

Final Report

Protecting electrical/electronic equipment from red imported fire ant damage

**Harlan Thorvilson and Bobby L. Green
Department of Plant and Soil Science
and
Department of Engineering Technology
Texas Tech University**

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Abstract

Fire ants invade electrical equipment and cause damage that jeopardizes human safety. Two Texas utility companies estimate that an annual cost of more than \$700,000 each is incurred due to equipment failure, outage, and repair. We are developing an electrical device that alters the behavior of fire ant colonies and repels them from sensitive electrical equipment. Laboratory research showed that as a static electric device (SED) electrifies ants, ants release alarm pheromones that result in general chaos and conflict among colony members and culminates in mortality or repulsion of the colony from the vicinity. Diode-controlled, 70-VAC SED show greatest promise for affecting RIFA behavior in confined areas. Field studies have been initiated at six, Texas electrical utility company locations, thus far, but hot, dry weather in summers 1998 and 1999 and SED equipment failures have frustrated further evaluations. We are incorporating integrated pest management (IPM) tactics to transformer protection programs to reinforce SED technology. A goal of this project is to develop a pre-commercial prototype SED that is optimized both technically and economically to reduce RIFA problems in an assortment of electrical equipment, such as step-down transformers, air-conditioning units, traffic signal lights, and residential service boxes.

This work is an interdisciplinary effort of Texas Tech entomologists and engineers and, for the last several years, has included personnel, equipment, and financial support from corporate sponsors. In addition, protecting sensitive electrical equipment from fire ant invasion has been identified as a core project by the Fire Ant Research and Management Account Advisory Committee (FARMAAC) of Texas.

Introduction

The red imported fire ant (RIFA), *Solenopsis invicta* Buren (Hymenoptera: Formicidae), has affinity for electrical equipment. Alternating magnetic fields generated in and by equipment attract ants (MacKay et al. 1989, 1992a, 1992b), at least at short distances. However, contact with bare, actively conducting material (MacKay et al. 1992b) is necessary for characteristic behavioral responses. It is not known whether RIFA responses are caused by detection of electrical fields, magnetic fields, or some other phenomena. The earliest reports of RIFA accumulating in and damaging electrical equipment came from Southwestern Bell Telephone Co. in Galveston, Texas. In September 1939, 83 of 446 residential telephone failures were caused by ants (Eagleson 1940). The RIFA accumulate in such large numbers that proper movement of mechanical switches in electrical equipment is prevented (Little 1984, MacKay et al. 1989, Vinson and MacKay 1990). Sealing all mechanical relay switches with epoxy cement has been an effective control measure (MacKay and Vinson 1990); however, this tactic is time-consuming and may necessitate design changes. Ants may remove insulative material from wires (Eagleson 1940, Galli and Fernandes 1988, MacKay and Vinson 1990) and physically bridge electrical components with their bodies which result in excessive internal current flow and short-circuits. The frequent electrocution of ants during short-circuits creates large numbers of ant corpses that remain around circuitry and exacerbate the damage. In addition, ant colonies frequently nest within electrical equipment and bring soil and other foreign debris in the space which creates corrosion and subsequent failure.

Ant reaction and accumulation in equipment is dependent upon their ability to touch or bridge electrical contacts or bare wires carrying electricity. Current flow through ant bodies causes derangement, incapacitation, and peculiar behaviors, including gaster-flagging, the involuntary release

of gut contents and pheromones from the abdomen that excites and confuses colony members and attracts others to the site (Slowik et al. 1996). Ants fight among themselves and clamp their mandibles upon legs and antennae. Clumps of reacting ants develop; subsequently, ants pile soil and other debris as if to neutralize the effects of the device (HT, personal observations).

Red imported fire ants do not indiscriminately release all exocrine gland products as a result of being electrically shocked. Instead, they respond defensively through release of alarm pheromones and of potent alkaloid chemical weapons from the poison sac (Vander Meer, et al. 1999). Large quantities of venom alkaloids, stored in the poison sac, are released through the sting apparatus in aerosol form or by directionally flinging the poison sac contents (Obin and Vander Meer 1985). Electrically shocked RIFA gaster-flag, release venom alkaloids as an aerosol, and release alarm pheromones from their mandibular glands. The alarm pheromone elicits rapid and erratic movement and may help direct or attract other workers to the site of electrical circuitry (Vander Meer et al. 1999).

Step-down electrical transformers in RIFA-infested residential neighborhoods are vulnerable to invasion and subsequent outages. Houston Lighting & Power Co. (HL&P) estimated that damage caused by the RIFA is \$600,000 per year (D. Visconti, personal comm.). We have been cooperating with HL&P, Texas Utilities Co. (TU), and the Electric Power Research Institute (EPRI) to test in the laboratory and to install in the field various electrical devices that we have invented (see Appendix A for our history of static electrical device [SED] development). Devices use the well-documented attraction of RIFA to electrical equipment but turn this behavior against colonies. The devices alter RIFA behavior, cause confusion, conflict, and mortality, and repel colonies from pad-mounted transformers and other electrical equipment. Integrated pest management (IPM) tactics will be incorporated to reinforce effects of our electrical devices.

The relevance to the Texas Imported Fire Ant Research and Management Project is that imported fire ants invade electrical equipment and cause damage that jeopardizes human safety. Ant reaction and accumulation in equipment is dependent upon their ability to touch or bridge electrical contacts or bare wires carrying current. Ants build mounds and pile soil and other debris within pad-mounted transformer cabinets. Corrosion and equipment failure result which requires expensive repair or replacement. Elimination of fire ant invasion of transformers will improve safety and reliability of electrical service.

Research Objectives.

The laboratory research objectives include:

- (1) to determine the efficacy of SED in eliciting gaster-flagging behavior of RIFA colonies,
- (2) to document the defensive reactions of colonies in response to electrical shocks of individual members.
- (3) to develop video capture and computer enhancement techniques for counting RIFA in colonies.

The field research objectives include:

- (1) to install the latest prototype of SED in pad-mounted, step-down, electrical transformer cabinets at various Texas sites,
- (2) to determine if transformer cabinets with installed SED have less RIFA colonization, compared to unprotected transformers, over 6-month or longer time periods,
- (3) to reinforce SED efficacy by incorporating IPM tactics (including insecticides, mound soil removal, and inorganic materials) to transformer protection programs,
- (4) to develop a pre-commercial prototype of the device which is optimized both technically and economically.

Methods and Materials

Laboratory Studies

Effects of SED2 of several voltages on fire ant colonies. To determine the optimal alternating current voltage (VAC) for ant reactions, attraction and gaster-flagging of RIFA colonies in contact with SED2 of different voltages were measured in the laboratory. Experiments were conducted in four, separate plastic trays (55 x 44 x 13 cm) each of which contained an equally sized RIFA colony. SED2 were designed to deliver 50 VAC, 60 VAC, 69 VAC, or 0.0 VAC (unpowered control) when ants bridged between metal grids of devices. In response, ants fell from the device and/or gaster-flagged, releasing alarm pheromones. Devices were electrified continuously during trials. Numbers of gaster-flagging ants on SED2 were counted, and numbers of individuals within a 2.5-cm zone from a SED2 were ranked. A mean rating index was constructed for estimating numbers of ants around 2.5-cm zones. One corresponded to 1-25 individuals, and two, three, four, and five corresponded to 25-50, 50-75, 75-100, and >100 ants, respectively. Each observation of colony behavior was conducted in five-minute intervals once every other day. Two trials were conducted, and 28 and 35 observation periods were made for the first and second trials, respectively.

RIFA attraction to SED3 from relatively long distance. A plastic colony tray (55 x 44 x 13 cm) was cleaned and disinfected with 70% EtOH. Two SED3 devices were placed in the tray, one each on opposite ends of the tray. One device was powered with 70 VAC, and the other device was unpowered. A piece of nylon string was used to draw a line 8.0 cm from each device. Both devices were 17.0 cm from a plastic brood box containing a RIFA colony. After placement of ants into the tray, each ant that crossed either line were aspirated and counted. Each observational period lasted five minutes, and 10 replications (colonies) were conducted. Student's t-tests were used to determine differences in mean numbers of ants collected crossing the lines.

Response to gaster-flagging RIFA on an SED3. Ten experimental colonies were subjected to a powered 70-VAC SED3, and ten control colonies were subjected to an unpowered SED3. Bone piles of dead ants were removed from colony trays, and observations were conducted on the numbers of gaster-flagging ants and rankings of the numbers of ants around a 2.5-cm zone from a SED3 were assigned. Each colony was observed five times daily, for ten minutes, and for four days (n=16). An unpaired t-test was used to determine differences between treatments.

RIFA aggregation to SED3 and to a diode-controlled device. One plastic tray (55 x 44 x 13 cm) was cleaned and disinfected with 70% EtOH. A 70-VAC SED3 was placed at one end of the tray and a diode-controlled SED (d-SED) was placed at the opposite end of the tray. The powered transformer of the SED3 touched the bottom of the tray surface, and the SED3 had a grid perimeter of 70.0 cm. The d-SED allowed direct current (50 DC) and alternating current (50 AC) to charge grid plates. The grid perimeter of the d-SED was 57.0 cm. A piece of nylon string was used to designate a line 8.0 cm from each device. A brood box filled with a RIFA colony was placed in the center of the tray, and ants had equal access to each electrified device. After placement in the tray, colonies were given 30 min to acclimate to the environment. Once acclimated, both devices were powered, and counts began. Numbers of gaster-flagging ants on devices and numbers of ants behind the 8.0-cm line near each device were counted. Each

observational period lasted 10 minutes, 30 minutes lapsed between each observational period, and three periods were conducted for each of eight replications (colonies). A Student's t-test was used to detect differences between d-SED and SED3 responses.

Residual effects of gaster-flagging on responses to electrical devices. The same procedures as in the preceding experiment were followed except that after a 30-min acclimation period, both devices were powered, and ants were given 30 min to explore and be shocked by either device. Then, a new brood box of RIFA from the same colony replaced the previous brood box in the middle of the tray. Ten replications using a random selection of different colony sizes were used. Eight, 10-min observation periods were conducted for each colony at 30-min intervals for eight hours (n=84). A Student's t-tests was used to test differences in mean numbers of gaster-flagging ants and mean numbers of ants that crossed the 8.0-cm lines.

Alarm pheromone attraction. Two experiments were conducted to determine effects of alarm pheromone on RIFA workers. The first experiment used two plastic trays (27 x 36 x 18 cm) connected by a passageway of 30.5-cm piece of clear tygon tubing (i.d. 1.5 cm). One tray was covered with a piece of cardboard and contained gaster-flagging ants upon a powered SED3. An air pump (VWR Scientific, model U522-U4F-G180DX, Benton Harbor, MI) was used occasionally to lightly waft air on the gaster-flagging ants and to transfer the airborne pheromone through the tygon tubing into the second tray. Tubing was set at a diagonal to the second tray and was bent to reduce responses to simple air flow. A piece of nylon string was used to mark designated lines 8.0 cm from the source of the incoming pheromone (tube opening). A brood box of RIFA was placed in the middle of the second tray, after which counting started. Each observational period lasted five minutes, 11 replications (colonies) were completed, and the experiment lasted 24 hours.

In the second experiment, one individual tray (55 x 44 x 13 cm) was used. Two, 4.5 x 6.5-cm pieces of Kimwipes®(Kimberly-Clark, Roswell, GA, no. 34155) paper were placed in the tray, one each at opposite ends of the tray lengthwise. A piece of nylon string was used to draw a line 8.0 cm from each piece of paper. One piece was tainted with alarm pheromone. This was achieved in two ways, by firmly restraining RIFA with forceps and allowing them to gaster-flag on the paper, or by allowing shocked RIFA on an SED3 to gaster-flag on paper. A brood box filled with RIFA was placed in the center of the tray. Both pieces of paper were 17.0 cm from the brood box; therefore, ants had equal access to both pieces of paper. Counting started after ants were placed into the tray. Each observational period lasted five min, there were 11 replications (colonies), and the experiment was conducted in a single day.

Field Research

In May 1996 with Houston Lighting and Power (HL&P), we installed 40 SED's randomly in pad-mounted transformers in residential neighborhoods in Houston, Texas. HL&P has approximately 125,000 pad-mounted transformers in service that are vulnerable to RIFA infestation (D. Visconti, personal comm.). After a lineman opened each transformer box, the enclosed RIFA colony was evaluated and given a vitality ranking. Then, one treatment was applied from a 2x2 factorial design (SED1 or control, mound removal by shoveling or control). Transformer boxes were opened again after two and 22 weeks, and colonies were rated. Although this initial trial was a worst-case scenario (removal of well-established colonies), the data were encouraging because significantly fewer mounds were active in SED- and shovel-treated boxes.

In March 1997, 24 different transformer boxes received one treatment from a 4x2 factorial design. Boxes received either two SED2's or one, two, or no SED3 devices, and resident mound soil was either shoveled out or was left intact. Four weeks later, all boxes were again opened, and the condition of colonies and devices were checked. Decreased activity ratings of colonies in all treatments ranged between 22% and 42%, and mounds in control treatments decreased 30.8%. Significantly, disturbance of mounds with shovels was the most important treatment factor; however, the interaction of SED3s and disturbance was also significant ($P < 0.05$). Again, the field trial was run under the most difficult conditions, that of removal of well-established RIFA colonies from ideal locations in a heavily infested habitat.

The major contributing factor in SED failure in transformer cabinets was that RIFA covered the devices with soil. These devices were single-stage; therefore, burial of a small proportion of a device caused short-circuit, a fuse would blow, and the device would completely shut down. For these reasons, a new device (d-SED1) was designed as a three-stage device with three half-wave rectifiers per device using a single fuse (Appendix A). In the new design, conducting material was stainless steel with three small, rectangular, energized plates separated from the larger grounded substrate by a thin piece of electrical insulation. The device was assumed to have a graceful failure mode. The three stages provided an extended device lifetime as three diode failures would be necessary before the device was disabled. Trials of the new device against laboratory colonies was encouraging.

During spring 1998, three-stage, diode-controlled SED (d-SED1) were manufactured at the Texas State Technical College in Waco, Texas, with delivery in late May. Devices were tested in the laboratory at Texas Tech University, and pronounced fit for field trials.

Arrangements were made with Texas Utilities-Electric Co. for installation in pad-mounted transformers at several sites (Fig. 1).

Figure 1. Electric company sites of diode-controlled devices in 1998 and 1999. Texas Utilities-Electric in association with the Electric Power Research Institute (EPRI)

Texas Utilities-Electric Site (Texas)		Dates of Treatment		Number of Transformer Treatments ^a	
				Devices ^b	control
Waco		16-17 June 1998		39	18
		10-11 August 1999		39	20
Tyler	18-19 June 1998	35	15		
	3-4 August 1999	35	15		
Dallas, North	7-8 July 1998	34	18		
	15-17 Sept. 1999	32	19		
Ft. Worth, West	9-10 July 1998	31	17		
	17-18 August 1999	28	17		
Arlington, SE	13-14 July 1998	21	15		
	19-20 August 1999	21	13		

^a Treatments in 1998 and 1999 included removal of mound soil before installation of device. In 1999, 5% carbaryl dust was also dusted inside transformer cabinets after soil was removed.

^b diode-controlled device (d-SED1), stainless steel, 3-strip, 18" long installed in 1998; d-SED2, printed circuit board installed in 1999.

After approaching a transformer, a technician rapped against the metal cabinet with a metal wrench (hammer test) to agitate the RIFA colony that may have been inside, notations of numbers of RIFA swarming from cabinet seams were made, and ant activity was videotaped for later image analysis. Then the technician would carefully unlock and raise the transformer lid to reveal its contents. The size and activity ranking of an enclosed RIFA colony was recorded. During summer 1998, most ant mounds were abandoned, and colonies were very deep in the soil, so as not to respond to disturbance. Summer 1998 was extremely hot and dry in central Texas, and fire ants were under extreme stress.

If an active RIFA mound was present in a transformer box, mound soil was shoveled out, and a d-SED1 was installed or was not. If no ants were present, a d-SED1 was installed or was not (control treatments). If a transformer box had evidence of an oil leak or of previous insecticide treatment, the transformer was not used in this experiment.

A new prototype device was designed during spring 1999 for later construction and replacement installation. The newest design (d-SED2) featured a printed circuit board with seven independently active strips and fused and diode-controlled components. In addition, the d-SED2

design featured a magnetic strip backing to allow placement of the device against a steel wall of a transformer cabinet. In this way, the device was not placed on the soil but was still accessible to RIFA foragers.

Texas Utilities-Electric sites (Fig. 1) were visited again in August and September 1999, and the same transformers were opened. The position, size, and activity of RIFA mounds in transformers were recorded. All d-SED1 devices were removed, and mound soil was shoveled from open boxes. The new, circuit board, d-SED2 were installed, or in control treatments, no device was installed. A thin application of 5% carbaryl (Sevin®) dust was made in all transformers. Preliminary autopsies of failed d-SED1 indicated about 85% failure rate in the field.

Currently, the state of the art for evaluating the size of RIFA colonies is to either count each individual ant by capturing the entire colony, or by using a rating system to compare relative colony sizes. Video imaging can be used to standardize time-consuming quantitative measurements or subjective rankings. Using video image capture and computer enhancement techniques, we may be able to quantify the number of RIFA present on surfaces of disturbed mounds. By using image technology and information theory (IT), our goal is to automate labor-intensive counting procedures (Appendix B and C). Our primary concern is to quantify RIFA activity in and around pad-mounted transformers and will serve as a model for other disciplines. Currently, the mathematical models for this technique have been derived (Tang 2000). Laboratory and field imaging and computer enhancement is continuing.

Results and Discussion.

Laboratory Studies

Laboratory studies are reported in R. Ipser's (1998) M.S. thesis and in manuscripts in preparation. Support for his work was partially supported by the Texas Fire Ant Initiative Project.

Effects of SED2 of several voltages on fire ant colonies. In the first trial, t-tests detected significantly greater numbers of individuals near the 60- and 69-VAC electrical devices and numbers of gaster-flagging ants than those exposed to 50 VAC and to the control (Table 1). However in the second trial, more ants accumulated near the 50 VAC device, and more ants gaster-flagged on the device charged with 69 VAC.

Table 1. Mean ratings and numbers of gaster-flagging ants (\pm SD).

SED3 treatment	Mean Rating ^a		Mean number ^a	
	2.5 cm from device		of gaster-flagging ants	
	trial 1	trial2	trial 1	trial2
50 VAC	1.0 (\pm 1.0)a	4.0 (\pm 0.7)c	0.0 (\pm 0.0)a	2.2 (\pm 2.2)b
60 VAC	2.4 (\pm 0.6)b	2.9 (\pm 1.5)b	2.9 (\pm 1.9)b	1.8 (\pm 2.5)b
69 VAC	2.9 (\pm 0.8)c	3.4 (\pm 1.3)b	3.7 (\pm 1.5)c	4.0 (\pm 3.6)c
control	1.0 (\pm 1.0)a	1.0 (\pm 1.0)a	0.0 (\pm 0.0)a	0.0 (\pm 0.0)a

^a Means followed by the same letter within a column are not significantly different (t-tests; n= 28 [trial 1]; n= 35 [trial 2]; $P > 0.05$). Ratings 1-5 correspond to 1-25 ants, 25-50, -50-75, 75-100, > 100, respectively.

RIFA attraction to SED3 from relatively long distance. No significant differences were detected between mean numbers of ants crossing the designated lines towards the 70-VAC device (17.8 ± 7.2) and the unpowered device (17.2 ± 6.6) ($t=0.36$; $df=9$; $P=0.72$). We concluded that RIFA were not attracted from a relatively long distance (approximately 17 cm) to the powered SED3.

Response to gaster-flagging RIFA on an SED3. Significantly greater numbers of gaster-flagging ants and individuals within a 2.5-cm zone were detected on powered SED3 as compared to unpowered SED3 (Table 2.). No ants gaster-flagged on unpowered SED3. In addition, RIFA colonies apparently responded to the powered SED3 by piling debris on the device, perhaps in an attempt to "defeat" the disturbing presence of the electrified grid plates.

Table 2. Mean number (\pm SD) of ants reacting to SED3^a

Treatment	Mean ranking of ant individuals ^b 2.5-cm zone	Mean number of individuals ^b gaster-flagging
Electrified	4.0 (\pm 0.9)a	7.8 (\pm 3.6)a
Non-electrified	1.0 (\pm 0.0)b	0.0 (\pm 0.0)b

^a Static electrical device, voltage = 70 VAC

^b Mean numbers with different lower case letters within columns are significantly different (t-test; $df= 168$; $P < 0.05$)

RIFA aggregation to SED3 and to a diode-controlled device. Significantly more ants crossed the line towards the d-SED (100.5 ± 70.4) than towards the transformer-powered SED3 (45.7 ± 43.4) ($t=7.2$; $df=25$; $P<0.0001$). The mean number of ants gaster-flagging on the d-SED (4.8 ± 3.4) was significantly greater than that of the SED3 (1.5 ± 2.0) ($t=6.8$; $df=25$; $P<0.0001$).

Residual effects of gaster-flagging on responses to electrical devices. Significantly more ants were attracted to the d-SED that had residual gaster-flagged material (99.7 ± 62.0) than to the transformer-driven SED3 (23.1 ± 15.6) ($t=14.2$; $df=83$; $P<0.001$). Apparently, ants were attracted to the d-SED where a greater residual environment of alarm pheromone was located than to any other feature of the SED3, including, perhaps, vibrational cues from a step-down transformer that powered the SED3.

Alarm pheromone attraction. In the first experiment, significantly more ants (43.4 ± 28.1) were attracted to the side of the tray where a gentle air stream introduced alarm pheromone as compared to the side of the tray with relatively clean air (22.8 ± 17.0) (paired t-test, $t=4.23$, $df=10$, $P=0.002$). In the second experiment, more ants were attracted to the tainted paper (mean = 42.8 ± 22.0) than to the clean paper (mean = 19.7 ± 9.0) ($t=4.84$, $df=10$, $P=0.001$). Alarm pheromone alone attracted ants to the targets.

Conclusions from Laboratory Studies.

Seventy VAC was determined to be the optimal voltage for our SED technology. At 70 VAC, ants were induced to gaster-flag and release alarm pheromones, some were killed outright, but they were not blown apart as would happen at higher voltages. RIFA were not attracted from long distances to our SED in the laboratory. However once investigating individuals were shocked, other ants were attracted to the site, and they, in turn, became shocked and gaster-flagged. Diode-controlled SED attracted more ants than did transformer-powered SED. We concluded that pheromone emission by shocked ants was the major factor in ant attraction to SED.

In reaction to gaster-flagging individuals in the confines of a laboratory tray, nest-mates became agitated and aggregated near reacting ants. More ants became shocked, and a general disturbance spread throughout the colony. Nest-mates began a defensive behavior by locking their mandibles upon whatever nest-mate body part could be gripped (clamping) and frequently dismembered individuals. This general disruption of colony behavior and of focused aggression against sister colony members led us to hypothesize that low-voltage technology could be used to drive ant colonies from confined areas, such as transformer cabinets, air-conditioning units, circuit boxes, and safety light signals.

Field Research

Unfortunately the three-stage, d-SED1 design did not hold up well under the 1998 drought then wet conditions. Several transformers were opened at Dallas, North, sites on 4 December 1998, and the status of the d-SED1 was checked. Of seven devices, six (86%) had blown fuses and were not functional. In response, functional d-SED1 were exchanged for blown devices in December in those six transformer cabinets. Under closer inspection in the laboratory, failed devices were shorted out because either moist soil had been piled by RIFA against conductive strips or cut metal edges bridged thin insulation between conductive surfaces and caused excessive current to flow. Considering that each device was checked by multimeter at installation in summer 1998, failure was not expected. Failure of the d-SED1 was a disappointment and was probably the result of moist conditions and increased RIFA activity and mound-building of autumn 1998. Preliminary autopsies of failed d-SED1 indicated about 85% failure rate in the field. Devices probably failed shortly after installation and had little, if any, effect on RIFA colony behavior.

During August and September 1999, sites were evaluated again. Transformers at Arlington sites had most ant activity (Table 2.). Mounds were located more frequently under primary and under secondary sides of transformers. Attraction to 120 VAC electromagnetic fields may be the important factor. Soil moved by RIFA buried approximately one-third (mean =31.3%) of each SED device upon summer 1999 inspection. The mean percents of transformers that did not have RIFA activity in August and September 1999 was 33.5% and 37.5% for device-installed and control treatments, respectively. Because the d-SED1 devices failed early in the 1998 trial, few conclusions of their effectiveness in the field may be made.

Transformers at all sites will be inspected after 6-12 months to evaluate d-SED2 performance. Also, the newest device prototype will be installed in transformers in Houston, Texas. Central and Southwest Utility sites in Corpus Christi, Texas, and Idabell, Oklahoma, will be initiated during autumn 1999.

Table 2. Condition of d-SED1 and RIFA mounds in transformer cabinets, August and September 1999

Location	Treatment	Percent transformers ^a with mounds under				Mean percent clean cabinets
		primary	middle	secondary	burial of device	
Tyler	device	20.2	2.9	31.4	50.3	28.6
	control	30.0	0.0	26.7	-	40.0
Waco	device	28.2	5.1	17.9	20.0	33.3
	control	25.0	5.0	25.0	-	45.0
Ft. Worth	device	28.6	7.1	42.9	17.0	39.3
	control	17.6	5.8	35.3	-	52.9
Arlington	device	52.4	47.6	57.1	40.0	23.8
	control	46.2	38.5	61.5	-	23.1

Dallas	device	30.3	30.3	36.4	29.2	42.4
	control	21.1	31.6	47.3	-	26.3
Means (5 sites)	device	31.9	18.6	37.1	31.3	33.5
	control	28.0	16.2	39.2	-	37.5

^a Inside transformer cabinets, the primary side is where the high-voltage, underground cables enter the transformer. The secondary side has aluminum busses carrying stepped-down, 120 volts (AC) upon which residential service cables attach. The “middle” portion of a cabinet is that area between the primary and secondary sides.

Conclusions

The major focus in this project is elimination of electric utility industry problems in preventing RIFAs from invading and damaging distribution equipment. This technology will be easily adapted to protect other electrical equipment such as traffic signal controllers and other electrical/electronic equipment. This technology will save thousands of dollars in manpower, injuries, down-time, and repair and replacement costs for industry and consumers. Several devices have been built in our engineering shop under the design specifications of electrical and mechanical engineers and of entomologists who have studied ant behavior. These static electrical devices have been consecutively numbered by design changes (SED1, SED2, SED3, d-SED1, d-SED2, etc.). One prototype edition (SED3) had approximately 70 linear cm of plate surface upon which ants may become electrified and had no moving parts to jeopardize reliability. The device has been continually cost-engineered to an annualized life cycle cost of \$1.34 per year. It was extremely energy efficient needing less than 1.0 kilowatt-hour of power per year. However, diode-controlled devices are more reliable in the field and are probably more cost-effective. Recent prototypes have utilized this diode design.

Laboratory studies have confirmed that low-voltage electrical shock will initiate gaster-flagging and the consequent behavioral changes in RIFA nestmates. We believe that alarm pheromones and potent alkaloid chemicals released by gaster-flagging individuals are triggers for colony disruption. These data led us to hypothesize that our equipment protection programs are vital. Insecticides, mound removal, diatomaceous earth, and other components may be used to develop more effective pest management protocols. The goal remains the same – to reduce RIFA populations to levels not economically important to Texas citizens

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APPENDIX A

Fire Ant Electrical Static Electric Device Previous Field Trials and Device Design

In order to disturb the Red Imported Fire Ant (**RIFA**) electrically it was discovered that energizing the ant with any voltage from a minimum of 10-volts to a maximum of about 70-volts would cause the ant to excrete an alarm pheromone and exhibit an aggressive behavior. Energizing the ants above 100-volts would cause violent muscle contractions, sometimes rupture the ant's abdomen and kill the ants. The alarm pheromone attracts more ants to the disturbance site and many times disrupts the colonies normal activities; a ruptured abdomen does not attract many ants.

We have designed, built, and deployed several generations of electrical devices to inhibit RIFA activity in the laboratory. We have also deployed some of the designs in the field on a small scale and have seen a positive result. The designs of our Static Electric Device (**SED**) are for use in residential pad mounted transformers by the electric power industry with the previous and current work being supported by the Electric Power Research Institute (**EPRI**) and two power companies in Texas.

Step down Transformer

The residential power distribution transformers come in several configurations. They are nearly always a step down voltage transformer and they may be in either a single phase or three-phase configuration. The high voltage, primary, side of the transformer operates from 2,400-Vac, to 28,000-Vac and a secondary side operates at 208-Vac phase-to-phase and 120-Vac from phase-to-ground, depending on the transformer voltage and winding configuration. A single transformer usually services several residences and is either mounted on a high line pole for overhead service or mounted on a concrete pad for underground service. The pad mounted transformers are in direct contact with ground water and all the ground flora and fauna. With the invasion of the Red Imported Fire Ant (RIFA) the pad-mounted transformers are facing serious reliability challenge. RIFA invade the transformer and colonize it by building an earth nest. The earth is introduced in large quantities eventually filling the transformer causing electrical shorting of either the primary or secondary side of the transformer.

Transformer 208-Vac, 60-Hz to 60-Vac, 60-Hz

The ants were discovered to respond to any voltage between 10-V and 70-V. The first field design was constructed to operate as a phase-to-phase device. The secondary transformer phase-to-phase voltage is a nominal 208-Vac. We used a low voltage step down transformer to step down to around 100-Vac then a voltage divider to further reduce the voltage to about 45-Vac and an indicator lamp. The voltage divider network served two purposes, 1) to reduce the output voltage to levels effective for use on RIFA and 2) as a current limiter to protect the transformer and fuse from high current short circuits during normal operation.

A transformer is an expensive device and is always energized. Energizing the transformer uses electrical power continuously. The voltage divider network is also energized continuously as

long as the transformer is operating. Continuous operation of both the transformer and the voltage divider network costs the power company money in lost revenue whether there are RIFA invaders or not. The 208-Vac transformer was also a large bulky device so the next deployed device was redesigned to use a smaller transformer. Figure 2.1 shows an electrical schematic of the first device

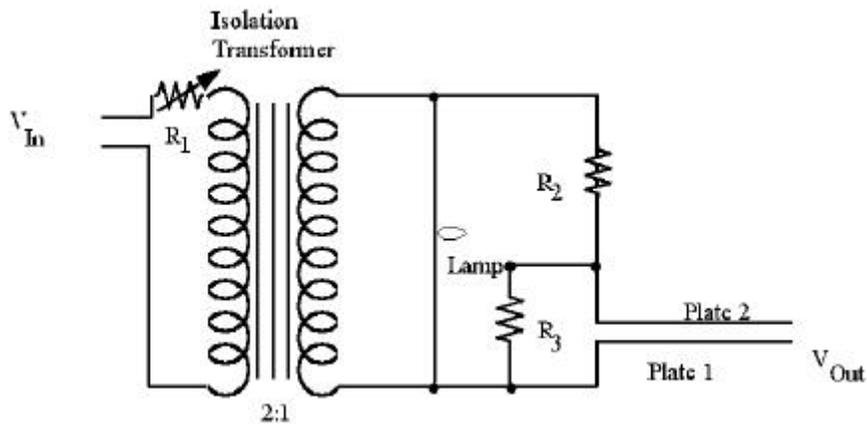


Figure 2.1 Electrical Schematic of 208-V Field Device 1

As can be seen from the figure the SED was an elaborate device to deploy in a hostile environment in the field. As the number of parts on the device increases the probability of device failure also increases. The materials cost for this device was high, the energy cost for this device was also large, and the device was too bulky and complex for a field unit.

Transformer 120-Vac, 60-Hz to 60-Vac, 60-Hz

The second device deployed in the field used a fused 120-Vac to 60-Vac step down transformer with a current limiting resistor. The lower voltage transformer was less bulky and less expensive than the 208-V transformer and when energized used less than half the power of the 208-V device. The transformer could be used with the 120-V phase-to-ground connection in the pad-mounted transformer. The electrical schematic in figure 2.2 shows the reduced complexity of the design. The secondary was an open circuit operating at around 60-Vac so the power consuming voltage divider network and indicator lamp had been removed. Reducing the complexity of the device made it more reliable in the field, however it was still bulky, heavy and was the transformer was a power-consuming device. The device operated relatively well in the field for a prototype device and gave us the opportunity to determine ant behavior in the field when confronted with the SED. The ant behavior was to attempt to defeat the device. Super colonies could defeat the device by covering the device completely with earth. Because the device was a single stage device covering the single stage would short the output of the device and allow the current limiting resistor to overheat and fail. When confronted by a small colony the device would often the colony before it was covered with earth.

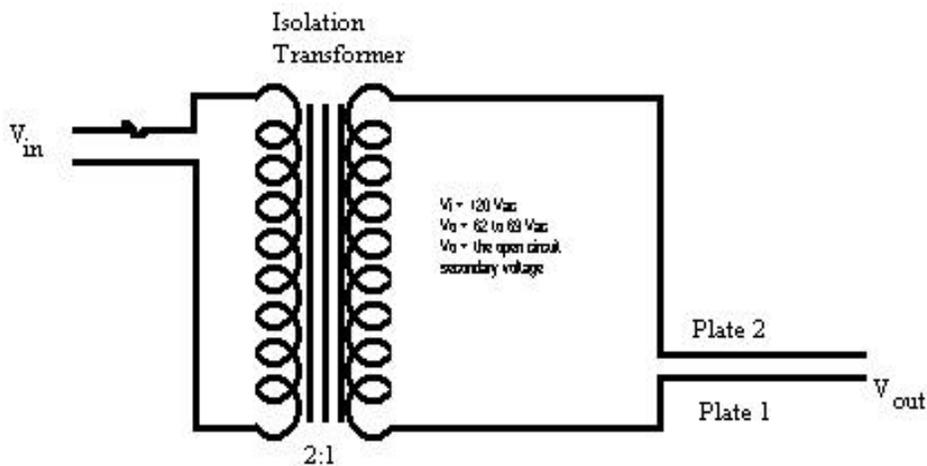


Figure 2.2 Electrical Schematic of 120-V Field Devices 2 and 3

After discovering the behavior we modified the device from a single stage device to a double stage device. Having two independent circuits operated from the same transformer allowed for defeat of a single stage while leaving one stage in tact and operational. In order to defeat the

Materials

In the materials studies associated with the SED we found copper or brass to be the best materials to use for the energized plates. Neither copper nor brass develop a significant electrically insulating oxide layer. Copper and brass do corrode and develop a green oxide over time when exposed to the elements but the surface area of corrosion are usually visible and easy to clean. Copper and brass are also easy to work. They are however, relatively expensive material with brass generally being cheaper than copper. We chose brass because it showed the least corrosion over time and was readily available.

Aluminum was tested early on in the laboratory and it was discovered to have an oxide layer that was a good electrical insulator as far as the ants were concerned. The initial test was conducted with brass and copper conducting plates with operating voltages from 0.0-V to 190-V. When aluminum plates were used for an active surface the ants did not react until the voltages were well above 60-V to 100-V. Although aluminum would have been the economical material of choice it could not be used in the field due to the properties of the oxide layer. The first devices deployed in the field were brass devices.

Stainless steel has the desirable qualities of the brass conductors, it does not develop an electrically insulating oxide layer, economically it is less expensive than the copper or the brass, and it is readily available. However it is more difficult to work than copper or brass. After some consideration the second devices deployed in the field were constructed with stainless steel conductors. So the second and third devices deployed in the field were made of stainless steel with a 120-V to 60-V step down transformer.

Current Field Trial and Device Design

When we developed the third device, operating at around 60-Vac, we learned they operated well in the laboratory and relatively well in the field. After operating the devices at the 60-V lever we reconsidered the design to remove the transformer completely. The transformer was physically the largest, heaviest, and most expensive part on the device. The Transformer also was the largest power user and uses power continuously while it is in operation.

A small isolation transformer is a vulnerable part to remain exposed to the elements for an extended length of time. Redesigning the device to remove the isolation transformer would make the device more reliable and much cheaper to manufacture. Using the 120-Vac-to-ground terminals of the pad mounted residential power transformer we could redesign the device as a diode rectifier circuit to work at either 80-Vdc + 50-Vac or 40-Vdc + 60-Vac. Full wave rectification produces the higher voltages and half wave rectification produces the lower voltages.

Fourier Analysis

A 60-Hz, 120-Vac RMS sinusoidal voltage signal is written as:

$$v(t) = 170\text{-V} \sin (2*\pi*60*t) \quad \text{Eq. 2.1}$$

Where:

170-V is the peak voltage of the ac signal

$\pi = 3.14\dots$ radians/180°

60-Hz is the frequency in cycles/second

t = seconds

and is shown below in figure 2.3. The diodes act as a current check valve or gate.

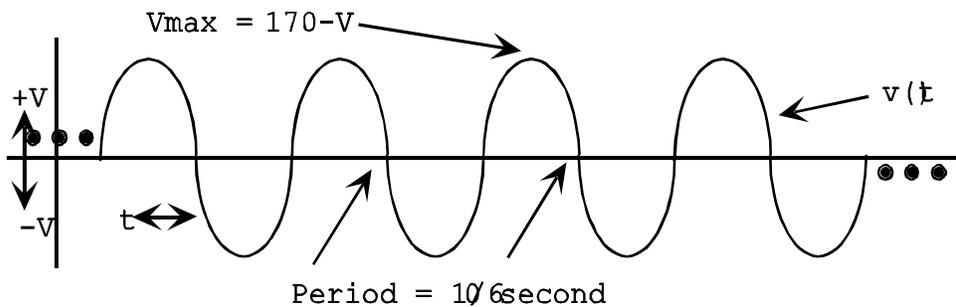


Figure 2.3 A 60-Hz, 120Vac RMS Voltage Signal

They show a very high resistance to reverse current and very low resistance to forward current. The diode may be connected in several ways for rectification of a voltage signal. For single-phase full wave rectification usually 4 diodes are used in a bridge network and single-phase half wave rectification may be accomplished using only one diode as shown in figure 2.4

The two rectifiers are shown with the output as an open circuit, a "no load" configuration. In the no load configuration no current flows through the network so no power is consumed in the no load configuration. Power will be consumed only when a load appears across the output of the rectifier and the power consumed is proportional to the resistance of the load.

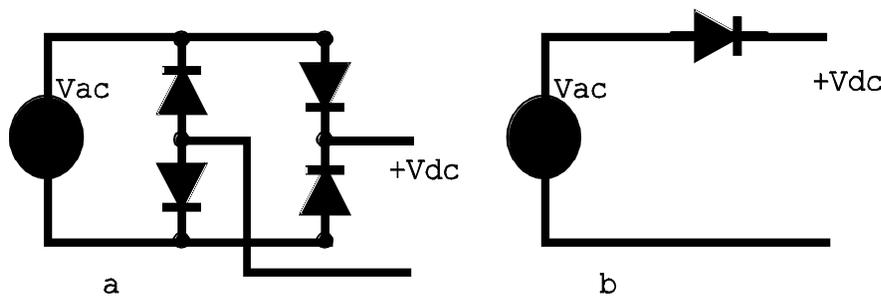


Figure 2.4 a) Full wave rectifier and b) Half wave rectifier networks

The voltage signals resulting from the full wave and half wave rectification networks are shown in figure 2.5.

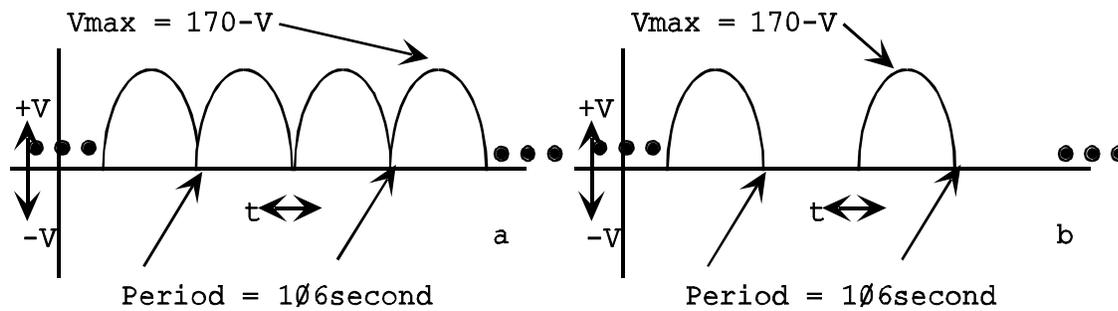


Figure 2.5 a) Full wave rectification and b) Half wave rectification

The diodes change the voltage signal from a positive and negative alternating voltage signal to a pulsating positive signal. Full wave rectification saves the entire voltage wave from the sinusoidal signal, while half wave rectification saves only half of the voltage signal.

Rectification of 120-V, 60-Hz

Using Fourier analysis techniques on the rectified sinusoidal voltage signal shown in figure 2.5 we can calculate the voltages supplied by both the full wave rectified signal and the half wave rectified signal.

Fourier analysis is used to determine the voltage components of any periodic signal as shown in equation 2.2. A periodic signal can be characterized as the sum of a constant term and several sinusoidal terms.

$$w_n = n w = 2 n \pi u$$

Eq. 2.2.

Where: a_n 's and b_n 's are amplitudes of the sinusoidal terms,
 ω_n 's are the harmonic frequencies in radians/second, and
 u is frequency in Hertz (cycles per second)

The zeroth term, a_0 , is the constant or DC term and all the higher order terms are the harmonics for the periodic signal. The full wave rectification of a 120-Vac RMS signal has a DC voltage of 76-Vdc and the higher order terms are 50-Vac at 120-Hz, 10-Vac at 240-Hz, etc. with the ac voltages decreasing as the frequency increases. The full wave rectification of a 120-Vac RMS signal has a DC voltage of 38-Vdc and the higher order terms are 60-Vac at 120-Hz, 25-

Vac at 240-Hz, etc. with the amplitudes of the ac voltages decreasing as the frequency increases. The average dc voltage plus the harmonics for the full wave rectifier supplied a voltage greater than 100 volts when the first terms are summed. The sum for the first two terms of the half wave rectifier is less than 100 volts and within the upper range of voltages we have found to be effective for forcing the ants to gaster flag excreting an apparent alarm pheromone.

Design Philosophy

The design philosophy for the diode SED was to use the ants as the load for the output of the rectifier. The ants complete the output circuit of the half wave rectifier providing a current path for the output. The ants are also a very high resistance, several thousand kilohms, so the current load of the rectifier is very low, on the order of 0.0001 amperes or less per ant. When an ant completes the electrical it is energized causing it to gaster flag, and then to eventually die.

Failure due to ant activity

The failure of the SED due to ant activity in the field has been for the ants to cover the devices with earth. For the previous field experiments we have conducted the test has been to introduce the device into a pad-mounted transformer regardless the level of ant activity present. We were looking for the ant response to the presence of the device.

Many of the colonies in the transformers were well-established colonies several years old. We did not remove any ants or any material from the ant mounds in the transformers. The very large colonies would begin to bury the device immediately and would complete the task within a few hours causing failure of a single stage device.

In transformers that were not heavily infested there were not enough ants to bury the device so the device would not be defeated and the ants usually either left the transformer or their numbers appeared to be reduced.

It should also be noted there are other creatures invading the transformers however they usually do not cause transformer failure. The transformers are also invaded by wasps, snakes, lizards, snails, slugs, spiders, and many other ground dwellers. The only real threat among these creatures is the snake; they can short either the primary or secondary side of the transformer. Snakes are a well known but low probability problem.

Three stages distributed design

)2

The expected failure mode was burial of the device so the device was designed as a three-stage device or three half-wave rectifiers per device using a single fuse. As the ants cover a stage a large current would be drawn through the diode. As each diode was drawn into a high current mode of operation the diode would over heat and fail leaving the remaining stages in tact and operational. In a catastrophic failure a mode very low resistance short circuit would draw a very high current and activate a fuse to prevent transformer damage. A drawing and simplified schematic of the device is shown in figure 2.6.

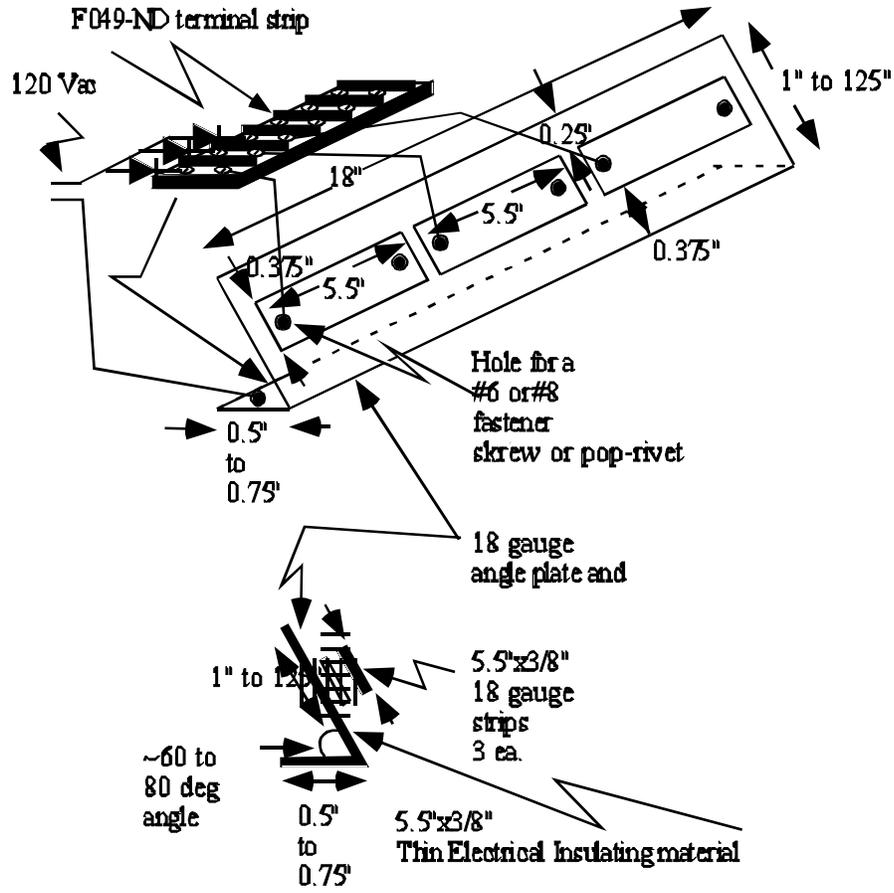
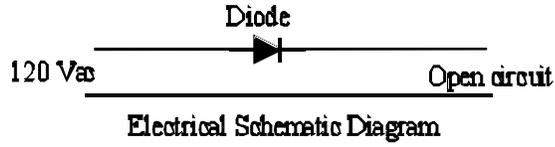


Figure 2.6 A three stage SED

In figure 2.6 it can be seen that the device is made in three sections. The device conducting material is stainless steel with three small rectangular energized conducting plates separated from the larger grounded substrate by a thin piece of electrical insulation material. Stainless steel conductors were 18 gauge 304 or 316 SS with a 4 to 6 mil plastic insulating material between the two conductors. The energized plate was fixed to the ground plate with non-conducting nylon screws. A terminal strip was installed for all the necessary electrical connections. A fused conductor was connected between a 120-Vac terminal inside the residential transformer and the terminal strip with the fuse as close to the transformer terminal as possible. The fuse is to provide electrical protection for the power transformer. In the event of a short circuit from a 120-Vac terminal to ground inside the transformer a small conductor would go to its maximum current carrying capacity. The intense current surge would rapidly heat the conductor to the melting point of the conducting material. The small conductor can explode and ignite any combustible material in the transformer. Power wires, ground wires, diodes, the three energized plates, and the ground plate were attached to the terminal strip.

We did not view a resistor in the output of the device as a necessary element because the ants were going to be the resistive load and a resistor might limit the effectiveness of the output of the device. The device was assumed to have a graceful failure mode. If there is enough moisture in the ground, as the ants buried the device shorting it between an energized plate and the ground plate, the diodes will begin to conduct. If the earth is a large enough conducting load the diode would over heat, open circuit, and fail while the fuse would pass the load until diode failure. The

three stages provided an extended device lifetime as three diode failures are necessary before the device is disabled.

The devices were constructed, tested, and delivered to Texas Tech in spring of 1998 and were deployed to several locations in: Waco, Tyler, North Dallas, Arlington, and Houston.

Field Trial

2.3 1998 Field Trials

Upon receiving the field trial devices a small sample were tested at Texas Tech in the laboratory and preformed satisfactorily. Arrangements were made to install the devices in the field and installation began in June.

During spring 1998, three-stage, diode-controlled SEDs (fig. 2.6) were manufactured at the Texas State Technical College (TSTC), Waco, Texas. Devices were delivered to Texas Tech University, tested in the laboratory, and pronounced as working satisfactorily. Arrangements were made with Texas Utilities–Electric for device installations in pad-mounted transformers in Waco, Tyler, Dallas, Ft. Worth, and Arlington, Texas Table 2-1.

Table 2-1. Number of diode-controlled SEDs and control treatments at Texas Utilities-Electric sites.

<u>Location</u>	<u>date (1998)</u>	<u>no. devices</u>	<u>no. controls</u>
Waco	16-17 June	38	20
Tyler	18-19 June	35	15
Dallas, North	7-8 July	34	18
Ft. Worth, West	9-10 July	30	16
Arlington, SW	13-14 July	21	15
	Totals	158	84

After each transformer was approached, a technician rapped on the metal transformer box with a metal wrench. If a red imported fire ant colony was located inside the box, ants would typically become very agitated and would swarm out through seams in the box. Notations were made as to the ant activity, and some colonies were videotaped for image processing. These procedures were the initial attempts to develop a “hammer test” to measure fire ant colony activity without dependence on physically opening transformer boxes. Then, the technician would unlock the box and carefully lift the lid to reveal the contents. The activity and size of a fire ant colony inside the box was rated. During summer 1998, most ant nests inside boxes were abandoned, or colonies were very deep in the soil as to not respond to disturbance. Summer 1998 was extremely hot and dry in central Texas, and fire ant colonies were under extreme stress.

If no ant colony was present in a box, one of two treatments was applied: a SED was installed, or no device was installed. In a box had a resident colony, mound soil was shoveled from the box, and a SED was either installed or not. From previous field research, disturbance of colony mounds by shoveling was an important adjunct to SED installation in keeping transformer boxes free of ant damage. If a transformer box had been obviously treated with an insecticide or had considerable oil leaks, the box was not used in this experiment.

Devices were also sent to Mr. David Visconti, Houston Lighting & Power, for installation in transformers. Visconti incorporated our SEDs in insecticide trials to prevent red imported fire ants from building colony mounds inside transformers in residential neighborhoods.

On 4 December 1998, the Dallas, North, sites were visited to evaluate treatment effects. Seven transformers with installed SEDs were opened, and six SEDs were found to be inoperative, all with blown fuses. Inoperative SEDs were replaced with operative devices. Typically, failed

SEDs were covered with moist, mound soil that caused malfunction. In one box where the SED was still working, a small fire ant colony was present. Of the three opened transformers without an SED (control treatment) at this date, two had small mounds and one had no mound.

Failure of d-SEDs was a disappointment and probably was the result of moist conditions and increased fire ant activity and mound-building of autumn 1998. Because of observations in Dallas, north, in December, other experimental sites have not been visited since initial installation of devices. New prototypes have been developed as replacements for failed devices. Detailed discussion of d-SED failures and engineering concepts for the future appear elsewhere in this report.

Device installation

As non-power company employs, non-High voltage linemen, and for safety reasons we were not allowed to install the devices in the pad mounted transformers. We were allowed to observe and instruct a qualified lineman from a safe distance when the transformers were opened. The residential transformers usually have two High voltage power connections on the primary side and two low voltage connections with a ground on the secondary side. The power companies also use earth as a ground for safety reasons so each transformer has a ground rod driven into the earth inside the pad mounted transformer base. All grounded portions of the transformer are connected to the ground rod with a large non insulated conductor, these include the metal transformer case, the internal transformer ground connections and all the ground connections returning from the residents served by the transformer. Figure 2.7 shows a typical pad mounted transformer with the High voltage and low voltage electrical wiring.





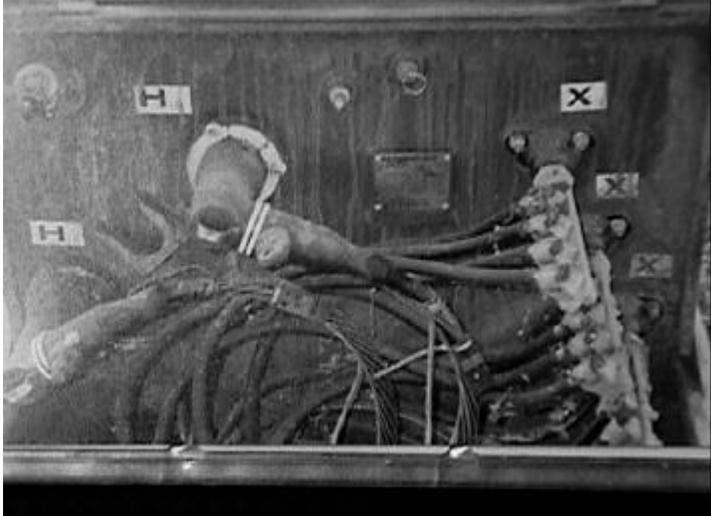


Figure 2.7 Pad Mounted Residential Transformer Internal Wiring

The high voltage connections are well insulated and the low voltage and ground connections are sometimes left bare for ease of residential connection.

As can be seen from figure 2.7 there are several wires pulled into a very limited space. Usually when one of the transformers is opened, if it has been in the field for a while, it will have

an ant infestation or the remains of an ant infestation. The infestations are characterized by the presents of ants and an ant mound inside the transformer or and abandon ant mound only. In either case the ant mound is removed from the transformer and the device is installed.

Installing the ant device among these conductors is a difficult task. The device is the shape of a 45-cm steel bar so cleaning out an old ant mound and manipulating the device around all the conductors and advantageously positioning it is tedious and time consuming. Many times the device will be gouged into the soil, or tipped onto the active surface after installation, or poorly positioned in the transformer. After the device is positioned and energized it is sometimes necessary to reposition the device. The linemen often repositioned the device while it was energized. It is not an unsafe procedure, the linemen are well protected and the device is operated at a very low voltage as far as electrical power voltages are concerned. If the device is unintentionally grounded during the manipulation a high current short circuit is introduced onto the device, the fuse and several of the diodes are usually destroyed. The fuse protects the pad mounted transformer from any wire melting from the device power conductor but the high current pulse through the fuse and a diode, due to the short, usually cause voltage and current reflections that damage one or both of the remaining diodes. In the confined space and uneven surfaces the devices would be repositioned several until a satisfactory position was accepted. The concern with positioning the device was due to the several different internal designs of pad mounted transformers encountered in the field. The conductor congestion in the transformers was also variable. Several residences served by a single transformer meant several sets of residential conductors in the transformers. Few residences served meant few conductors.

Weather conditions

During installation the period of the devices in the pad mounted transformers, the Midwest in general and Texas in particular was suffering from a drought. All the field installations were conducted during temperatures in excess of 100°F and very low humidity conditions. There was virtually no ant activity found in the pad-mounted transformers and the mounds found in the transformers were usually deserted. The mounds in the transformers were the consistency of baked clay and were very difficult and time consuming to break up and remove.

Device failure in field trials

During device field installation about one device in 15 would fail. The failure mode was a high-current arc from the energized plate to the ground plate when the device was energized. Figure 2.8 shows a typical device short circuit arc failure.

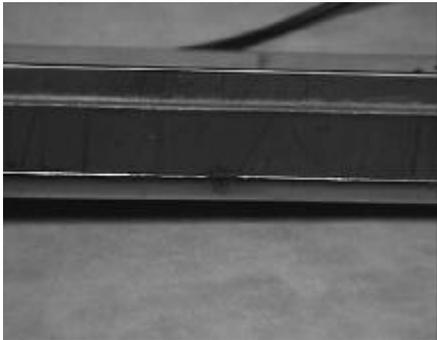


Figure 2.8 Typical Field Device Short Circuit Arc Failure

When the short-circuit failures were discovered in the field, the uninstalled devices were retested for continuity in the field before further installations. Any devices found to fail were repaired and prepared for installation. After testing the devices in the field, about one device in 25 failed the continuity tests. All the devices were easily repaired and installation continued without delay. The continuity failures found before installation may have been caused by handling or transportation damage.

Device Field Failure Modes

Two installation failure modes were recognized in the field. The first failure mode was due to difficulty of manipulation of the device by the linemen in confined and congested spaces. The second failure mode was a spontaneous short circuit of one of the energized plates when the devices were connected to power or sometimes several seconds after the device had been energized.

There were maybe five to seven devices lost to manipulation and five to seven devices lost to spontaneous short-circuits. The losses to manipulation were quickly recognized and understood. The device was not an optimum shape for installation into a congested environment. The major dimension of the device was the 45-cm length. The foot-print of a conductor vault for a pad-mounted transformer is about 40-cm x 90-cm, with the exact dimensions varying depending on the manufacturer of the transformer and the year model. The linemen must wear insulated leather gloves during all their work inside the transformer. The gloves are very bulky and cumbersome making manipulation of the device a difficult task. The device was designed for protection of the pad mounted transformers from ants but the device was not well designed for the linemen to

manipulate around and through a maze of high and low voltage conductors. Due to the congestion in the transformer, the device was sometimes difficult to set properly or easily. A device was easily tipped over during installation, and its face could be gouged into the dirt during installation. The device would need to be removed, cleaned, and reinstalled before it could be energized.

The second failure mode, a short-circuit failure, was a catastrophic failure and was later determined to be a design defect. The active portion of the device was designed in three layers, conductor, insulator, and conductor. The conductors were 18-gauge stainless steel conductors, and the insulator was a 4-mil to 6-mil flexible plastic insulating material. The stainless steel and plastic were chosen for long-term corrosion resistance. During the initial design and testing the device was not found defective. The device was tested in Waco, TX and Lubbock, TX. The test devices were probably more carefully prepared than the prototype production devices. After initial test the devices were installed in several locations around the Dallas-Fort Worth area. A few of the devices spontaneously failed during installation and the failure was attributed to poor craftsmanship in those cases. On the return inspection trip after device installation, we discovered many of the devices had spontaneously failed in place with little or no activity. A forensic study was conducted on the devices returned from the field to determine the cause for the catastrophic failure mode.

During design and construction a drought was in progress in Texas, so very low humidity and high temperatures were the normal weather conditions for several months. Lubbock, TX is also located in the arid and semiarid region of the United States, so low humidity conditions are

normal for the Panhandle region of Texas. Air resistance is very large making air a good insulator having an average breakdown voltage of 30-kV/cm [**Ref: Introductory Circuit Analysis 6th Ed., by Robert L Boylestad, Merrill Publishing Co., Columbus, OH, 1990, ISBN0-675-21181-6**] or about 76-kV/inch. The insulating material used in the device separated the conductors at least 0.004 inches or more for an air insulation value of more than 300-V. The largest peak voltage a 120-Vac rectifier is usually exposed to is 180-V so the 300-V gap gave a margin of safety of over 100-V under the worst-case conditions. The design appeared to be adequate and the laboratory test appeared to confirm the design expectations.

An arc failure in the field indicated an unanticipated design flaw in the device. During manufacture the stainless steel was cut with a mechanical shearing device. The shear is a large pair of scissors with two cutting edges, one fixed and one movable. As the movable shear cuts any sheet metal the metal is deformed as it is cut leaving a smooth edge and a jagged edge on the sheared metal. The shearing operation also leaves metal fibers attached to the sheared surfaces. It is a standard procedure to cut thin sheet metal with these shearing machines in the manufacture of mechanical devices. In the manufacture of electrical devices the jagged edges and metal fibers are very bad. The jagged edges cause electric field enhancement regions between conductors. Whereas a pair of conductors may be separated by several kilovolts of air insulation, a sharp edge will enhance the electrical field in the region near the edge causing an electrical corona to form. The corona is an ionized gas plasma and the plasma forms a very good conductor near the sharp edge. The insulating qualities of the non-ionized air is still 30-kV/cm; however, the insulating qualities of the ionized air is about 0.0-kV/cm, or a short circuit. During design of the SED, the jagged edge problem was recognized and the metal was to be sheared in a manner to reduce the

field enhancements or eliminate them completely. Figure 2.9 illustrates the jagged edge associated with shearing sheet metal.

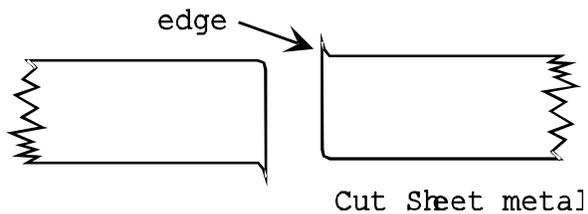


Figure 2.9 Sheared Sheet Metal with Edge

The shearing process always leaves the jagged sheared edge, but the sheet metal may be manipulated to produce the edge on the same plane surface. If the cut sheet metal is placed with the jagged edges facing each other (Figure 2.10a), the distance between conductors is reduced and each edge can generate an electric field enhancement region causing ionization and arcing. The sheet metal is shown with only one edge (Figure 2.10b). The field enhancements at the sharp edge are still large, but only one enhancement region exists, and the separation distance between conductors is increased improving the insulating qualities of the air. The edges are facing away from each other (Figure 2.10c), and smooth rounded surfaces are facing each other. The smooth rounded surfaces reduce field enhancements and reduce the risk of an arc discharge.

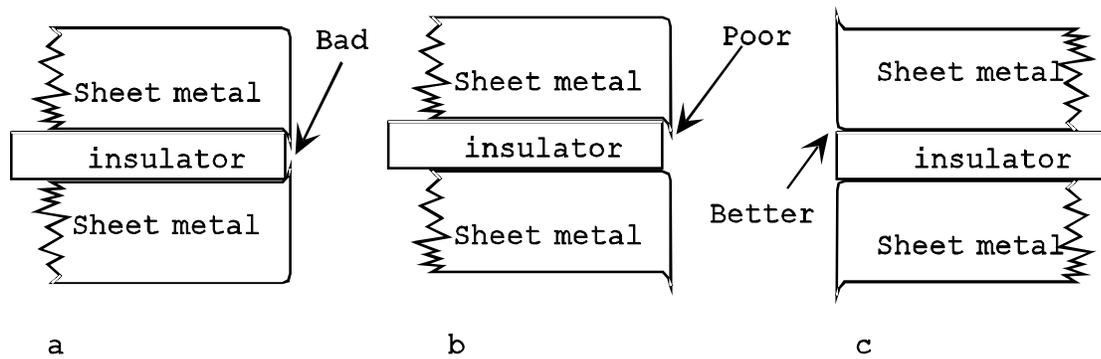


Figure 2.10a) Facing Edges b) Single Facing Edge c) No Facing Edges

The jagged edges can either be ground off or the edge may be faced away from the ground plane. We chose to leave the edge and face the edge away from the ground plane. The solution worked well, and device manufacturing continued. Some of the arcing failures experienced in the field was due to metal shavings and debris near the edge of the conductor-ground boundary as shown in (Figure 2.11).

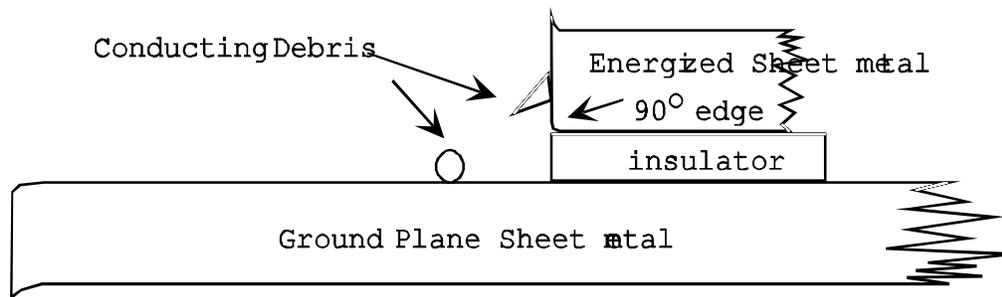


Figure 2.11 Conducting Debris Near Device Conductors

The conducting debris reduces the insulating separation distance of the air or, in the case of a sharp edged piece of material, will cause field enhancements and arcing. The stray sharp pieces can result as a residue from the sheet metal cutting operation. Also a dirty contaminated area may introduce stray conducting material in or around the active region of the device.

The low humidity and dry air conditions during the drought improved the insulation qualities of the air so the devices did not fail when they were installed. The majority of the field failures occurred after the devices had been placed in the transformers. The Dallas-Fort Worth area is a much more humid region than the Texas Panhandle. When the drought was broken and it began to rain in the Dallas-Fort Worth area, the increasing humidity reduced the insulating qualities of the air and enhanced the corona discharge regions around any sharp edges of the energized conductor, eventually caused an arc short-circuit.

The onset of an arc introduced a very high current pulse load onto the device because there were no current limiting resistors in the current path. A fuse is a very low resistance and the diodes form a very low resistance path in the diodes forward current direction. During the arc discharge it takes a few hundredths of a second for the fuse to operate, and during that short time the diode will not reach its power limit until after the fuse has operated. High-voltage current and voltage pulses are reflected through the other diodes after the fuse operates and will usually destroy at least one more diode in the circuit. Devices experienced around a 5-kWatt pulse for a few hundredth of a second exceeding the power limits of the fuse and the diodes causing device failure. Humidity, condensation, corona discharge, and lack of a current-limiting resistor were the primary causes of device failure.

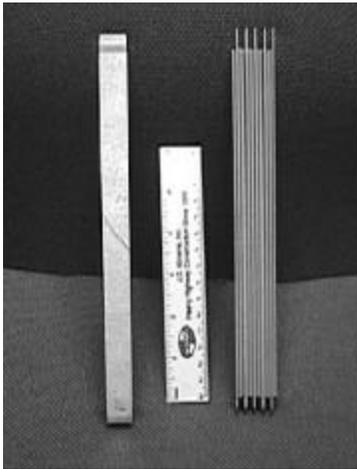
Current limiting resistors in the diode circuit might have prevented catastrophic device failure, but the catastrophic failure pointed to a very serious weakness in the design of the device and demanded a new more robust device design.

Redesign Device

The first redesign effort concentrated on using stainless steel as the conducting material, increasing the thickness of the plastic insulation material, removing the jagged edges, and reintroducing the current limiting resistor. In the previous design, shown (Figure 2.6), only the perimeter of the energized plate is active. The ants are not energized unless they completed the circuit from the energized plate to the ground plate. We wanted a multistage device with an increased effective perimeter protected from catastrophic failure. When properly set in the pad-mounted transformer the three-stage device did not present a vertical, self-cleaning surface. The surface was 20° to 30° from vertical with a 1-mm edge at the top of the energized plate to collect ant debris. The 1-mm edge would simplify the task of defeating the device from above. The redesign also eliminated the 1-mm edge and replaced it with a plane vertical surface.

The first redesign was a sandwich of stainless steel and plastic insulator (Figure 2.12), and Figure 2.13 shows the construction of the sandwich. The insulator and the stainless steel are both 18-gauge materials sandwiched together with an adhesive material. Materials were purchased in standard industrial sheets then cut into 20-cm x 30-cm sheets. Sheets were then bonded in an insulator-stainless steel sandwich with 10 layers of stainless steel and 9 layers of insulator. The sandwich was about 2.5-cm thick with five independent, active sections. The 20-cm x 30-cm sheets were then cut into 20-cm x 1.5-cm x 2.5-cm strips using a supersonic water jet cutter. Cuts were made with the jet cutter to prevent metal contamination and produce a vertical edge with a very smooth surface. The insulating material has a breakdown strength of about 500-kV/cm. After design and construction of a few of the sandwich devices, they were found to be very strong, tough, and fail-safe. The new construction increased the working surface by a factor

of four. The reduced length of the devices would make them simpler to install, and the rectangular foot print and weight of the device made it very stable; however, being only 2.5-cm tall an aggressive colony of ants could cover the new device with soil. Devices were very expensive to construct, and bonding electrical conductors to stainless steel is difficult. The cutting operation was very clean , left a very nice edge, but was expensive, and the device was limited in height by the limitations of cutting tool. The cost of the stainless steel sandwich was too great to be acceptable for a several hundred devices.



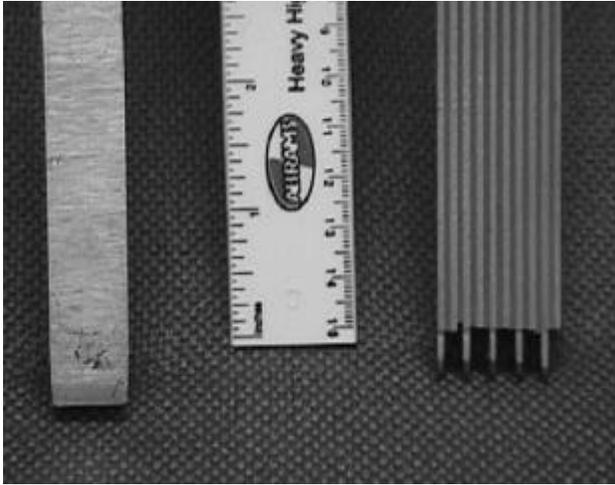


Figure 2.12 Stainless Steel Sandwich

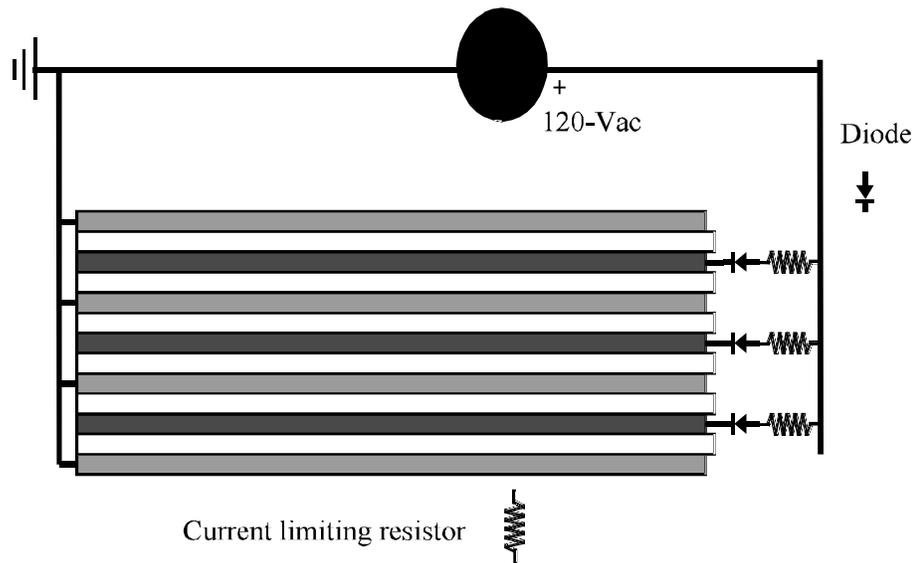
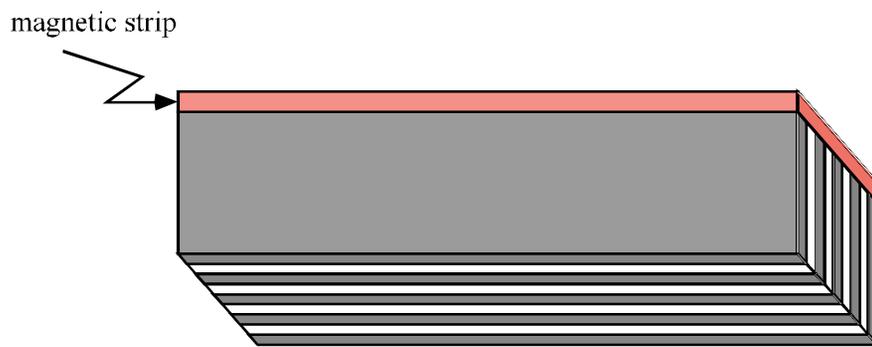
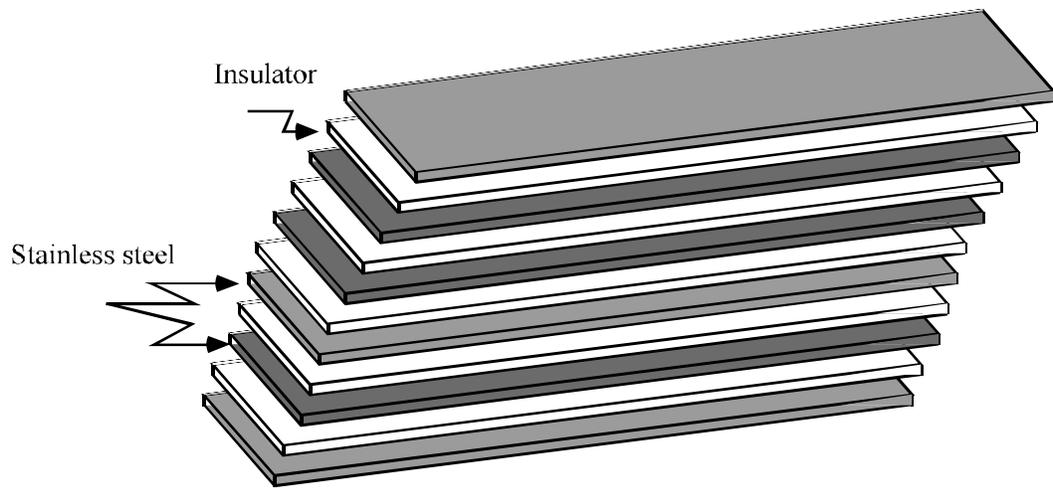


Figure 2.13 Sandwich Construction

Circuit Board

In the second redesign effort, an electronic circuit board was chosen as the basis for device. The circuit board is made of an insulating material and a copper-plating sandwich. The circuit board may have one or several layers. Most of the circuit boards used in computer equipment have several layers. The circuit board we chose is a one-sided circuit board with copper plating only on one side. In order to make the copper circuit network on the circuit board, it is necessary to outline the circuit configuration then make a circuit mask for the copper plating. The copper plate is masked with a chemically resistant material, then the board is placed in an acid bath to etch away the unwanted portion of copper. After the unwanted copper is removed, the masking material is removed and holes are drilled in the board of the electronic components. The finished circuit board is about 20-cm x 8-cm x 0.15-cm. The copper conducting traces are coated with a lead-tin solder to prevent copper corrosion then holes are drilled in the board to accept all the electronic components.

The conducting traces can be precisely located and their dimensions may be controlled to within 0.01-cm or less. The insulating substrate has a voltage standoff of about 45-kV/cm or more, depending on the circuit board material, and is dimensionally stable, light weight, and moisture resistant. The larger dimensions of the circuit board, compared to the sandwich device, will make it more difficult to defeat using soil to cover the device. The circuit board can easily be

Figure 2.14 Fire Ant Circuit Board Device

The circuit board uses a fuse for transformer protection and the half-wave rectifier design for disturbing the ants. It is a seven-stage device with the conducting traces about 3-mm wide and the insulating spaces about 2-mm wide. The critical dimension is the insulating space. It is necessary for the insulating space to be narrow enough for a small worker ant to bridge gaps between the energized conducting trace and a grounded conducting trace.

Using lead-tin to protect the copper conductor was initially a concern. Nearly all metals develop an oxide barrier when exposed to air. The oxide layer is generally an electrical insulating barrier. The lead develops an insulation lead oxide layer as expected. In the presence of very low voltages, less than 40-V, the insulation layer would protect the ants from being energized. Above 40-V the insulating boundary is not a significant insulator and the ants are energized. The half-wave rectifier typically operates around 60-V, so the insulating boundary layer is defeated.

The circuit board is attached to a vertical surface inside the pad-mounted transformer and at the bottom of the transformer adjacent to the conductor access hole. There are two choices for attachment: 1) sticky back foam tape or 2) magnetic strips. Sticky-back foam tape is cheap, reliable, and easy to find but is difficult to remove and leaves a residue after it is removed. The sticky-back tape only allows one opportunity to position the device. If the device is poorly positioned, it must be removed, old sticky-back tape removed, new sticky-back tape replaced, and the device repositioned. The sticky-back tape is a use once device and allows no repositioning after it has been used. Magnetic strips are also reliable, easy to find but a little more expensive.

The magnetic strips allow repositioning the devices after they have been installed with no trouble.

Circuit Board Laboratory Tests

In the laboratory we tested the circuit boards for the short circuit failure mode and we tested the devices for ant response.

In the transformer models there is a great deal of inductance due to the transformer windings. In a short-circuit failure the inductance will enhance the voltage and current pulses associated with the short circuit. The enhanced current and voltage are usually recognized as a spark. When the device is short-circuited without a current-limiting resistor, the spark is large; when it is short-circuited with a current-limiting resistor the spark is small. In the circuit board device the components are only diodes, current-limiting resistors, and open circuits or an ant as the load. There is very very little inductance, so a short circuit causes only a very very small arc. The arc is so small that it is only noticeable with very careful observation. The low inductance and the current-limiting resistor prevent any large surge current so the fuse is protected from a short-circuit failure. Under short circuit conditions the 100- Ω , 1/4-watt resistor will overheat and fail to save the device from catastrophic failure or the diode will overheat and fail, also saving the device from catastrophic failure.

The laboratory ant test was conducted to determine the ant response to the device. An oxide boundary layer associated with the lead-tin coating on the copper conductors exists. The oxide is slightly insulating so it reduces the voltage available to the ants slightly. The half-wave rectifier operates at 60-Vac with a 40-Vdc component, so the boundary layer is easily overcome. As the

ants walk across the device and bridge the conductor-to-ground connection they become the power load for the device. The ants have a very high resistance, several thousand ohms, so when they make contact they draw only a few microamperes of current. It is not enough current to kill an ant immediately, but it is enough current to induce the gaster flagging response.

APPENDIX B

Fire Ant Imaging

Necessity of Fire Ant imaging

Currently the state of the art for evaluating the size of an imported fire ant colony is to either count each individual ant, capture the entire colony and weigh the total colony, or observe the ant mound and mound activity. Counting each individual ant does not take an expert, but it does involve capturing the ant colony, removing all the ants from the dirt, killing all the ants, then counting the ants. Weighing requires an expert in the field. A colony is captured, ants are separated from the soil, and then the ant mass is weighed. If an ant count is needed without killing the colony, one may use a probability distribution to estimate the percentage of majors and minors in a colony, assume the average weight of majors and the average weight of minors, and estimate the ant population. Observing the ant colony and estimating the size of the ant colony from the observation of ant activity, brood size, mound size, and other variables may only be performed by an expert in the field.

Counting and weighing are quantitative measurements, but the colony is destroyed using these quantitative measures. Observing the colony is a qualitative measure made by an expert, it is relatively accurate based on the expert's experience and does not destroy the colony, although it may disturb the colony.

In the pad-mounted transformer work, we need to install the ant device and then make several hundred observations of the ant activity over the following two to five years. Installing the devices in the field in a pad-mounted transformer by the researchers is not allowed for safety and

liability reasons. Most power company linemen are not allowed to work above 550-Vac until they have been apprentices for four years. The pad-mounted transformers have primary voltages of 7,200-Vac to 28,000-Vac and secondary voltages of 120-Vac to 208-Vac. Residential transformers are usually 25-KVA to 50-KVA so they can supply about 200-amperes of current at 208-Vac continuously to the resident's load, hair dryers, refrigerators, stoves, light and electronics. If the transformer primary is short-circuited it will supply several thousand amperes for a few tenth of seconds until a safety device saves the system. A short in the secondary can cause a several thousand amperes load until a safety device saves the system or the transformer is destroyed. The safety equipment usually does not save the people. The environment requires an expert power company lineman and the lineman's safety equipment to open the transformer.

Usually the power company must supply a vehicle, one to two linemen, and all the electrical power safety equipment necessary to open the pad-mounted transformers for a fire ant researcher. The linemen are about \$100.00 per hour straight time, \$150.00 to \$200.00 per hour overtime, and the vehicle is about \$200.00 per hour to \$700.00 per hour. The power company can easily invest \$2000.00 to \$5000.00 per day during the installation of the ant devices. After device installation pad-mounted transformers must be opened for inspection each time the researcher takes a data point, and the power company must invest the same \$2000.00 to \$5000.00 per day during inspection.

During installation and inspection only about 15 to 20 pad mounted transformers may be worked in a single day, so it takes about 10 days to work with 150 transformers. The cost to the power companies is between \$20,000 to \$50,000 per installation or inspection. In the course of

only five inspections the power companies can invest in excess of \$150,000.00 in this project.

The power companies face a significant cost when committed to this project. A simpler and non-expert inspection method is necessary to save the power companies time, resources, and money during the lifetime of the project.

Transition from qualitative to semi-quantitative measurement

Using video-imaging techniques we are transitioning from a qualitative to semi-quantitative measurement of ant activity.

In the past an expert observation is necessary to determine the size and activity of an ant mound. The expert observes the mound size and the mound activity after it has been disturbed in some way. The expert estimates the volume of the mound and categorizes the volume of the mound. The expert disturbs the mound and observes the level of ant activity. The expert makes a subjective evaluation of ant activity and ant quantity after the observation. Variations in expert's subjective opinions are determined by the training each expert has received in evaluating the ant mounds. Fire ant experts must be able to communicate, cross correlate, and calibrate their observation. In the future it may be difficult to cross correlate the opinions and observations of several thousand experts.

Video imaging can be used to standardize the subjective measurements into a relative objective measurement. Video images may also be presented to an expert for gathering ant mound data without the expert going to the field for each observation. Using video image capture and computer enhancement techniques we are working on quantifying the number of ants

present on the surface of a disturbed colony. We are also using the images to determine the level of agitation the colony is experiencing. The level of surface agitation is a disturbance measure and the maximum number of ants on the surface of the disturbed mound is a relative measure of the size of the colony.

Develop non-invasive methods to quantify ant-transformer activity

Our purpose in developing video imaging techniques for ant investigation is to develop a non-invasive method to quantify ant-transformer activity. By developing non-invasive transformer measurements, we may make many thousand measurements rather than a few hundred. To make an ant-transformer measurement today, we must open each pad-mounted transformer and look at the ant mound. Opening the transformer requires the power company's presence not just their permission. The power companies presence costs the company several thousand dollars a day and must be coordinated to accommodate the power company personal. A non-invasive ant-transformer measurement requires the power companies permission, and only minimal coordination with the power companies.

Methods of Quantifying Ant Activity

In order to use video images to determine a more quantitative assessment of fire ant evaluations, a great deal of video imaging during device installation needs to be accumulated. After video images are accumulated, a fire ant observation expert or experts are necessary to calibrate the fire ant video images. After the images have been categorized for calibration, a computer algorithm expert system may be generated to answer the fire ant questions in the same way a fire ant expert would answer the question.

A video camera may capture images at a rate of 1 to maybe 100 frames-per-second (fps) depending on the video camera. Let us use 20-fps for an example video camera. In order to determine the activity of a fire ant mound timed video images need to be captured. Each image is captured $1/20^{\text{th}}$ -sec or 50-ms. from the next. In 50-ms an active ant moves only a few tenths of a millimeter while the ant's background does not move at all. When consecutive images are digitally subtracted only the motion of the video image, and maybe some electronic noise artifacts, remain. In mathematical terms, the difference in the images with respect to time is the same as a first derivative of the image with respect to time. The difference in the consecutive images may be used to get an ant count. In a few more seconds many more images are obtained, and two more consecutive images maybe captured and subtracted. After capturing and subtracting consecutive images we have obtained several consecutive image-first derivatives. Taking consecutive first derivative images and subtracting them gives us a second derivative. The first derivative is usually thought of as a velocity, the second derivative is thought of as acceleration. With each first derivative an ant count may be established. With the second derivatives a change in the number of ant count can be established, and ant disturbance activity can be established until an ant image

saturation level is reached.

Currently we are working on several methods to quantify fire ant activity in and around a disturbed mound so the methods may be applied in the field. Our primary concern is to quantify fire ant activity in and around pad-mounted transformers. Pad-mounted transformers are a unique environment for study because they are not a naturally occurring nest site. The all pad-mounted transformers have a characteristic size and shape and a characteristic access mode. Fire ants disturbed in a transformer usually exit from the transformer seams and travel along the ground or the transformer case in an enlarging surface area pattern. Counting the ants in the surface area and estimating their level of disturbance is a method of estimating a transformers level of infestation without opening the transformer for an internal inspection.

APPENDIX C

Quantifying Fire Ant Activity Using Information Theory and Image Processing

Doug Gransberg, Ph. D.

Dept. of Engineering Technology

A. Background

One aspect of the fire ant research conducted by the Texas Tech University research team focused on the use of an electrical device to protect pad-mounted transformers from fire ant infestation. This problem causes millions of dollars worth of damage each year throughout Texas as well as in the entire southeastern United States. Houston Light and Power (HL&P) estimates that they spend about \$600,000 annually to repair fire ant damage in transformers alone. A previous research project sponsored by the Electric Power Research Institute found that fire ant behavior can be manipulated by means of a static electric device (SED) to protect transformers from fire ant infestation. This project proved the efficacy of the device in a series of limited field trials where about 30 devices were installed in infested transformers in the Houston, Texas, area.

During the Houston trials, the research team was required to have all the transformers opened by an HL&P lineman and to be escorted by an HL&P supervisor. The cost to HL&P to support the experiments is estimated to be about \$3,000 per day. It took three days to collect data on 30 installations. Thus, the in-kind support cost to the utility company was significant. Additionally, the researchers were unable to have unrestricted access to the test sites, which created problems for the experiment with regard to time-scaling the results. The team also observed that some statistical problems developed when different entomologists visually rated the level of fire ant activity in the same locations. Thus, the team felt that a low-cost, objective method to measure (rather than rate) fire ant activity was required to successfully complete large-scale field trials of the SED. The

engineers on the research team were simultaneously working on another research project for the Texas Department of Transportation (TxDOT) that involved the use of digital image processing to collect data. They had successfully developed a method using information theory (IT) to make accurate measurements on digital images. It was felt that this emerging technology could also be applied to measuring fire ant activity. The focus was to create a data collection system that permitted the accurate collection of fire ant activity data without the need to open transformers. This would eliminate the project support cost to the utility companies while at the same time giving the researchers unlimited access to the test sites. Additionally, the use of imaging would permit activity data to be collected by anyone with a camera, and thus, reduce statistical problems due to different scientists qualitatively rating the same samples. Finally, the knowledge gained in the TxDOT could be leveraged to the benefit of this project by exploiting a parallel technology.

B. Significance of the Work to Date

The purpose of the next few paragraphs is to explain in layman's terms the significance of the application of Information Theory (IT) to the measurement of fire ant activity. As previously mentioned, entomologists use a qualitative activity rating scale from 1 to 5, and different raters can easily rate the same sample with a slightly different number, i.e. one might rate a nest at 3, and another might rate the same nest at 4. This creates problems with statistical variation and leads to potentially false conclusions or the lack of required statistical significance in experimental results. Coupling this problem with the high cost of data collection makes a large-scale experiment hard to justify. To adequately evaluate the efficacy of the SED, this project needed to deploy at least 300 devices across three states for a period of two years. Therefore, a quick, accurate measuring

technique was essential to the success of the experiment. The team developed the concept of what was named the "Hammer Test." The idea was to collect data after SED installation by tapping the sides of a transformer to stimulate a burst of fire ant activity. This would cause some ants to emerge from inside an infested transformer where video images taken over a fixed period of time would capture the level of fire ant activity. This could then be correlated with a second set of images taken after the transformer was opened exposing the infestation. Simultaneously, an entomologist would visually rate the infestation giving the researchers three observations of the same data point and allowing a metric to be developed. This would take place during the initial installation of the SED's. Subsequent visits would only use the hammer test to measure fire ant activity. The primary information of interest is the presence or absence of fire ants after installation of an SED in a transformer. The level of activity is of less importance but nevertheless required for proper evaluation over time.

Laboratory trials of the hammer test showed that it could be used to stimulate the desired behavior. The team then attempted to implement the procedure during field deployment of SED's in the summer of 1998. Unfortunately, that summer was unusually dry, and as a result, little observable activity in the test transformers existed because the ants were much deeper in the ground than in normal years. The test was canceled in Fall 1998 when the team found that there was a manufacturing problem in the SED's that caused their premature failure in the field. The bright side of the rescheduling of the field trial was that it gave the team additional time to develop the specific application of information theory and image processing for this project.

C. Information Theory Basics

Information Theory (IT) has been widely used by the communications industry for twenty years. It provides a means to quantify many desirable parameters. In this application, we use the IT concept of entropy to measure fire ant activity. Entropy is basically a measure of randomness. Each image contains a unique quantity of information. That information is arranged in some fundamental order, and one image's information can be shown to be more or be less random than another image's information. When imaging biological organisms such as fire ants, one must deal with the fact that living things change positions over time. Thus, the randomness changes over time. An image with more ants will intuitively be more random over time than an image with fewer ants. Subsequent sections of this report will show that this is true. We have shown experimentally that entropy increases with the number of ants in an image. Therefore, we can take that concept to the next step by developing a metric that relates image entropy to observed fire ant activity. When complete, this metric will greatly increase the precision and objectivity with which fire ant activity can be measured over current qualitative rating practices.

The procedure operates on several easily understood concepts. First, a picture of an active fire ant nest contains two types of information. The first is static information about the environment. This information is essentially the picture of the dirt and other material that does not change over time. In other words, if there are no ants, the quantity of information will be the same in every image regardless of time. The second type of information is dynamic information. This is everything that moves in the picture. Generally, this is the living component of the image. By imaging the same exact area twice in a specified time interval, the static information will be the same and the dynamic information will be different. Thus, the images can be transformed to a mathematical format and subtracted. The resultant can then be reversed transformed, and the remainder will be the dynamic information content. In other words, we can remove the dirt and leave only the ants. Because we

now have a resultant image, it will show the same ant twice: one image of the ant's location in the first picture and a second of its location in the second picture. Knowing this, we can adjust our measurement accordingly. It must be noted that we are not trying to achieve a discreet count of the numbers of ants. To do so, would take thousands of experiments to calibrate the procedure and may in fact be impossible. What we want to do is measure the level of activity and compare it to other observations. Hence comes the use of entropy as our metric for quantifying activity level. By taking the resultant image (i.e. after subtraction) and calculating its entropy, we now have a numerical measure of fire ant activity level, and this measure is not dependent of the experience of a human observer to be of relatively constant accuracy. We are also able to measure image information content and use that as another metric to further refine the accuracy of the observation.

The final result of the above discussion is that the researchers now have a powerful tool for data collection that is not dependent on human vagaries and no longer requires a large investment by the sponsor to facilitate the necessary data collection. It should be noted that no one has ever used IT for this application. The creative effort involved to reach this point has been considerable. The researchers have had to develop the theoretical foundation in mathematics to be able to evaluate and understand the output of this algorithm. However, we feel confident that it is sound and that it will prove its effectiveness in the SED large-scale field trial.

The SED has been redesigned and manufactured to eliminate the engineering problems it had in the 1998 aborted experiment. The rainfall amount received so far in 1999 is above average that makes the conditions in which the hammer test can be calibrated ideal. The computer image analysis algorithm is ready for use, and the researchers better understands its scope and limitations. Thus, everything is in place to conduct a successful trial of the SED as previously designed and envisioned.

The remaining sections detail the theoretical developments achieved to date. It seeks to carefully document the image analysis procedure that will ultimately be used to measure fire ant activity for this project. The technology appears to be extremely robust. The engineers on this team are successfully applying it to problems that range from measuring highway pavement texture to the measuring of resultant visibility in roadway lighting installations. Its use in biology will not be constrained to fire ants. It can conceivably be applied to any experiment where change in biological activity needs to be measured over time. Its greatest strength in this field will be its ability to remove the variation between qualitative raters.