpaired t-test, critical *P*= 0.05)

# 4

# DISCUSSION OF LABORATORY AND FIELD TRIAL RESULTS

## Design of Static Electrical Device

The static electrical devices (SED) tested in this project disrupt red imported fire ant (RIFA) colony organization and cause destruction or movement of the colony. Devices stimulated the defensive behaviors characteristic of RIFAs including gaster-flagging (release of alarm pheromones), fighting within the colony, and death. The dead ants were accumulated in "bone piles" around the device, and other debris was piled near the device in an attempt to defeat the aggravating element in their environment.

When tested in the field under the most challenging conditions (removal of established colonies from ground-mounted transformers), the devices had a significant effect. Physical disturbance of the colonies by shoveling was effective in field trials and should be implemented in an integrated pest management (IPM) program. The devices will have most efficacy when used in tandem with additional IPM tactics, such as application of short persistence, insecticides, sealing of electrical connections, and ant-excluding boxes. However, SEDs have the advantage of long-term efficacy at a low annual cost.

The most efficacious SED design may be one of stainless steel with maximum perimeter of charged surface. This design would require as many as possible numbers of narrow, vertically aligned steel strips ($\leq$ 10 mm) upon a charged steel base that also supports a transformer and necessary resistors and connectors. By maximizing perimeter features, ants would have greater chances of bridging two charged surfaces, becoming electrified, and eliciting the peculiar behaviors that disrupt colony organization.

## Life Cycle Cost Analysis: Static Electric Device #1 (SED1), Static Electric Device #2 (SED2), Ultraviolet Radiation (UVD), and Microwave Radiation (MRD)

An important feature of this project is the continuous economic analysis of the SEDs as they are developed. The research team has found this to be the fundamental decision making criteria for direction of the research effort. The contract calls for a detailed economic analysis of the final prototype and that analysis will draw on the work done throughout the course of the project. The team's goal is to design, test, and produce a device which is not only technically feasible in terms of being manufacturable and effective in the field, but also minimizes the life cycle cost (LCC) per unit to the electric power industry if they should decide to adapt and use this device. Thus, as technical and scientific information is learned in both the field and the laboratory, the impact of that information is evaluated on an economic basis to determine if the new information will be exploited in future generations of the device.

The initial economic analysis was to compare three competing technologies identified as possible candidates in the original proposal. The following assumptions were made.

1. Energy costs are $0.05 per kilowatt hour.

2. All devices will have equal useful lives of 20 years.

3. Interest is 7% and consistent with other public utility analysis.

4. The Static Electric Device (SED) and the Ultraviolet Radiation Device (UVD) can be manufactured and installed at a first cost of $20 per device. The Microwave Radiation Device (MRD) will cost $50 per device to manufacture and install.

5. All devices will operate with no maintenance or replacement for their entire useful life.

The energy consumption used by the three different devices are listed below.

- SED @ 1 watt = 8.76 KW-hr/year

- UVD @ 24 watts = 210.24 KW-hr/year

- MRD @ 125 watts = 1,095.00 KW-hr/year

Using the above assumptions and factors, the results of the economic analysis are shown below.

**Table 4-1**
**Economic Analysis of Competing Technologies**

| Device | First Cost | Annual Energy Cost | Net Present Worth of the Costs | Equivalent Uniform Annual Cost |
|---|---|---|---|---|
| SED | $20.00 | $0.44 | $24.66 | $2.33 |
| UVD | $20.00 | $10.51 | $131.34 | $12.40 |
| MRD | $50.00 | $54.75 | $630.00 | $59.47 |

The assumptions made are appropriately conservative for a preliminary analysis. The energy consumption rates are an order of magnitude apart. Thus, a linear cost relationship can be assumed between devices. Sensitivity analysis on the assumptions will not find much variance in relative differences between the devices because of the well-established differences in energy consumption rates. To change the order of merit between alternatives, a major difference in manufactured cost or operation and maintenance cost would have to be found. The SED can probably be manufactured at a lower cost than assumed, and the microwave device will probably cost more to manufacture and install than assumed. Maintenance costs for the three devices will roughly be equal, with the UVD having the lowest of the three. Energy consumption is the major operations cost, and an analysis shows that the SED will be the preferred technology in that category. Neither the value for the interest rate nor the actual figure for hourly energy cost will impact the final decision or the relative order of merit. If economic lives are significantly different, the result may be changed.

The MRD can never compete with either the SED or UVD on a life cycle cost basis. The SED is the most economically appropriate device to put in the transformers to repel RIFAs. The annual energy cost for the SED2 is $0.44, compared to the UVD of $10.51, and the MRD of $54.75. In comparing the life cycle cost between the SED1 and SED2, the SED2 was the more economical. The UVD is not feasible as UV has a documented history of deteriorating insulation. Therefore, SED was selected as the best candidate for exploitation and work continued in that direction.

The team has made a number of decisions not to develop features which exploit all aspects of RIFA behavior based on the potential impact to the LCC of the device. For example, the original proposal contemplated the development of a dynamic device (DED) which could clean itself of debris left by the ants. Subsequently, it was discovered that if the device was turned off after a period of about 2 hours, the surviving ants would clean the charged surface of corpses and debris that accumulated during that period in which the surface was charged. Economic analysis of a design which incorporated an electronic timer found that including this feature caused the LCC of the DED to increase by nearly 600 percent. After discussions with the project manager and sponsors, it was decided to change the contract to focus all efforts on the development of the SED. The benefits accrued by making the device self-cleaning did not justify the exorbitant increase in LCC.

Work was generally directed at determining the optimum material, voltage, and charged surface area. Each of these parameters presents an interesting challenge to the problem of minimizing LCC. Obviously, the charged surface's size will directly influence the cost to manufacture the SED with a larger area creating a need for more material, and hence a greater first cost. The research has shown that an area of about 24 square inches provides the optimum RIFA mortality rate. Forensic analysis conducted after the second field trial showed that corrosion due to gaster- flagging was greatest along the perimeter of the charged surface. When taken into consideration, it makes sense that the RIFAs have the greatest probability to gaster-flag on the portion of the charged surface where they are first subjected to an electric charge as they complete the circuit between the two plates. Thus, SED3 was designed to maximize the perimeter with respect to the charged surface area and took on a different geometric shape.

Stainless steel was found to be the best solution for providing a material which is resistant to corrosion. It provides a good conductive surface and is relatively inexpensive to procure and manufacture. Its performance in the field was the best of all alternatives. It also seemed to be more resistant to damage due to power surges and other environmental challenges. After the second field trial, the team determined to minimize the operating voltage as a way to reduce the energy requirement and directly reduce LCC. The SED2 was designed as an open circuit which effectively eliminated operational power requirements until FIRAs engaged the device and completed the circuit. This was extremely successful from a LCC standpoint. However, the design was susceptable to electronic failure due to environmental factors. The SED3 solved this problem by providing two separate parallel open circuits which appeared to "harden" the device substantially. This design change reduced the failure rate from 45% in the SED2 to only 6% in the SED3. While the sample size in both cases is not significant, the trend is clear, and this feature will be retained and enhanced in future versions of the technology.

The following LCC analysis assumptions were made during the course of this analysis.

1. Inflation is 7% and will represent the time value of money in this computation.

2. Electric power is available at a cost of $0.05 per kilowatt hour.

3. The devices can be installed by a lineman in 15 minutes at a labor cost of $5.00 per device.

4. The cost to mass produce the devices is 50% of the actual labor and material cost to produce them during this project.

5. Expected costs due to device failure can be annualized based on the field failure rate for each version of the SED. This idea is extremely conservative due to the relatively short time frame of this study and the long time frames that this device is expected to operate. Two sets of analyses will be shown. One will neglect expected cost of failure, and one will include it. The actual costs will fall between the two values calculated in the study and would tend to be closer to the lower value than to the higher one.

6. The DED was assumed to be an SED2 with an electronic timer and is included in the Net Present Value (NPV) analysis for completeness, but because of its cost it was eliminated as a viable option for the remainder of the LCC. The life cycle cost analysis for each of the devices is detailed below.

<u>SED1 Costs:</u>

| | |
|---|---|
| Cost to produce | = $202.62/unit |
| Mass production cost | = $101.31/unit |
| Cost to install | = $ 5.00/unit |
| Annual energy requirement | = 8.76 kilowatt hours/year |
| Annual energy cost | = $ 0.44/year |

<u>SED2 Costs:</u>

| | |
|---|---|
| Cost to produce | = $ 40.49/unit |
| Mass production cost | = $ 20.25/unit |
| Cost to install | = $ 5.00/unit |
| Annual energy requirement | = 1.00 kilowatt hours/year |
| Annual energy cost | = $ 0.05/year |

SED3 Costs:

| | |
|---|---|
| Cost to produce | = $ 24.59/unit |
| Mass production cost | = $ 12.30/unit |
| Cost to install | = $ 5.00/unit |
| Annual energy requirement | = 1.00 kilowatt hours/year |
| Annual energy cost | = $ 0.05/year |

DED Costs:

| | |
|---|---|
| Cost to produce | = $ 40.49/unit |
| Mass production cost | = $ 20.25/unit |
| Cost to install | = $ 5.00/unit |
| Annual energy requirement | = 592 kilowatt hours/year |
| Annual energy cost | = $ 29.60/year |

If a useful life of 20 years is assumed for each alternative, the net present value of the life cycle costs are as follows.

**Table 4-2**
**Net Present Value Analysis SEDs & DED**

| DEVICE | NPV ($/unit) |
|---|---|
| SED1 | $ 110.97 |
| SED2 | $ 25.78 |
| SED3 | $ 17.83 |
| DED | $ 339.36 |

It is standard practice to evaluate alternatives on an equivalent uniform annual cost (EUAC) basis. This form of analysis spreads all the costs involved across the useful life of the device and seeks to give the user an objective method in which to determine between competing alternatives. This method tends to favor those alternatives with lower periodic costs and is thus very sensitive to the actual number used for the assumption of a useful life. Additionally, since this particular analysis is for a device which will be installed and not maintained, the useful life assumption will be varied between five and forty years to show the ultimate sensitivity of the outcome to that given assumption. Finally, the DED is dropped from this analysis based on the outcome of the previous Net Present Value analysis. Annual device failure rates are 39% for SED1, 45% for SED2, and 6% for SED3 based on field trial data. The expected cost of device failure is calculated by multiplying the first cost of a given device times its expected annual failure rate. This is then added to the EUAC to find an EUAC including failure. The results of this analysis are shown in Tables 4-2 and 4-3 and Figures 4-1 and 4-2.

**Table 4-3**
**Equivalent Uniform Annual Cost Analysis SED1, SED2, and SED3 Neglecting Expected Cost of Device Failure**

| Useful Life (years) | SED1 EUAC ($/year) | SED2 EUAC ($/year) | SED3 EUAC ($/year) |
|---|---|---|---|
| 5 | 27.02 | 6.29 | 4.35 |
| 10 | 15.80 | 3.67 | 2.54 |
| 15 | 12.18 | 2.83 | 1.96 |
| 20 | 10.48 | 2.43 | 1.68 |
| 25 | 9.52 | 2.21 | 1.53 |
| 30 | 8.94 | 2.08 | 1.44 |
| 35 | 8.57 | 1.99 | 1.38 |
| 40 | 8.32 | 1.93 | 1.34 |

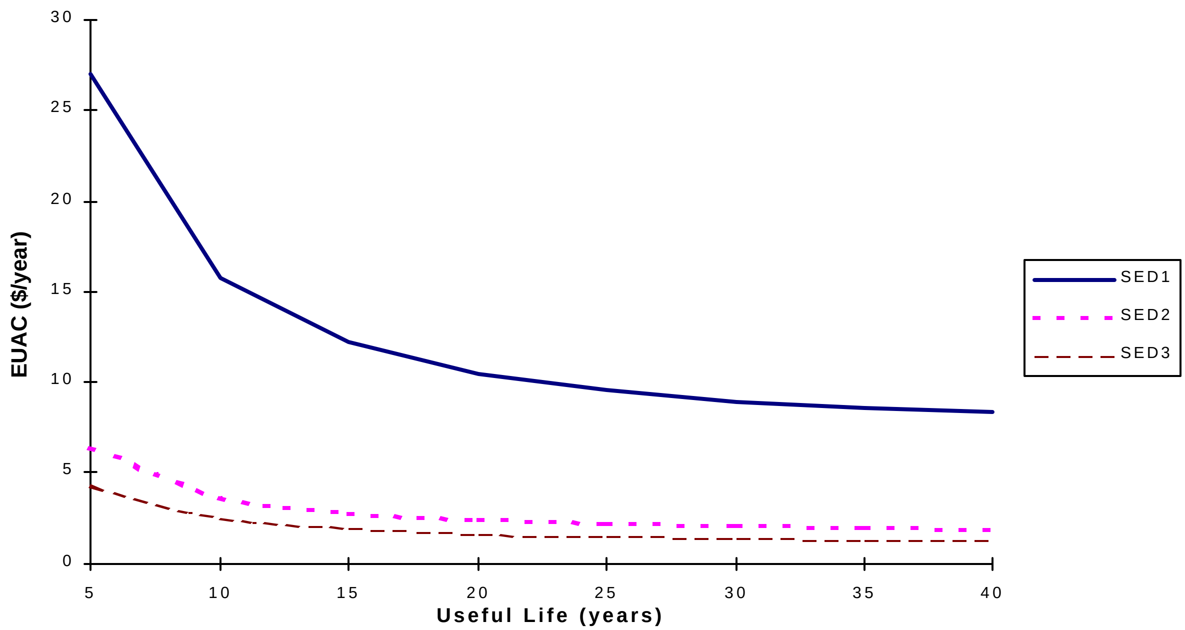



**Figure 4-1**
**EUAC versus Useful Life, SED1, SED2, and SED3 Neglecting Expected Cost of Device Failure**

**Table 4-4**
**Equivalent Uniform Annual Cost Analysis SED1, SED2, and SED3 including Expected Cost of Device Failure**

| Useful Life (years) | SED1 EUAC ($/year) | SED2 EUAC ($/year) | SED3 EUAC ($/year) |
|---|---|---|---|
| 5 | 68.48 | 17.65 | 6.13 |
| 10 | 57.26 | 15.03 | 4.32 |
| 15 | 53.64 | 14.19 | 3.74 |
| 20 | 51.94 | 13.79 | 3.46 |
| 25 | 50.98 | 13.57 | 3.31 |
| 30 | 50.40 | 13.44 | 3.22 |
| 35 | 50.03 | 13.35 | 3.16 |
| 40 | 49.78 | 13.29 | 3.12 |

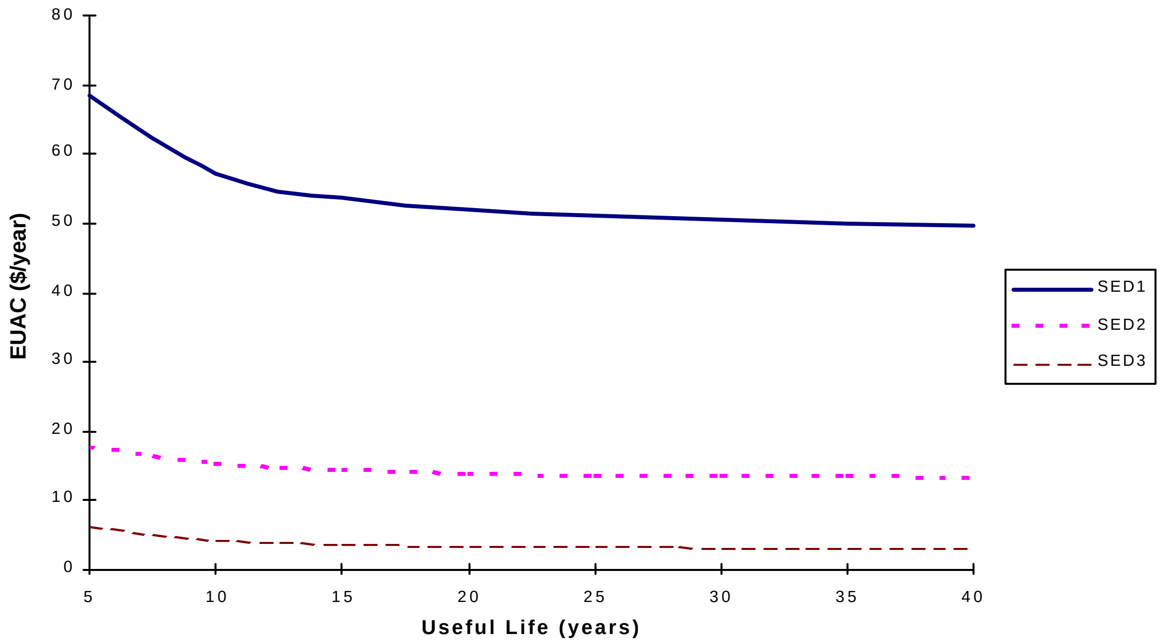



**Figure 4-2**
**EUAC versus Useful Life, SED1, SED2, and SED3 Including Expected Cost of Device Failure**

Figure 4-1 shows that the EUAC of SED1 tends to go asymptotic at a value of approximately $8.30 per year. The same figure shows SED2 at a cost of about $2.00 per year and SED3 at about $1.35 per year. Comparing the alternatives on a LCC basis shows the SED2 is about four times less expensive than SED1, and the SED3 is about one and a half times less than SED2 and about six times less than SED1. Thus SED3 would be preferred over SED1 and SED2. The trend across the development of the device is also favorable since each successive version further reduces LCC.

The following conclusions are drawn from this analysis.

1. Depending on its actual useful life, SED3 will cost between $1.35 and 3.12 per year per unit to manufacture, install, and operate depending on actual device failure rates.

2. Engineering enhancements made to date have been successful in substantially reducing estimated LCC.

3. Further enhancements can be made to further reduce LCC and enhance device reliability.

Forensic analysis of SED3s after the third Houston field trial showed that corrosion from gaster- flagging concentrated along the perimeter of the device. A version of SED4 which doubles the charged surface of the SED3 and maintains a maximized relationship between perimeter and area is being tried in the laboratory with encouraging results. Economic considerations will be to maintain the same total amount of stainless steel and thus minimize the cost of additional area. The next phase for this study should seek to optimize material costs with RIFA mortality in the laboratory as a means of determining optimum operating characteristics in the field.

The following is a list of characteristics of an SED that are found to be most significant in repelling RIFA from transformers.

1. Mean failure time of an SED.
2. Size and type of charged surface area.
3. Optimal positioning of the SED.
4. Proper insulation between base and charged surface area.
5. Charged surface which is not easily covered by debris.

# 5

# RECOMMENDATIONS

The SED is the best technology for repelling RIFAs. Its presence inside a RIFA-infested transformer with physical disturbance to the colonies significantly impacts the behavior of the ants in that colony, and it causes RIFA colony vitality to decrease inside a transformer. Researchers believe that a viable means to protect uninfested pad-mounted transformers against RIFA infestations and reduce colony numbers significantly in infested transformers has been discovered. SED3 experiments show conclusive evidence that this specific device is most economical, reliable, and produces higher significant changes in RIFA colony vitality. Gaster-flagging is being continuously initiated on all devices. Disturbance is more intense when the ants are in close proximity to the electrical device. There seems to be a trend on higher voltage devices for more debris to be piled on transformers and grid plates, greater intensity of gaster-flagging, and more RIFAs on the grid plates. The new electrified plates and insulation used produce a greater effect on RIFA colonies than the other SEDs, and the SED3 is the best self-cleaning SED engineered so far.

The technology has been proven in the field and the laboratory to be capable of providing protection to pad mounted transformers and other electrical equipment enclosures. It should be noted that the field trials were conducted in a manner which maximized the challenge to the technology by installing the SED3s in heavily infested transformers. In practice, the devices will be installed in new or recently serviced transformers where RIFA activity has been reduced through insecticides. To gauge the device's ability to protect clean transformers from RIFA infestation, large scale field trials will need to be conducted over a one to two year period. At this point in the development of this technology the SEDs have clearly demonstrated the potential to change RIFA behavior in the desired manner, and this exhibits all the signs of a process which, when implemented on a large scale, will reduce the cost of transformer failure due to RIFA infestation. In the Houston Light and Power area alone, RIFA damage accounts for a annual cost of around $600,000. If this device was only effective in 80% of the installations (a number which is easily supported by the field data), the cost of this research project would be amortized in less than one year. When the current cost across the southeastern United States for RIFA damage is considered, the provision of a simple piece of functional technology will accrue a substantial annual benefit to the electric power industry.

In the field, the main problem is still debris being piled on the grid plates and the transformers. This can be a significant problem to the life span of the SED. The design of the SED3 helped prevent this problem by optimizing voltage and position inside the transformer. Environmental conditions and the size of the transformer may also be a factor in RIFA infestation. These conditions might subdue any disturbances of one SED, so the idea of placing two SEDs in a transformer has arisen and been tested in the field. The current experiments in the field so far have shown that more charged surface area produces greater results in reducing RIFA vitality. Covering enough area to produce large disturbances should deter RIFAs even when prime environmental conditions are present in the transformers. Physically shoveling the ants out of the transformers has the highest significance, but in combination with the SED3, the significance is greater. Future work throughout the spring and summer is being anticipated. Field tests as a means to replicate the results obtained in May and November will add statistical credence to decisive conclusions.

Future engineering and experiments should focus on these primary characteristics. Devices with five times as much charged surface area as one SED should be implemented in the field. Additionally, large scale field tests on uninfested transformers should be conducted to test the device's ability to repel initial infestation by RIFA.

The following recommendations are made for further work.

1. Long-term field trials need to be conducted to accurately model mean time between failure and device reliability.

2. Once good reliability data is at hand, a more accurate LCC can be determined.

3. SED4 should be tested to challenge engineering enhancements in the field.

# 6

# BIBLIOGRAPHY


Adams, C. T., Banks, W. A., and C. S. Lofgren. (1988). "Red imported fire ant (Hymenoptera: Formicidae) correlation of ant density with damage to two cultivars of potatoes (*Solanum tuberosum* L.)." *J. Econ. Entomol*. 81:905-909.

Adams, C. T., Banks, W. A., Lofgren, C. S., Smitle, B. J., and Harlan, D. P. (1983). "Impact of the red imported fire ant, *Solenopsis invicta* Buren, on growth and yield of soybean." *J. Econ. Entomol*. 76:1129-1132.

Adams, C. T., and Lofgren, C. S. (1982). "Incidence of stings or bites of the red imported fire ant and other arthropods among patients at Fort Stewart, Georgia, USA." *J. Med. Entomol*. 19:366-370.

Anderson, J. B., and Vander Meer, R. K. (1993). "Magnetic orientation in the fire ant, *Solenopsis invicta*." *Naturwissenschaften* 80: 568-570.

Apperson, C. S., and Powell, E. E. (1983). "Correlation of the red imported fire ant, *Solenopsis invicta* Buren, with reduced soybean yields in North Carolina." *J. Econ. Entomol.* 76:259-263.

Banks, W. A., Adams, C. T., and Lofgren, C. S. (1991). "Damage to young citrus trees by the red imported fire ant (Hymenoptera: Formicidae)." *J. Econ. Entomol*. 84:241-246.

Buren, W. F., Allen, G. E., Whitcomb, W. H., Lennartz, F. E., and Wiliams, R. N. (1974). "Zoogeography of the imported fire ant." *J. New York Ent. Soc*. 82:113-124.

Clemmer, D. I., and Sterfling, R. E. (1975). "The imported fire ant: dimensions of the urban problem." *South. Med. Journal.* 68:1133-1138.

Eden, W. G., and Arant, F. S. (1949). "Control of the imported fire ant in Alabama." *J. Econ. Entomol.* 42:976-979.

Eagleson, C. (1940). "Fire ants causing damage to telephone equipment." *J. Econ. Entomol*. 33:700.

Galli, J. C., and Fernandes, D. A. (1988). "Dano causado por formigas do genero *Solenopsis* (Hymenoptera: Formicidae) a fias electricos em jaboticabal." *Sp. Anais da Soc. Entomol. Bras*. 17: 225-226.

Gould, J. L., Kirschvink, J. L., and Deffeyes, K. S. (1978). "Bees have magnetic remanence." *Sci*. 201: 1026-1028.

Harris, W. G., and Burns, E. C. (1972). "Predation on the lone star tick by the imported fire ant." *Environ. Entomol*. 1:362-365.

Hepworth, D., Pickard, R. S., and Overschott, K. J. (1980). "Effects of the periodically intermittent application of a constant magnetic field on the mobility in darkness of worker honey bees." *J. Apic. Res*. 19: 179-186.

Hsu, C. Y., and Li, C. W. (1993). "The ultrastructure and formation of iron granules in the honey bee (*Apis mellifera*)." *J. Exp. Biol*. 180: 1-13.

Hsu, C. Y., and Li, C. W. (1994). "Magnetoreception in honey bees." *Science* 265: 95-96.

Hunt, T. N. (1976). "Agricultural losses due to the imported fire ant as estimated by North Carolina, USA, farmers." *J. Elisha Mitchell Science Soc*. 92: 69.

Jolivet, P. (1986). " Les fourmis et la televsion." *L'Entomologiste*. 42: 321-323.

Kirschvink, J. L., Walker, and M. M. (1995). "Technical comments." *Science* 269: 1889.

Kuterbach, D. A., Walcott, and B. (1986). "Iron-containing cells in the honey bee (*Apis mellifera*). I. Adult morphology and physiology." *J. Exp. Biol*. 126: 375-387.

Kuterbach, D. A., and Walcott, B. (1986). "Iron-containing cells in the honey bee (*Apis mellifera*). II. Accumulation during development." *J. Exp. Biol*. 126: 389-401.

Kuterbach, D. A., Walcott, B., Reeder, R. J., and Frankel, R. B. (1982). "Iron-containing cells in the honey bee." *Science* 218: 695-697.

Lindauer, M., and Martin, H. (1972). "Magnetic effects on dancing bees." *Science.* pp. 559-567.

R. Galler, Koeing-Schnidt, K., and Belleville, R. E. (eds.), "Animal orientation and navigation." U.S. Government Printing Office, Washington, DC.

Little, E. C. (1984). "Ants in electric switches: note." *N. Z. Entomol*. 8: 47.

Lofgren, C. S. (1986). "History of imported fire ant in the United States." *In.* pp. 36-47.

Lofgren, C. S., Vander Meer, R. K. (eds.), “Fire ants and leaf cutter ants” *Biology and management*. Westview, Boulder, CO.

Lyle, C., and Fortune, I. (1948). “Notes on an imported fire ant.” *J. Econ. Entomol*. 41:833-844.

MacKay, W. P., and Vinson, S. B. (1990). “Control of the red imported fire ant, *Solenopsis invicta*, in electrical equipment (Hymenoptera: Formicidae).” *In.* pp. 614-619.

Vander Meer, R. K., Jaffe, K., and Cedeno, A. (eds.). “Applied myrmecology - a world perspective.” *Westview*, Boulder, CO.

MacKay, W. P., Majdi, S. O., Vinson, S. B., Messer, C. J., and Irving, J. P. (1989). “Prevention of fire ant damage to signal controls.” Research Report 1135-2F, Texas Trans. Inst., Texas A&M Univ. 51pp.

MacKay, W. P., Majdi, S. O., Irving, J., Vinson, S. B., and Messer, C. (1992) “Attraction of ants (Hymenoptera: Formicidae) to electric fields.” *J. Kansas Entomol. Soc*. 65: 84-92.

MacKay, W. P., Vinson, S. B., Irving, J. Irving, Majdi, S., and Messer, C. (1992) “Effect of electric fields on the red imported fire ant (Hymenoptera: Formicidae).” *Environ. Entomol*. 21: 866-870.

Martin, H., Horall, H., and Forster, B. (1989). “Magnetic field effects on activity and aging in honey bees.” *J. Comp. Phys. A*. 164: 423-431.

Morrill, W. L. (1977). “Red imported fire ant foraging in a greenhouse.” *Environ. Entomol*. 6:416-418.

Morrill, W. L. (1978). “Red imported fire ant predation on the alfalfa weevil and pea aphid.” *J. Econ. Entomol*. 71:867-868.

Mount, R. J. (1981). “The red imported fire ant, *Solenopsis invicta*, as a possible serious predator on some native southeastern vertebrates: direct observations and subjective impressions.” *J. Alabama Acad. of Science* 52:71-78.

Nesson, M. H. (1995). “Technical comments.” *Science* 269:1889-1890.

Nichol, H., and Locke, M. (1995). “Technical comments.” *Science* 269: 1889.

Nielson, R. J., Bhatcar, A. P., and Denmark, H. A.. (1971). “A preliminary list of ants associated with aphids in Florida.” *Fla. Entomol*. 54:245-248.

Reagan, T. E., Coburn, G., and Hensley, S. D. (1972). "Effects of mirex on the arthropod fauna of a Louisiana sugarcane field." *Environ. Entomol*. 1:588-591.

Reilly, J. J., and Sterling, W. L. (1983). "Interspecific association between the red imported fire ant (Hymenoptera: Formicidae), aphids, and some predaceous insects in a cotton agroecosystem." *Environ. Entomol*. 12:541-545.

Rhoades, R. B., Schafer, W. L., Newman, M., Lockley, R., Dozier, R. M., Wubbena, P. F., Tower, A. W., Schmids, W. H., Neder, G., Brill, T., and Whittig, H. J. (1977). "Hypersensitivity to the imported fire ant in Florida - report of 104 cases." *J. Florida Med. Assoc.* 64:243-254.

Sikes, P. J., and Arnold, K. A. (1986). "Red imported fire ant (*Solenopsis invicta*) predation on cliff swallow (*Hirundo syrrhonota*) nestlings in east central Texas." *Southwest. Nat*. 31: 105-106.

Slowik, T. J. (1995). "Response of the red imported fire ant (*Solenopsis invicta* Buren) to electricity and magnetism." M.S. thesis. Texas Tech University, Lubbock. 150 pp.

Slowik, T. J., Green, B. L., and Thorvilson, H. G. (1997). "Detection of magnetism in the red imported fire ant (*Solenopsis invicta*) using magnetic resonance imaging." *Bioelectromagnetics* 18:396-399.

Slowik, T. J., and Thorvilson, H. G. (1996). "Localization of subcuticular iron-containing tissue in the red imported fire ant." *Southwest. Entomol*. 21(3): 247-254.

Slowik, T. J., Thorvilson, H. G., and Green, B. L. (1996). "Red imported fire ant (Hymenoptera: Formicidae) response to current and conductive material of active electrical equipment." *J. Econ. Entomol*. 89(2): 347-352.

Vinson, S. B., and MacKay, W. P. (1990). "Effects of the fire ant, *Solenopsis invicta*, on electrical circuits and equipment." *In.* pp. 496-503.

Vander Meer, R., Jaffe, K., and Cedeno, A. (eds.), "Applied myrmecology - a world perspective." *Westview*, Boulder, CO.

Vinson, S. B., and Sorenson, A. (1986). "Imported fire ant: life history and impact." Texas Dept. of Agric. 78711. Austin, TX. 28 p.

Walker, M. M., and Bitterman, M. E. (1989). "Conditioning analysis of magnetoreception in honey bees." *Bioelectromagnetics* 10: 261-275.

Wilson, D. B., and Eads, J. H. (1949). "A report of the imported fire ant areas in southern Louisiana." *J. Econ. Entomol*. 62:1268-1271.

# A

# ANALYSIS OF ULTRAVIOLET RADIATION'S EFFECT ON ELECTRICAL INSULATION

The effect of ultraviolet radiation on polymer insulating materials was a concern expressed during the May 1996 project review meeting. After a detailed search of the literature the concern is correctly placed, and this technology was determined to be unusable in this application.

Radiation damage occurs when a material tends to absorb radiation rather than reflect it or allow the radiation to pass through it. There are four types of UV radiation in wavelengths less than 200 nanometers to 400 nanometers (Andrady, 1993) . They are listed below.

- Vacuum UV <200nm
- UV-C 200-280nm
- UV-B 280-320nm
- UV-A 320-400nm

Vacuum UV and UV-C are not present at the earth's surface due to their absorption by the ozone layer and other gases present in the atmosphere (Andrady, 1993). The ultraviolet light that is of concern to us is UV-B and UV-A wavelengths. The proposed UV lighting for the RIFA control experiment radiated a significant amount of UV-B. The lamps are also capable of radiating a small amount of UV-C at about 250nm. This type of radiation can have a deleterious effect on typical insulating polymers. UV radiation quanta have an energy of about 72 to 97 kilocalories per mole. Most natural and synthetic polymers have bond dissociation energies ranging from 76 to 99 kilocalories per mole (Andrady, 1993). In essence, the UV radiation happens to be at just the right 'power' to break down the molecular bonds of most polymer substances. The effects can include yellowing, loss of strength, brittleness, molecular weight loss, and other changes in desired mechanical properties (Andrady, 1993). At high enough intensities, UV-C radiation can rapidly abate or etch polymer surfaces to a depth of several microns.

There are methods for protecting polymer materials from UV radiation by doping the polymer with a UV stabilizing compound. The insulating polymer used in the wiring of a transformer is polyethylene, a widely used hydrocarbon thermoplastic. Typical UV stabilizers are Carbon Black, Flame Bloc, UV-Chek, and Cyasorb (Modern Plastics, 1995). For the most part, these stabilizers protect against UV radiation found in sunlight received from outdoor exposure. Thus, they may not be suitable to resist the radiation emitted by the UV lamps intended for use inside transformers. The power intensity on an area also varies with the lamp model (Bjorn and Teramura, 1993). The effect this type radiation would have on the insulation can only be hypothesized at this time. Therefore, it can be safely concluded that while UV radiation demonstrates excellent promise as a means to repel fire ants, the presence of polymer insulation inside the transformers prevents its use in this application.

## References

Andrady, A. L., "UV-B Radiation and Ozone Depletion," *Polymer materials*, Lewis Publishers, Boca Raton, Florida, 1993.

Bjorn, L.O. and A.H. Teramura, "Simulation of Ultraviolet Radiation and Effects of Ozone Depletion," *Environmental UV Photobiology*, Plenum Press, New York, 1993.

"Ultraviolet Stabilizers," *Modern Plastics*, November 1995.

# B

# DRAWINGS, SCHEMATICS, AND PARTS LISTS OF SED1 AND SED2

## Parts List

### *SED1*

1 Dover Industrial Control Transformer Type K50D1

1 120 VAC incandescent lamp ¼ watt

1 Incandescent lamp socket ¼ watt

1 AC 120 VAC lamp dimmer switch

1 1 amp fast blow fuse and fuse holder

1 5 amp fast blow fuse and fuse holder

1 120 VAC switch

1 Electronics project box 6 x 4 x 8 inches

2 Banana plugs

2 Banana sockets

1 ¼ inch rubber grommet

3 feet of 16 gauge wire

2 Brass grids 9 x 3 inches

### SED1 (variation)

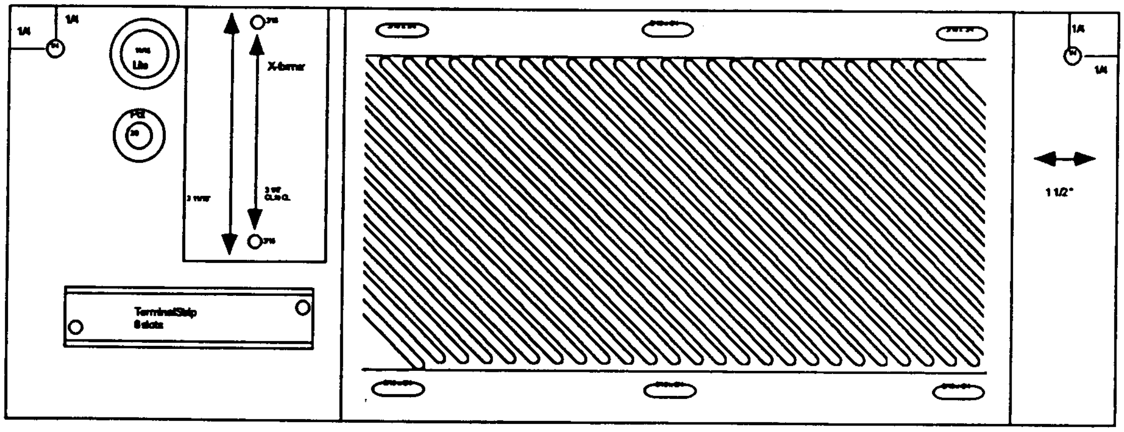
| | | |
|---|---|---|
| 30 | Wavetek isolation transformers N-68X | $550.50 |
| 28 | Terminal strips CNH 8-140 | |
| 28 | ¼ watt incandescent lamps | |
| 28 | ¼ watt incandescent lamp holders | |
| 28 | 500 kilo-ohm, 2 watt potentiometers | |
| 50 | 6 inch long ¼ inch diameter steel toggle bolts | |
| 50 | ¼ inch steel nuts | |
| 2 | 3 x 8 foot sheets of 16 gauge brass | $599.00 |
| 200 | 3/16 nylon screws 1 inch long | |
| 200 | 3/16 nylon nuts | |
| 200 | 3/16 nylon washers | |
| 100 | 6/32 machine screws 1 inch long | |
| 100 | 6/32 nuts | |
| 100 | 6/32 washers | |
| 100 | 6/32 lock washers | |
| 100 | 1 watt fuses | |
| 100 | 1 watt fuse holders | |

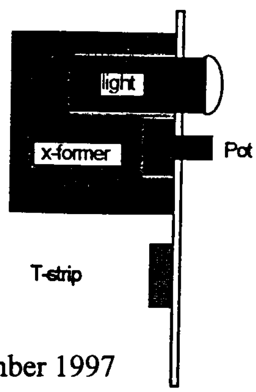
18 gauge wire of variable length

### SED2

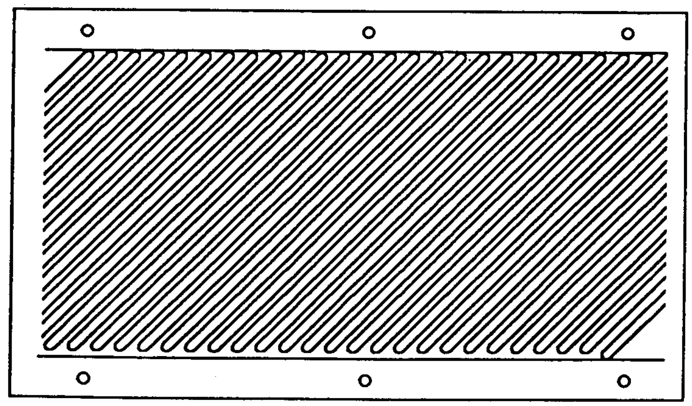
| | | |
|---|---|---|
| 1 | 3 x 8 foot sheet of 18 gauge 304 stainless steel | $186.00 |
| 1 | 3 x 10 foot sheet of 18 gauge 304 stainless steel perforated ¼ inch 3/16 stagger | $355.00 |
| 25 | Signal isolation transformers 241-3-56 | |
| 25 | Terminal strips CNH 8-140 | |
| 300 | Solderless connectors 18 gauge size 6 stud | |
| 25 | 1 watt fuse holders | |
| 25 | 1 watt fast blow fuses | |
| 100 | Nylon 6/32 ‘through’ washers | |
| 30 | Nylon 3/16 screws | |
| 30 | Nylon 3/16 nuts | |
| 25 | ¼ watt 1 kilo-ohm resistors | |
| 200 | 1 inch long 6/32 machine screws | |
| 200 | 6/32 nuts | |
| 200 | 6/32 washers | |
| 200 | 6/32 lock washers | |

## Drawing of SED1

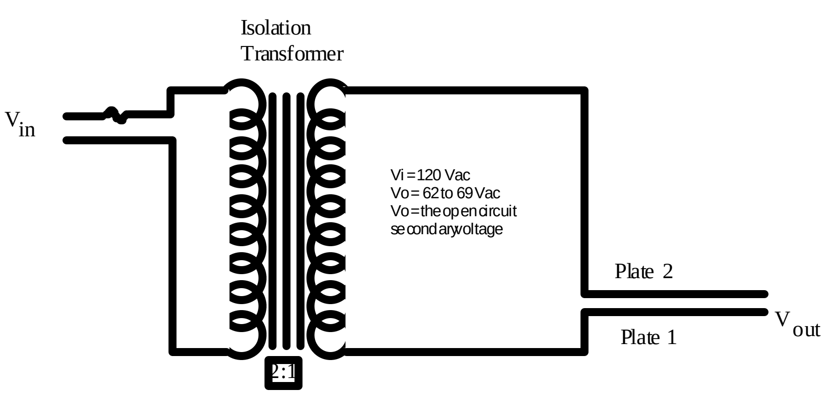


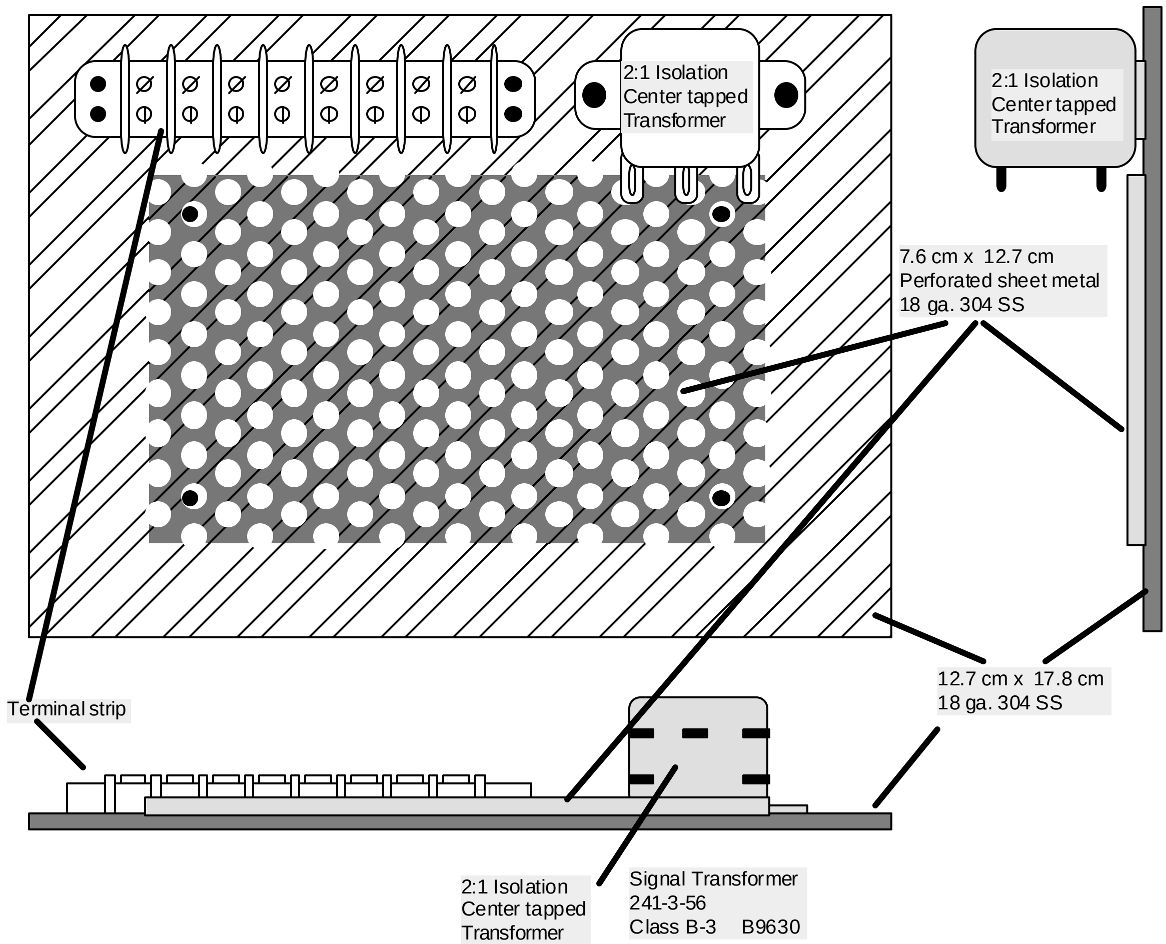

November 1997



## Schematic for the Stainless Steel SED2 Prototype



## Drawing of SED2



# C

# SED2 AND SED3 FIELD TRIALS: RAW DATA

Activity ratings of red imported fire ant mounds in transformers at Houston, TX, 1997.

| Treatment<br>Device | <br>Disturbance | March rating<br>(pre-trt) | April<br>rating | August<br>rating | comments |
|---|---|---|---|---|---|
| 1 SED3 | disturbed | 5 | 2 | 0 | |
| | | 3 | 4 | 0 | |
| | | 4 | 3 | 0 | |
| | | 4 | 0 | 0 | |
| | | 5 | 4 | 2 | |
| | undisturbed | 4 | 5 | 0 | buried & dead, then replaced |
| | | 3 | 2 | 2 | |
| | | 3 | 3 | 2 | |
| | | 3 | 3 | 0 | |
| | | 3 | 2 | 0 | |
| 2 SED3 | disturbed | 3 | 2 | 0 | |
| | | 5 | 2 | 2 | |
| | undisturbed | 3 | 2 | 2 | |
| | | 4 | 3 | 0 | |
| 2 SED2 | disturbed | 5 | 1 | 0 | |
| | | 5 | 1 | 0 | snail shorted out device |
| | undisturbed | 5 | 4 | 0 | one device dead, technical glitch |
| | | 5 | 5 | 0 | one device dead |
| | | 4 | 5 | 0 | one device dead, bad resistor |
| Control | disturbed | 5 | 2 | 2 | |
| | | 5 | 2 | 0 | |
| | | 2 | 1 | 0 | |
| | | 5 | 2 | 0 | |
| | | 3 | 1 | 0 | |
| | undisturbed | 3 | 3 | 0 | |
| | | 4 | 4 | 0 | |
| | | 3 | 3 | 0 | |
| | | 4 | 4 | 0 | |
| | | 5 | 5 | 2 | |

# D

# FORENSIC ANALYSIS OF SED1 AND SED2 FIELD TRIALS

Field trials of SED1s began in the Houston area in May of 1996, and field trials of SED2s began in the Houston area in October of 1996. A total of sixty devices have been deployed, thirty-five of those devices failed for various reasons. SED1s and SED2s were inspected in November of 1996, two weeks after the SED2s were placed in the field. All of the failed devices were brought into the laboratory for forensic analysis.

In total, twenty-five of the SED1s and ten of the SED2s were taken out of the field for analysis. Upon inspection of the devices in the laboratory seventeen SED1s and one SED2 were, in fact, operational. These SEDs failed in the field due to short circuits caused by RIFAs piling debris on the devices. The analysis of these devices is explained in Table D-1.

**Table D-1**
**Forensic Analysis of Operational SED1s and SED2 that Failed in the Field**

**SED1**

| unit number | Fuse Condition | Transformer | in/out | Lamp | Plate Potentiometer | R1/R2 Voltage |
|---|---|---|---|---|---|---|
| 11 | good | 220/110 | out | good | good | 45v |
| 13 | good | 220/110 | out | good | good | 45v |
| 27 | good | 220/110 | good | good | good | 45v |
| 2 | good | 220/110 | good | good | good | 47v |
| 12 | good | 220/110 | good | good | good | 43v |
| 20 | good | 220/110 | good | good | good | 45v |
| 17 | good | 220/110 | out | good | good | 45v |
| 22 | good | 220/110 | out | good | good | 45v |
| 33 | good | 220/110 | out | good | good | 43v |
| 32 | good | 220/110 | good | good | good | 62v |
| 16 | good | 220/110 | out | good | good | 44v |
| 25 | good | 220/110 | out | good | good | 38v |
| 30 | good | 220/110 | out | good | good | 52v |
| 31 | good | 220/110 | good | good | good | 59v |
| 36 | good | 220/110 | good | good | good | 45v |
| 35 | good | 220/110 | good | good | good | 45v |
| 34 | good | 220/110 | good | good | good | 47v |

**SED2**

| Unit Number | Fuse Condition | x-former | Resistor |
|---|---|---|---|
| 9 | good | good | bad |

After the forensic analysis, all of these devices were classified in working condition. The research team assume transportation of the devices to the laboratory loosened RIFA debris, removing any short circuits from the plates. The SED1 was designed not to have electronic parts fail under short circuit conditions. Under short circuit conditions the energized plate voltage would drop to 0-volts or a very low voltage. Short circuiting the energized parts would give an operations failure not a parts failure. Removing the cause of the shorting would remove the operational failure and re-energize the active plates. A high resistance short in the field across the energized plates would have given the appearance of an SED1 power failure. The SEDs that were inoperative in the field and during the laboratory analysis are explained in Table D-2.

**Table D-2**
**Forensic Analysis of Inoperative SED1s and SED2s that Failed in the Field**

**SED1**

| Unit number | Fuse Condition | Transformer in/out | Lamp | Potentiometer | R1/R2 | Plate Voltage |
|---|---|---|---|---|---|---|
| 24 | good | 220/110 | good | good | good | 0v |
| 3 | good | 220/110 | good | good | good | 0v |
| 4 | 1 bad | 220/110 | good | good | good | 45v |
| 19 | good | 220/110 | bad | bad | good | 0v |
| 28 | 1 bad | bad | bad | good | good/bad | 0v |
| 29 | 1 bad | 220/110 | good | good | good | 48v |
| 10 | 1 bad | 220/110 | good | good | good | 57.4v |
| 18 | 1 bad | 220/110 | good | good | good | 55v |

**SED2**

| Unit Number | Fuse Condition | x-former | | Resistor |
|---|---|---|---|---|
| 5 | good | good | bad | |
| 2 | good | good | bad | |
| 4 | good | good | bad | |
| 6 | good | good | bad | |
| 11 | good | good | bad | |
| 19 | good | good | bad | |
| 1 | good | good | bad | |
| 17 | good | good | bad | |
| 14 | good | good | bad | |

All of the SED2s that were inoperative had current limiting resistor failure. The current limiting resistor was placed in the network as a current protection device to protect the transformer in case of a short circuit secondary type condition. An analysis determined that only one of the SED2s had a short between the plates. The other SED2s probably had short-term insulation failure between the energized plates, or were piled with ant debris. Some of the energized plates had had short-term high resistance shorts causing resistor failure, or the SED2s may have experienced a power surge or high voltage electrical event causing short term insulation failure resulting in resistor failure. Field data and laboratory analysis gathered from the

SED1s and SED2s gave us information to design the next generation of SED (SED3).