Physical Examination of the DKL LifeGuard™ Model 3

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Executive Summary

In March of 1998, the Department of Energy asked Sandia National Laboratories in Albuquerque, New Mexico, to test the basic performance of the LifeGuard™ devices being marketed by Dielectrokenetic Laboratories (DKL). These devices are advertised as capable of detecting, indicating the direction of, and tracking the beating of a human heart at distances of up to 600 meters, depending on the model. The specific device tested in March was the Model 2.0. The three different models of the LifeGuard™ sold by DKL use the same passive detection module (claimed to be responsible for the rotate and point operation of the devices, which is the primary function). The models vary in active features (meant to assist in the primary operation) and advertised detection ranges. The results of the March performance tests were that the device failed to perform as advertised and performed no better than random chance, despite being operated well within advertised specifications and by an operator provided by the manufacturer.

Following these tests, the National Institute of Justice (NIJ) asked that Sandia perform additional testing and evaluation to determine if the devices are designed on solid scientific principles but simply did not perform well. A LifeGuard™ Model 3 was provided by NIJ to Sandia for disassembly and analysis. The analysis found that the Model 3 was composed of two distinct and separate parts: one active (powered) and the other passive (unpowered). The active part functions as a charge perturbation sensor and is based on a different operational principle than dielectrophoresis, which DKL claims is the technology behind the passive module. Since the antenna assembly is said to rotate until it points toward the nearest beating human heart and since the passive detection module is said to be solely responsible for the rotate-and-point, long-range detection of human heartbeats, this Sandia study focuses primarily on the passive detection module.

The passive detection module is an open circuit, and the most critical component of the passive detection module is composed of human hair glued between two small pieces of polystyrene. The conclusion of the analysis is that the design of the DKL Model 3 passive detection module and all other models designed using the same basic concept are not based upon the principle of dielectrophoresis nor on any other accepted scientific principles as understood by the scientific and engineering community. In the absence of DEP forces causing the antenna assembly motion, the only available sources for causing the motion are (1) operator motion, (2) gravity (gravity makes the antenna rotate when the handle is tilted even slightly), and (3) wind. It is also our conclusion that the device cannot function as a passive long-range detector of human heartbeats.

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1. Introduction

The National Institute of Justice (NIJ) recently asked that Sandia National Laboratories (SNL) examine and analyze the physical design of the Dielectrokenetic Laboratories, LLC (DKL) LifeGuard™ Model 3. The Model 3 (**Figure 1**) is part of DKL's series of devices designed to locate and track living human individuals based on a response to the beating human heart. In previous testing at SNL in March of 1998, SNL found that the DKL Model 2 did not perform any better than random chance.[1] The goal of this follow-up physical examination is to determine if the devices are designed on solid scientific principles but simply do not perform well, and whether performance could be enhanced with further development. In this report, we will examine the claims made by DKL and analyze the design in the context of these claims.

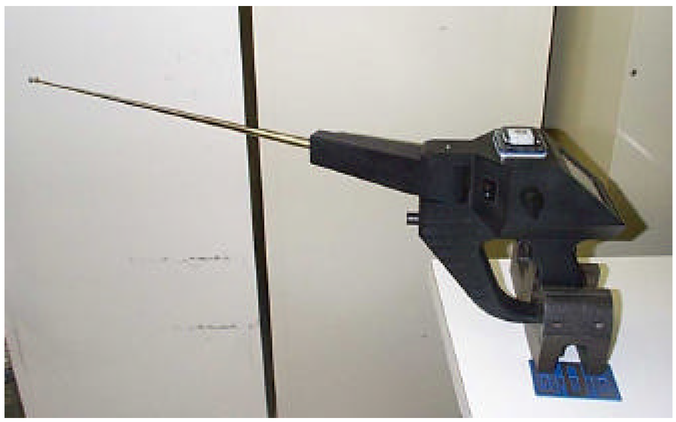

Figure 1. DKL LifeGuard™ Model 3 is shown mounted in a vice.

2. Manufacturer's Claims

According to DKL:

1. The Dielectrokenetic Laboratories, LLC (DKL) LifeGuard™ series of devices is designed to locate and track living human individuals, even when hidden from the operator, based on the device's response to the beating human heart.[2]
2. "DKL's unique polarization filter is so precise that the LifeGuard™ can distinguish a human from a primate. In fact, tests at Washington, DC's National Zoo, the LifeGuard™ located and tracked humans walking around the gorilla and orangutan cages and ignored the animals—even when the primates were between the humans and LifeGuard™."[3] "DKL LifeGuard's™ patent-approved electronic circuitry filters out everything but ultra-low frequency signals, and DKL's unique polarization filter responds only to the unique non-uniform electromagnetic field generated by the beating human heart."[4]
3. These devices operate at distances: 500 meters for the Model 1, 20 meters for the Model 2, and 600 meters for the Model 3.[5] Barriers reduce range in proportion to the thickness and

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[1] Dale Murray, Floyd Spencer, and Debra Spencer. *Double-Blind Evaluation of the DKL LifeGuardÔ Model 2*, SAND98-0977, May 1998. Also available at http://infoserve.sandia.gov/sand981.html.

[2] DKL web site, marketing literature, and material provided to Sandia by DKL Chief Scientist George Johnson.

[3] DKL web site and marketing literature.

[4] DKL marketing literature.

[5] DKL marketing literature.

density of the barrier. For the Model 2, an external wall in the average house will reduce the detection range by a foot.[6]

4. These devices have an accuracy of ±5° at 500 meters for the Model 1, ±5° at 20 meters for the Model 2, and ±5° at 600 meters for the Model 3.[7]

5. The devices indicate detection and tracking by the point of an antenna protruding from the front of each device when the antenna swings and points in the direction of the nearest beating human heart.[8] "Simply put, dielectrophoresis says that when an uncharged but highly polarizable material is placed in an irregular electric field it will point toward the strongest part of the field, much the way a compass needle points toward the strongest part of the earth's irregular magnetic field—the North Pole."[9]

6. The swing-and-point operation of the antenna is driven by the effect of dielectrophoresis (DEP).[10]

   Note: The dielectrophoretic effect causes a body of dielectric material to experience a force when exposed to a highly non-uniform electric field. Dielectric material is any insulating material that can be polarized (the molecules of the material align their positive and negative poles in opposition to the surrounding electric field). This effect is the basis for the design of laboratory equipment used to separate biological cells suspended in a liquid by moving them small distances.[11]

7. LifeGuard™ is composed of two parts: a passive dielectrophoretic (DEP) part and a set of powered parts (the company refers to these circuits as active circuits).[12]

   Note: Early versions of the Model 1 were completely passive and did not have a battery.[13] Later versions of the Model 1 appear to have the active circuits installed. However, DKL says that the LifeGuard™ operates passively.[14] Even if the device is equipped with active features, the device will continue to operate in the passive mode. "If the battery is dead, the LifeGuard™ will continue to detect humans in the passive mode. The laser and meter light, however, will not operate."[15]

8. The powered circuits cannot distinguish between humans and other targets and only the swing-and-point operation caused by the passive module in the device can accomplish this discrimination.[16]

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[6] *DKL LifeGuard Model 2.0 Operator's Manual*, page 3.

[7] DKL marketing literature.

[8] Demonstration at Sandia National Laboratories by DKL on March 20, 1998. *DKL LifeGuard Model 2.0 Operator's Manual*, page 8. This can also be inferred from the DKL training class for the Lifeguard™ as well as from the DKL web site words and photographs.

[9] DKL marketing literature and web site.

[10] DKL marketing literature and web site.

[11] http://www.york.ac.uk/depts/elec/resrev/sub412.htm.

[12] DKL marketing literature and web site.

[13] DKL marketing literature.

[14] DKL web site.

[15] *DKL LifeGuard Model 2.0 Operator's Manual*, page 5.

[16] Conversation with Howard Sidman and Robert VanDine at Sandia National Laboratories March 20, 1998.

9. "LifeGuard™'s patent-pending filtering circuits allow only signals from a human field to flow to a piece of special dielectric material in the upper part of the LifeGuard™ (Model 2's) case. This special dielectric material is capable of becoming highly polarized. When the LifeGuard™ is moved through a human field, this dielectric material polarizes, and positive and negative charges separate and collect on opposite ends of the instrument."[17]

10. "Dielectrophoresis causes the LifeGuard™ to actually swivel and point at the beating heart, the center of the human electric field. An analogy is a compass needle points toward the North Pole (magnetic north) when placed in the earth's non-uniform magnetic field."[18]

11. The powered circuits assist in determining whether the passive pointing indication is an actual detection and not due to operator motion or wind.[19] The output of the charge perturbation sensor is displayed by a red LED on the Model 2 and one LCD screen on the Model 3. "The meter light at the back of the LifeGuard™ lights up when the instrument is polarized by a human's nonuniform electric field. It helps confirm the operator's decision that detection has been made. This function is considered to be a training device for a new operator."[20]

12. Models 2 and 3 are equipped with a red laser. "Turning on the laser makes several significant improvements to the LifeGuard™."

    12.1. "It serves as a visible pointer to see where the LifeGuard™ is pointing."[21]

    12.2 It significantly enhances the device's performance by giving the device a dielectric antenna extension.[22] "It increases the LifeGuard™'s range in the open air, increases the torque strength during detection, and reduces response time. It gives a 10% increase in range between the LifeGuard™ and the first barrier. One pass across the human field is normally good enough for a detection. Without the laser on, the LifeGuard™ lags behind a moving person. With the laser on, it leads a moving person as if it is being pushed by the human field." [23]

    12.3. "It demonstrates tuning of the antenna stub. With the laser on and the antenna stub in the detuned position, the human field repulses the LifeGuard™. It will not point at a target."[24]

13. The Model 3 is also equipped with an electronic compass and a small LCD screen. The electronic compass on the Model 3 allows the operator to measure the bearing of any detection.[25] This electronic compass on the Model 3, with the help of the LCD, allows the

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[17] *DKL LifeGuard Model 2.0 Operator's Manual*, page 2.

[18] *DKL LifeGuard Model 2.0 Operator's Manual*, page 2.

[19] *DKL LifeGuard Model 2.0 Operator's Manual*, page 8. Also DKL web site specifications for the Model 3.0.

[20] *DKL LifeGuardÔ Model 2.0 Operator's Manual*, page 8.

[21] DKL web site.

[22] Material provided by DKL Chief Scientist George Johnson, entitled "DKL LifeGuard™ Human Locator: Phenomena, Hypotheses and Capabilities." Also *DKL LifeGuard Model 2.0 Operator's Manual*, page 8.

[23] *DKL LifeGuardÔ Model 2.0 Operator's Manual*, page 8.

[24] *DKL LifeGuardÔ Model 2.0 Operator's Manual*, page 8.

[25] DKL web site specifications for the Model 3.0.

operator to calculate the range to the detected human after performing a second reading from 10 meters away. The LCD on the Model 3 also provides a visual display of the output of the powered circuits.

14. Many (if not all) of the new units are equipped with an output port that provides a signal that allows the device to operate as an autonomous sensor. In autonomous operation, the signal received from the LifeGuard™ can be displayed on the monitor of a computer that has an analog to digital data acquisition board installed.[26] The company states that an output of the active circuit is what drives this port.

15. "The LifeGuard™ is dependent on the operator for four key activities."[27]

    15.1 "The operator must move the instrument through the human's non-uniform electric field in order to detect a target."

    15.2 "The operator must recognize the torque that signals detection."

    15.3 "The operator serves as part of the LifeGuard™'s dielectric array. This is why the LifeGuard™ does not detect the operator."

    15.4 "The operator provides a link to ground for the LifeGuard™."

16. "The LifeGuard™'s effectiveness is determined primarily by three of the four variables of Pohl's equation for dielectrophoresis force[28]:

    16.1 the irregularity of the nonuniform electric field,

    16.2 the polarizability of the uncharged material, and

    16.3 the volume and shape of the uncharged material, which acts as a kind of antenna.

    16.4 The field generated by the beating human heart is not very intense, but it is very irregular."

17. The LifeGuard™ will find the first human it encounters so people must remain behind the operator. "For the best performance of the LifeGuard™, people should stay at least 10 feet behind the operator. This increases the LifeGuard's™ sensitivity by keeping other human fields away."[29]

18. "DKL uses newly available polarizable materials and fabricates them into a size and shape that maximizes the dielectrophoresis force."[30] The LifeGuard™ uses "state-of-the-art materials".[31]

19. The LifeGuard™ requires only one day of operator training.[32] However, "the one day basic training class does not make the student a trained operator; the student is capable of becoming a trained operator with 20 to 30 hours of additional training on his/her own and monitoring by the student's organization."[33]

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[26] Demonstration performed by DKL personnel at Sandia National Laboratories. Also Appendix A.

[27] DKL web page FAQ section.

[28] DKL marketing literature and web site.

[29] *DKL LifeGuardÔ Model 2.0 Operator's Manual*, page 7.

[30] DKL marketing literature and web site.

[31] DKL marketing literature.

[32] DKL marketing literature.

[33] *DKL LifeGuardÔ Model 2.0 Operator's Manual*, page 16.

20. "These Lifeguard™ products are much less expensive than technologies with a fraction of their capabilities."[34]

21. DKL and LifeGuard™ inventor Thomas Afilani have claimed that the operator, the antenna, and the body of the device along with the dielectric material combine to form a *dielectric array*. "The operator serves as part of the LifeGuard's dielectric array. This is why the LifeGuard does not detect the operator."[35] "The dielectrophoresis force depends non-linearly upon several factors, including the dielectric polarizability of the surrounding medium (air plus any intervening walls, trees, etc.) the dielectric polarizability and geometry of the initially neutral matter (device's antenna and other component parts of the device), and the spatial gradient of the square of the human targets's local electric field."[36]

3. Initial Disassembly Observations

To conduct the physical examination, SNL personnel externally examined the product, then opened it up and took it apart. A block diagram (**Figure 2**) shows the major block components and subassemblies. The passive module (displayed in green in the diagram) is the part responsible for the primary operation of the device (rotation and point), while the active portion (shown in red) is intended to assist the operator in confirming detections by the passive module and with other functions such as electronic compass bearing and calculation of range. These features are not included in all models.

Both the passive module and the active circuit were covered with a black coating. This coating was not difficult to remove, and the identity and value of most of the components could be easily determined. The dielectric component was composed of what appeared to be human hair glued between two pieces of plastic with wires embedded for electrical leads. The Albuquerque Police Department's Crime Analysis Laboratory determined that it was human hair (**Appendix D**).

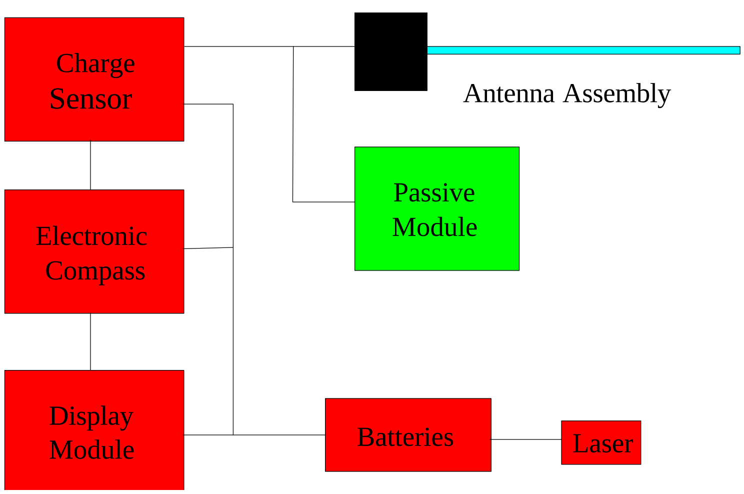

Figure 2. Block diagram of the DKL LifeGuard™ Model 3 shows the modules that require power in red (active) and the passive (DEP) module in green.

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[34] DKL marketing literature.

[35] DKL web page FAQ section. (Question 10)

[36] Patent no. 5,748,088 Device And Method Using Dielectrophoresis To Locate Entities, Inventor Thomas Afilani, page 3 of 11.

Figure 3. Mechanical alignment of the DKL LifeGuard™ is viewed from above device.

Externally, the device is well constructed with a professional quality package. The antenna pivoted freely with little friction. Mechanical alignment (**Figure 3**) of the antenna pivot axis was off slightly. This was determined by mounting the device in a vice and leveling the body with the assistance of a bubble level. With the body level, the antenna pointed off to one side.

The internal construction (**Figure 4**), however, was inconsistent with the quality of the external construction. The passive module, the batteries, and the active circuit were all held in place with glue. The nickel cadmium batteries were permanently soldered into the circuit and then glued into place. Only one corner of the electronic compass was held in place by a screw, and its printed circuit board was larger than the space provided and had to sit askew.

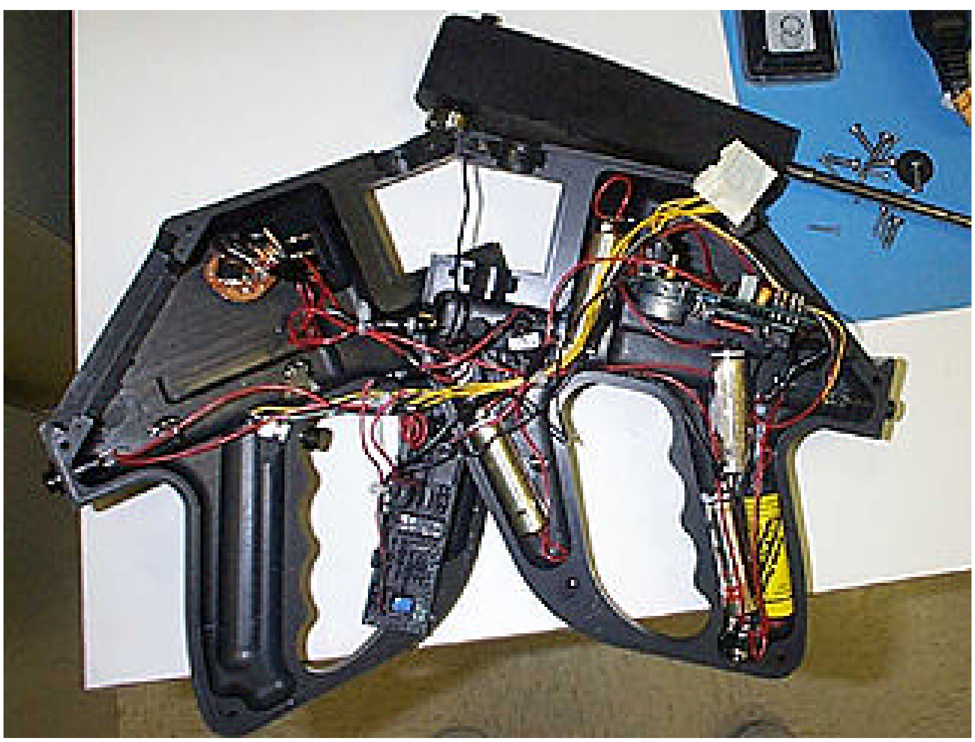

Figure 4. Internal construction of Model 3 is shown after unit is opened.

The LCD board and the electronic compass board were of high quality, surface mounted, printed-circuit-board construction. The active circuit was of single-sided, printed-circuit-board construction.

The passive module was assembled using point-to-point soldered construction techniques with many of the components not mounted on the assembly board. This aspect of the assembly is of considerable concern because many of the unsupported components were air core inductors wound without forms (**Figure 5**). Without support from forms and permanent mounting, inductors are subject to changes in their inductance values due to thermal expansion and mechanical shock. The mounting board was a prototype board (i.e., a generic circuit board used for laboratory prototype assembly of circuits and not commonly used in manufacturing).

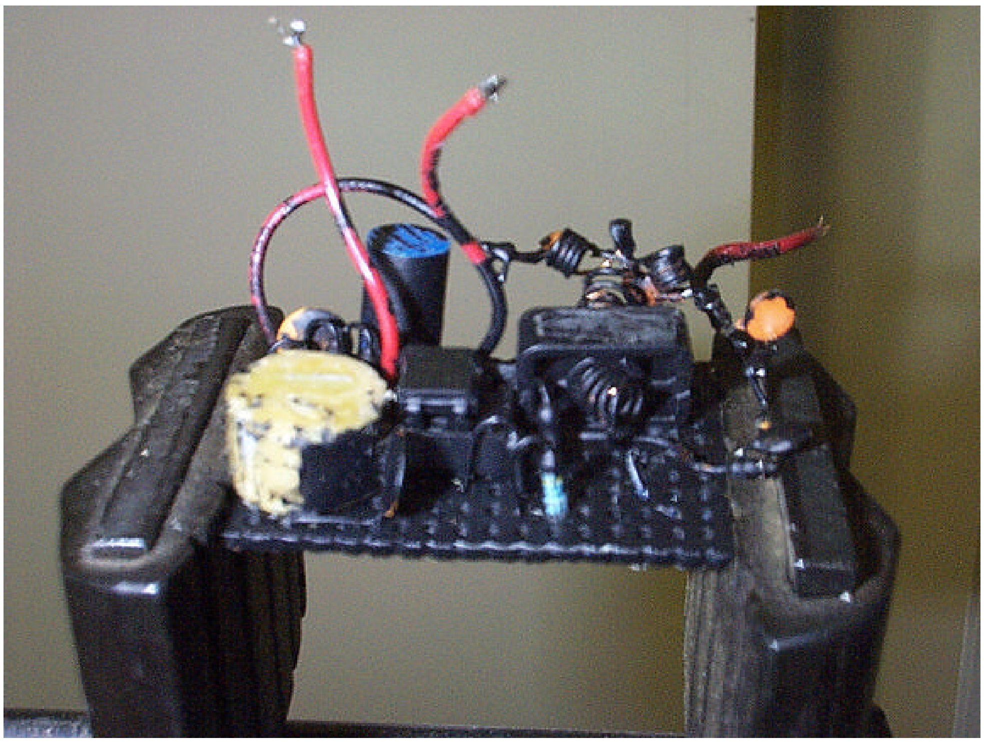

Figure 5. Passive module shows air core inductors not mounted and without forms. Black coating is partially removed. Yellow cylinder (lower left) is the dielectric component.

4. Component Analysis –The Passive Module

DKL Claim: *The passive module is designed to be responsible for the rotate-and-point (Manufacturer's claim 5), long-range detection (Manufacturer's claim 3) of human heartbeats (Manufacturer's claim 2). This is the primary advertised function of these devices. There is a piece of dielectric material located in the body of the LifeGuardÔ that polarizes and is responsible for the DEP force (Manufacturer's claim 9 and 18). DKL has stated that the antenna acts as an extension to the dielectric material. DKL refers to the combination of the device's body and the metal antenna as the dielectric array (Manufacturer's claim 21).*

Sandia Response: The claimed function of the passive module (direction, operation at a distance, and specificity to human targets) would make this product unique, which is why the following analysis focuses on this module. The directionality is presented in the patent as a key feature that separates these devices from prior art. Previous performance testing has shown that the passive module is unable to perform these functions. The physical analysis of the passive module has also shown that the passive module cannot perform these functions. The following analysis of the passive module supports this response.

Note: While the Model 3 has active components, these are not required for the device to perform its primary function. Even though the report does not focus on the active module, a later section will briefly discuss these nonessential features.

Opening the LifeGuard™ Model 3 revealed the location of the passive module and its dielectric component. The passive (DEP) module is composed of a signal filter with an embedded dielectric component. The dielectric component is that part where the dielectrophoretic (DEP) force, if any, would be directed. The DEP force is what would cause the antenna to move toward a human beating heart. If the DKL device's DEP component is capable of receiving a DEP force that would cause the antenna assembly to rotate and point, one would expect: 1) the component would be located in the antenna assembly or 2) there would be a mechanical or electromechanical mechanism to transmit the force from the dielectric component to the antenna assembly. Neither of these was the case—the passive module and its dielectric component are located in the main body, and there is no mechanical or electromechanical mechanism that could transmit any force acting on the dielectric component to the antenna assembly.

Metal cannot act as an extension of the dielectric material. Electromagnetic field theory and the theory of DEP do not support the concept of a dielectric array where some elements are not dielectric materials. (However, in later analysis where the dielectric constant for the device is estimated, the concept of a dielectric array is assumed to be true in order to make the most conservative estimate possible.)

Taking all of these factors into consideration, the fact that there is wiring between the antenna and the dielectric component cannot explain a DEP force acting on the antenna assembly. This alone would be sufficient to conclude that the device cannot operate as specified (as described in Manufacturer Claims 1-3).

4.1 The Dielectric Component

DKL Claim: *DKL states that the special dielectric material in the LifeGuardÔ is a highly polarizable material that becomes polarized when exposed to the electric field of a beating human heart and that patent pending filtering prevents other fields from polarizing the material (Manufacturer's claim 9 and 18). They state that this polarization is responsible for the DEP force and resulting torque that rotates the antenna assembly (Manufacturer's claim 10).*

Sandia Response: A complete circuit analysis was performed on the passive module (section 4.3) The passive module was found to be an inductive-capacitive-resistive (LCR) filter and a dielectric component composed of two pieces of plastic glued together with human hair inside. A filter of this type is inappropriate for the intended application (the filter can only filter signals carried by wire and not surrounding electric fields). The LCR filter part of the passive module is a typical low-frequency signal filter that cannot make this device specific to human beings. One could surmise from this that the presence of the hair was an attempt to achieve this specificity. Note that a dielectric material that would polarize in response to a non-human generated electric field will still polarize in response to that non-human generated electric field despite the presence of human hair. If human hair is included in order to make the response specific to humans, then this is inconsistent with all accepted scientific principles.

The following sections (4.1.1–4.1.4) describe the procedure and the analysis to support Sandia's response.

4.1.1 Discussion on the Examination of the Dielectric Component

The first step in determining the composition of the dielectric component was to remove it from the passive module. The component was cylindrical in shape with two wires protruding out of the bottom of the plastic casing. When the plastic casing was removed, the dielectric component was seen to be a sandwich of two pieces of gray plastic with the wire leads protruding out of the plane where the two pieces of plastic were joined (**Figure 6**).

Figure 6. Exterior of the dielectric component is diagrammed.

The next step was to separate the two halves of the component. When it was opened, many hair-like fibers were seen to be glued in place across one of the leads (**Figure 7**). A sample of the fibers was taken to the Albuquerque Police Department Crime Laboratory for analysis. This analysis confirmed that the fibers were human hair (**Appendix D**).

Figure 7. Inside the dielectric component, fibers across upper half of component are human hair.

The next step was to determine the type of plastic that was used in the construction of the component. The material was taken to a nuclear magnetic resonance (NMR) laboratory at Sandia. A ^{13}C NMR analysis revealed that the plastic used for the component fabrication is polystyrene-divinylbenzene, a common polymer available since 1938 (**Appendix E**). This plastic is known for its electrical properties. The most outstanding feature of its electrical properties is that its dielectric constant is highly stable over a wide range of frequencies. However, polystyrene's dielectric constant is not particularly high (2.5).

The components and their arrangement revealed the bulk of the passive module to be a passive inductive-capacitive-resistive (LCR) filter. This type of filter is commonly used to filter electrical signals to eliminate unwanted frequencies. However, as will be shown in the following subsections, the use of an LCR filter in conjunction with this device is inconsistent with the process of DEP.

4.1.2 LCR Filter Cannot Filter Signals Surrounding Dielectric

For the DEP effect to work, a dielectric (as found inside the DKL devices) must react to an electric field, in this case the electric field generated by a human heart. There are theoretically two possible ways that this electronic signal could be transmitted to the dielectric material in the passive module of the LifeGuard™. First, this electric field exists in three-dimensional space and, much like a gas, surrounds the dielectric component itself (this is the way that all biomedical devices based on DEP operate). Second, the antenna could react to the electric field from the human heart and transmit a signal over the Lifeguard™ wiring from the antenna, through the LCR filter, to the dielectric material.

Consider the first possibility. An LCR filter, such as the one used in the DKL devices, can only filter signals (voltages and electrical currents) carried by wires that interconnect the components; the LCR filter can not filter the surrounding electric field. Thus, if the dielectric material were to receive a signal from a human heart by means of the surrounding electric field, then such a signal is not being filtered by the LCR filter, violating the design intent of the circuits. Note, also, that if DKL intended that the dielectric not react to any field that exists around the dielectric and only to the signal that is carried within the wiring, the dielectric should have been surrounded by shielding material to prevent the electric field from reaching the dielectric. This is not the case; the dielectric is not shielded from external fields. Even if the dielectric were to respond only to the signals carried from the antenna through the filter and to the material, the question of directional information arises and is discussed next.

4.1.3 Directional Information Cannot be Carried in a Signal through an LCR Filter

In order for the swing-and-point function of the antenna to take place, some sort of directional information must be preserved about the electric field surrounding the antenna. How can the directional information contained in the original electric field be maintained after the field is converted from a three-dimensional electric field into a signal being carried over wires as voltages and currents? It cannot. This would be similar to funneling wind to a sheltered wind vane through a convoluted system of ducts. The wind vane could only respond to the air exiting from the duct and could not indicate the direction of the wind outside the shelter. The direction of any electric field developed across the dielectric between the wire leads embedded into the dielectric component will be determined solely by the physical location of the leads in relation to the dielectric (**Figure 8**). The component inside the device would be reacting to an internal field and not to the electric field surrounding the dielectric material.

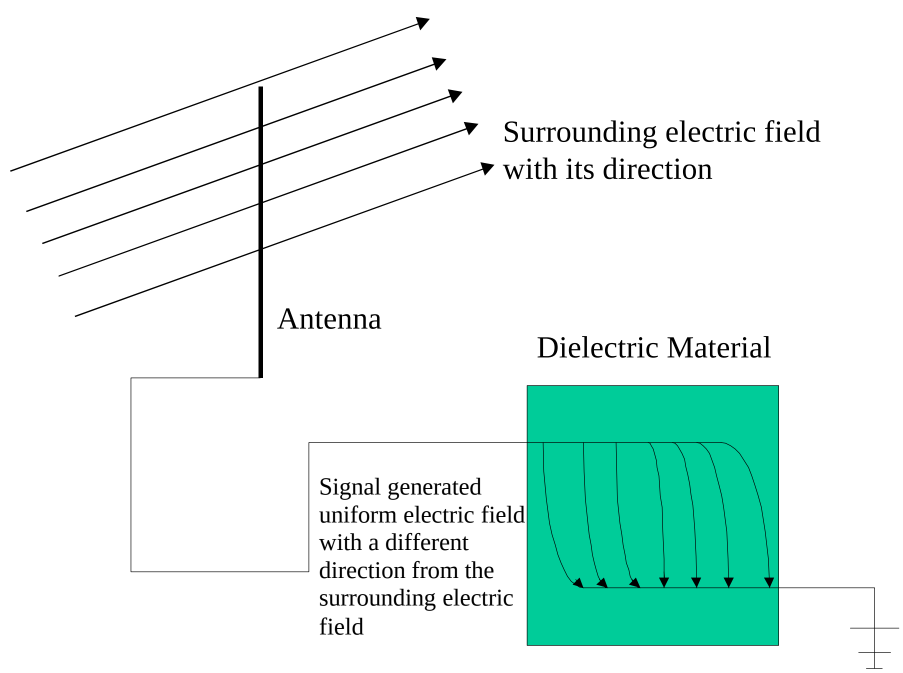

Figure 8. Signal-generated field has no directional relation to original field and is highly uniform.

4.1.4 Electric Field Between Embedded Wires Would be Regular and Balanced—Unable to Produce a DEP Force

In addition, a field developed between embedded wire leads in response to signals carried by wires to the embedded wire leads would loose the irregularity of the original electric field before conversion to a signal. In the case of the embedded wire leads in the dielectric component used by DKL, the generated electric field would be highly regular and balanced. DEP theory states that no force is generated by a uniform electric field. Thus, the electric field generated between the leads inside the DKL device by the signal cannot cause a force to rotate the antenna assembly.

To summarize, a signal received by an antenna can only carry magnitude information (as represented by voltages and currents) and would lose all other information carried by the field (field direction and spatial flux density gradient).

4.2 Circuit Analysis of the LCR Filter

***DKL Claim**: The patent-pending filter allows only signals from a human field to flow to a piece of special dielectric material (Manufacturer's claim 9).*

Sandia's Response: As detailed in the previous section, the LCR filter is inappropriate for this application. In addition, further engineering analysis of this filter indicates that it will not function at all as installed in this device.

The following sections (4.2.1-4.2.3) describe the procedure and the analysis to support Sandia's response.

4.2.1 The Passive Module Is an Open Circuit

The circuit analysis for the passive module and its passive LCR filter is performed by first examining the schematic and later using an electrical engineering modeling program (PSPICE) to determine the frequency response.

The LCR filter in the passive module is an open circuit, whereas electrical circuits must have a completely closed path in order to operate. However, in the case of the passive module, there are no means for completing the path. The path starts at one end with the antenna and dead-ends at the other end with the dielectric component. Since electrical circuits must have a completely closed path in order to operate, the passive module LCR filter is shown to be non-functional.

DKL has stated that the operator provides a capacitive and resistive path to ground by being in contact with both the LifeGuard™ and the ground (floor or other grounded surface). This cannot be the case. While the human body can conduct electrical signals despite being quite resistive, the DKL LifeGuard™ is housed in an insulating case preventing any electrical contact between the internal components and the operator. In addition, the operator may be standing on a carpeted floor (electrically insulated) and may be wearing insulating soled shoes (such as sneakers), and therefore may not be able to provide a path to ground even if he were in electrical contact with the device. Furthermore, any capacitive path to ground through the human body would be at an extremely small capacitance (on the order of a few picoFarads or lower). At the low frequencies at which this device is said to operate (1-3 Hz), this small capacitance is essentially an open. This would mean that the capacitive reactance (the capacitive equivalent to resistance) would be extremely high, and a large reactance will allow very little current to flow.

4.2.2 Diode in the Filter Path

Finally, there is a diode in the path through the filter. A diode is a semiconductor device that allows current to pass through it in only one direction. This is used to prevent current from flowing through a circuit in an undesired direction. This particular diode is a silicon device. In order for current to flow through a silicon device in the forward direction (forward biased), the signal must exceed 0.7 volts. The signal from the human heart a distance of a few meters away, let alone 500 meters, cannot ever exceed 0.7 volts without very high amplification (and there is no amplification in the passive module). Therefore, this diode will never conduct any signals from the antenna to the dielectric material (unless the signal is received from a much stronger source than the human heart).

4.2.3 Frequency Response of the LCR Filter

The frequency response analysis is performed on the LCR filter using the antenna as the input, and the output is the signal that would be delivered to the dielectric component. As stated before, the passive module is an open circuit. Open circuits cannot be modeled using PSPICE (an electrical engineering circuit modeling software). Therefore, in order to perform a frequency analysis, a path to ground must be inserted. This artificial path means that the PSPICE analysis presented in this report is for the passive module *if it were provided a ground reference*. The analysis determines the frequencies that would be delivered to the dielectric component in a complete circuit with signal strength high enough to cause the diode to start conducting in the forward direction. There are a total of six analyses (**Appendix C**)—one for each switch setting on the tuning switch.

The PSPICE model reveals that the frequency response of the passive model's filter is within the general range required for the described operation of the device. The LifeGuard™ is said to operate over frequencies of 1-3 Hz. The LCR filter acts as a low-pass filter (it only passes low frequency signals) with a cutoff frequency of about 20 Hz and with a sharp band-pass window (which allows only a narrow range of frequencies to pass) opening around 1MHz. The low-pass nature of the filter supports the concept that the LifeGuard™ design is based on filtering a signal carried over wire through the filter. The intention of the filter is to allow only signals of the same low frequency of the human heart's field to pass through to the dielectric material.

As can be seen in the PSPICE frequency diagrams in **Appendix C**, the electronic components that are switched into the filter by the tuning switch have little or no effect on the low frequency response of the filter. These components only serve to change the magnitude of the frequency response of the filter at the 1MHz band-pass window. The signal of the human heart has little or no frequency components in this range, and the components can therefore have no impact on the filtration of signals in the frequency range of the human heart.

4.3 The Human Heart Electric Field

DKL Claim: *DKL literature states, "The field generated by the human heart is not very intense, but it is very irregular." According to the company, a high spatial flux density gradient* ∇E *is the reason that the DEP force that results from the human heart's electric field is large enough to rotate the antenna (see Manufacturer Claims 16).*

Sandia Response: Analysis of the human heart's electric field indicates that at distances of greater than one meter, the human heart's electric field is very uniform. This does not support DKL's claim that a non-uniform electric field causes this device to rotate.

The value for the electric field of the human heart at 500 meters is calculated in **Appendix F**. This value is 12 nanovolts per meter (12 billionths of a volt per meter). Certainly the first part of this statement (the field generated by the human heart is not very intense) is correct.

To discuss what it means to say that an electric field is very irregular, we must introduce the spatial flux density gradient variable ∇E (∇E is a measure of how much the electric field strength changes through space; a large spatial flux density gradient indicates an irregular field.) For the gradient to be large, a small change in location must result in a large change in the field strength. Since the field strength at the operational location of the dielectric material in the LifeGuard™ is very small, then for the gradient to be large, the field strength at a location near the dielectric material must be very high. This is certainly not the case. As calculated in **Appendix F**, the spatial flux density gradient for the human heart's electric field at 500 meters would be about 0.072 nanovolts per meter per meter (72 trillionths of a volt per meter per meter.) In fact, since the electric field of the human is nearly zero at any significant distance (one meter) away from the heart, it is highly uniform at such locations. Note: one meter is approximately ten times the charge separation distance of the human heart dipole which is an engineering approximation for the transition between near-field and far-field. What this means is that for Pohl's equation operating at the stated operational distances, all of the variables are either small or extremely small which will result in an extremely small DEP force (as calculated in the next section).

The following section (4.3.1) describes the procedure and the analysis to support Sandia's response.

4.3.1 Magnitude of the DEP Force and Other Forces Affecting the LifeGuardÔ

For the DKL passive module to work as stated, a force large enough to rotate the antenna would need to exist whenever a human heartbeat is within range.

We set out to determine if a force of sufficient size could exist, given the design of the DKL. We will perform this analysis in the most conservative approach All bearings have some amount of friction, and any moving object is subject to air friction. In our analysis, we will neglect all friction, again in an effort to use only the most conservative approximation. The force required to rotate the antenna assembly 15° in 1 second (far less quickly than some of the rotations demonstrated by the company personnel) acting at the extended antenna tip would need be about 3 milliNewtons (3×10^{-3} Newtons). For a detailed description of the method for calculating this value and all others found in this section see **Appendix F**.

The DEP force calculated for the Lifeguard™ at a distance of 500 meters (remember the maximum range is stated to be 600 meters) is 29×10^{-32} Newtons. This calculated force is about one-thirtieth the weight of a single electron (8.9×10^{-30} Newtons). To illustrate the magnitude of this calculated force, a 15° rotation of the antenna assembly in response to this force would take over 3.2 million years (again neglecting all friction, which would overwhelm such a force). The dielectrophoretic force cannot account for the motion of this device. This is also true for distances much closer to the heart than 500 meters. Performing the same calculation for a distance of only 2 meters results in a calculated force of only 4.48×10^{-12} Newtons. While this force is certainly larger than the force at 500 meters, it is still far too small to be responsible for the rotation of the antenna assembly.

If the human heart's electric field as calculated for 2 and 500 meters is not large enough to rotate the antenna assembly, then how large must the spatial flux density gradient be in order to generate the calculated required force? Again using the method described in **Appendix F**, the required density gradient to produce the required 3 milliNewtons force is calculated to be 7.5 thousand volts per meter per meter. The human heart cannot under any circumstances generate such an intense spatial flux density gradient.

An even greater force than the bearing and air friction is the force of gravity—DKL instructions specify that the antenna be held with a slight angle downward.[37] All of the previous values were calculated assuming the antenna was held perfectly horizontal. This means that to rotate the antenna assembly, the force that gravity exerts on the tilted antenna assembly must also be overcome.

4.4 Other Questions Regarding DEP Forces

DKL Claim: *DKL has stated that dielectrophoresis causes the dielectric material to point toward the strongest part of the heart's electric field much in the same way that a compass points at the strongest part of the earth's magnetic field (Manufacturer's Claim 5). DKL instructs that the device must be moved through the human heart's electric field in order to "lock-on" to the target (Manufacturer's Claim 15.1). DKL also indicates that the LifeGuardÔ is directional. The device is supposed to ignore anyone behind it if they are kept ten feet back (Manufacturer's Claim 17).*

Sandia Response: The suggestion that the dielectric material will point to the strongest part of the electric field would mean that a DEP force will occur because the spatial flux density gradient is large somewhere in the field even though it is small at the location of the dielectric material. This is incorrect. For the DEP force to occur, the dielectric material in question must be located in a region where the spatial flux density gradient is large. This is somewhat like a wind vane that will not react to a tornado 100 miles away when the air is motionless around the wind vane. In fact the operation of a magnetic compass is not similar to the principle of DEP. The rotation of the compass needle is due to magnetic dipole alignment with the local magnetic field independent of the local magnetic flux density gradient. Also, a compass operating near the equator does not point to the strongest part of the earth's magnetic field (the magnetic North Pole) but points out in space since the earth is spherical. A dielectric body experiences a DEP force that is aligned with the local flux density gradient direction which may or may not point to the strongest part of the electric field. Because the human heart is a dipole, the local flux density gradient does not point to the heart through much of its electric field.

Another point of inconsistency with regard to DEP is when DKL instructs that the device must be moved through the human heart's electric field in order to "lock-on" to the target. DEP does not depend on dielectric motion for the DEP force to occur. If electrical field conditions are sufficient to cause a DEP force, the force will occur regardless of the motion (or lack of motion) of the dielectric.

The idea that the electric field of someone more than ten feet behind the device will not reach the device is inconsistent with electromagnetic theory. If a human field can reach the dielectric from more than ten feet in front of the device, it can also reach the device from the same distance from

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[37] *DKL LifeGuardÔ Model 2.0 Operator's Manual*, page 9.

behind. In fact, during demonstrations of the device operating in the unattended mode (as a charge perturbation sensor), the device detected individuals moving behind the LifeGuard™ at distances greater than ten feet. Tests in the laboratory have confirmed this.

5. Brief Component Analysis – The Active Portion

DKL Claim: *DKL makes several claims regarding the charge perturbation sensor and its related active components. First, the charge perturbation sensor output displayed on the meter light on the Model 2 and on the LCD screen on the Model 3 help the operator confirm the validity of a passive detection. They indicate that the meter is a training tool to the untrained operator. They claim this meter indicates when the instrument is polarized by a human's electric field (Manufacturer's Claims 11).*

Sandia Response: This active circuit does work as a charge perturbation sensor. However, the manufacturer's claim that this is based on polarization caused by a beating human heart is not supported by tests of the active circuit. The operation of this part of the device is based on different principles than the passive module, which is supposed to be based on polarization. This sensor will detect *any* charged body in motion. This has been verified in the laboratory with the active circuit's detection of an inflated toy balloon.

A report available on DKL's web site details the testing of the active circuit and is included in **Appendix A** in its entirety. The researcher, Dr. Joseph P. Dougherty, clearly states that the device operating in the unattended mode is a charge perturbation sensor. In his report, Dr. Dougherty never makes reference to the primary advertised operation the device, which would include DEP and the detection of beating human hearts as indicated by the pointing of the antenna.

Their claim that the meter output of the charge perturbation sensor can assist the operator in validating a passive detection is incorrect. Because the sensor detects the motion of the operator, it would be impossible to distinguish the device's response to the operator from its response to others.

The following section (5.1) describes the analysis to support Sandia's response.

5.1 Discussion on the Charge Perturbation Sensor

The following comments are based on published laboratory testing, observations of company demonstrations, and recent testing at Sandia.

- This active circuit produces a signal that can be displayed on a computer screen when wiring from a signal port to the computer connects the device. When operated in this manner (the company refers to this operation as the unattended mode), the device functions as a charge disturbance motion (perturbation) sensor. It generates a signal that indicates motion of charged bodies from a few meters away (**Appendix A**). However, generating a signal indicating motion of charged bodies from a few meters away is a very different function than indicating a beating human heart, whether moving or not, from 600 meters (the stated maximum range for the Model 3).
- There is no indication in the displayed signal that there is any detection of a beating heart. In fact, humans in close proximity to the device are not detected at all if they remain very still.
- The active circuit also detects static charge perturbations located behind the device. All known tests and demonstrations of the device operating in the active mode were with the

device located on a stationary platform, with no swing-and-point function. Laboratory experimentation has shown that when used in a hand-held mode (normal operation) that the movement of the operator is detected as well as movement of other individuals. The signals generated by the motion of the operator and other individuals are indistinguishable.

- This active circuit will detect *any* moving charged body whether human or not, living or inanimate. DKL provided Sandia with a hard copy of the detection of a dog moving through the detection field of the active circuit (**Appendix B**). Laboratory tests have shown that the active circuit will also respond to movement of an inflated rubber balloon.
- The demonstrated detection range of the active circuit and the stated range of the passive module are significantly different (4-5 meters for the active circuit, 600 meters for the Model 3 passive module.) The charge perturbation sensor cannot assist in validating a detection at greater than at most 5 meters. (During the demonstration at Sandia, the minimum detection of the active circuit occurred at about 4 to 5 meters.)
- The only point of electrical contact between the active modules and the passive module is where the wiring from the antenna splits and feeds both the passive module and the active module. Therefore, the active module can have no impact on the operation of the passive module and, for all practical purposes, the active components could be removed from the device (as in the case of the early Model 1) without any change to the LifeGuard™ being operated in the passive mode.

5.2 Comments on Other Active Components of the DKL LifeGuard™

DKL Claim: *DKL states that the laser provides a visual indication of where the device is pointing (Manufacturer's claim 12.1). Another function stated by DKL is that the laser improves the device's sensitivity by acting as an extension of the dielectric material (Manufacturer's claim 12.2).*

Sandia Response: In the case of the Model 2, the direction of the laser beam does indicate the aim of the antenna. The entire body of that device swivels so that the laser provides visual indication of where the device is pointing, and the aim of the antenna and the laser are reasonably well aligned. On the Model 3, however, the antenna assembly can rotate independent of the body of the device. The laser, which is mounted on the body, is not aligned with the antenna assembly. For the laser to point to where the antenna is pointing, the operator must manually rotate the body of the device into alignment with the antenna assembly. At 500 or 600 meters, even slight misalignments result in considerable difference between the antenna's aim and the location of the laser spot.

The laser cannot enhance the DEP operation of the passive module. A laser beam cannot act like a dielectric. The beam cannot carry charge or become electrically polarized (as compared to becoming optically polarized, which it can). Also, the laser cannot respond to the human heart's electrical field through the principle of dielectrophoresis (DEP) or translate a mechanical force to the body of the device.

6. Conclusions

Based on the previous analysis of the extremely small potential magnitude of any DEP force that may exist at the dielectric material inside the LifeGuard™, such a DEP force cannot be responsible for the motion of the antenna assembly. This is true for several reasons:

- The location of the dielectric material inside the LifeGuard™ is not in the antenna assembly.
- There is no mechanism for transferring force from the dielectric material to the antenna assembly.
- Any DEP force that may exist at the dielectric material inside the LifeGuard™ is too small to be responsible for the motion of the antenna assembly.
- There is no accepted physical principle or theory that supports the idea that human hair can tune a dielectric material to respond only to human heart electrical signals.
- The operator is electrically isolated from the internal components by an insulating case; therefore, the operator cannot provide a path to ground.
- The low-pass filter that is connected to the dielectric component is an open circuit and, therefore, it will not perform the intended function. Even if a ground reference were to be provided, the signal strength of the human heart at even small distances would never forward bias the inline diode.
- Signals carried over wire loose all directional and spatial electric flux density gradient information that was present in the ambient field.
- A filter composed of inductive, capacitive, and resistive components will only filter the signal carried on the interconnecting wiring and not the surrounding electric fields.
- Because DEP is a field effect and not a signal effect, the use of an LCR filter is inconsistent with the operational theory.
- DKL states that in order to operate the device, the operator must move the device through the heart's electric field. DEP is not dependent on motion of the dielectric material. A dielectric will respond to a non-uniform electric field even if it is motionless. This requirement is inconsistent with the theory of DEP.
- Laser light cannot act as dielectric material and cannot act as an extension to the dielectric material. Therefore, the laser cannot increase the sensitivity of the dielectric material to DEP forces.

The charge disturbance sensor (active circuit) does work as a motion sensor. However, this sensor operates by detecting changes in the distribution of electrical charge in the immediate region around the sensor. This sensor does not operate on the principle of DEP. The sensor cannot distinguish between humans and any other charged bodies. This sensor cannot detect a beating human heart. The fact that this sensor functions as a charge perturbation sensor and can be connected to a computer to display its signal in no way proves that the passive part of the device can rotate and point the antenna toward a beating human heart. Laboratory observations have found that the active circuit continues to detect the operator during the scanning process, which would preclude the operator from using this feature to reliably detect humans when the LifeGuard™ is held in the operator's hand.

It is our conclusion that the claimed theory of operation of dielectrophoresis being responsible for the motion of the antenna assembly is not correct. In the absence of DEP forces causing the antenna assembly motion, the only available sources for causing the motion are (1) operator motion, (2) gravity (gravity makes the antenna rotate when the handle is tilted even slightly), and (3) wind. It is also our conclusion that the device cannot function as a passive long-range detector of human heartbeats.

Since we concluded that the passive filter in the LifeGuard™ had nothing to do with DEP, we contacted a recognized DEP expert, Dr. Thomas B. Jones of the University of Rochester about the use of DEP in the LifeGuard™. Dr. Jones is listed as the author of one of the references cited by George Johnson, DKL's Chief Scientist (see **Appendix G**). Dr. Jones' response indicated that because the makers of the device claimed that its inner workings were based on dielectrophoresis (DEP), he was called about it by four or five different agencies. After his investigation, he concluded that if indeed the device's operation is based on DEP, then his own 25 years of study of the subject have been for naught.

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Appendix A: Test Performed by Dr. Joseph P. Dougherty of Advanced Materials Technologies, State College, Pennsylvania

Advanced Materials Technologies

524 E. Irvin Avenue
State College, PA 16801
Phone & Fax: (814) 867-4484

New Product Development Technology Assessment * Modeling & Simulation

TEST RESULTS AND EVALUATION

DIELECTROKINETIC LABS, LLC (DKL)

DKL LIFEGUARD MODEL 2.0

SUMMARY

I supervised and conducted a double-blind test of a DKL manufactured LifeGuard Model 2.0 being used as an autonomous device. The standard commercial LifeGuard Model 2.0 was mounted on a tripod and an electrical jack through the enclosure connected an output from internal circuits to an analog to digital converter input connected to a computer. The LifeGuard Model 2.0 circuits, enabled the device to function as a very effective charge perturbation sensor which could detect the motion of test subjects even through walls and doors.

A double-blind protocol was used where the human target assistant would randomly (based on a coin flip) go to one of two pre-selected locations either within the range of the sensor or outside the range of the sensor. The DKL LifeGuard Model 2.0 performed flawlessly, accurately detecting the correct position of the human target 25 out of 25 times.

TEST SET-UP

The test was performed in the DKL development labs using a prearranged test configuration put in place by DKL. The "DKL LifeGuard Model 2.0" was mounted on a stationary tripod. Its standard electronic circuitry, packaged inside the LifeGuard Model 2.0, (see attached DKL diagram) had an output jack connected from the Low Frequency Bandpass Amplifier to the A/D convertor and the computer which was being used as a data collection and analysis tool. The tripod was placed approximately one foot from a plasterboard wall which had a standard hollow core wooden office door immediately adjacent to the tripod. The electronic signal cable from the device was connected to the computer data acquisition system which was about 15 feet from the tripod mounted "DKL LifeGuard Model 2.0". The computer was behind a movable plasterboard separator wall that prevented the DKL computer operators, and myself from seeing or hearing any activity behind the door next to the "DKL LifeGuard Model 2.0".

The test protocol followed a double-blind system where neither the target nor any of the observers knew in advance what the order of the experiments would be. The target assistant, an employee of the outside test team, would flip a coin at the beginning of each new minute while she was in a neutral position just outside the sensitivity range. Based on the coin flip, the target subject would then go to one of two pre-selected locations either within the range of the sensor or outside the range of the sensor. The in-range location was approximately 2 to 3 feet from the sensor which was located facing the other side of the wall. The out-of range position was approximately 45 feet away from the location of the "DKL LifeGuard Model 2.0".
When the test subject went to the in-range position, she would walk up to a marked line in the room, turn around, and record the data. After waiting 30 seconds, she would return to the neutral position from either the in-range or the out-of-range position and remain there until the next coin flip which occurred at the beginning of each new minute.

The movement of the test subject was monitored by a time-marked video camera. The DKL people, the test supervisor, myself and the test subject all synchronized our watches to the time of the video camera before the test began. The motion of the target, as detected by the DKL LifeGuard Model 2.0 circuit was displayed on the computer screen as a low frequency signal in a strip chart recording format. An example of the typical voltage versus time output signal is attached. The data from this test was recorded in the DKL computer as "Test File 26". Data was recorded for the 25 trials, determining whether the sensor output detected the test human target either inside or outside the range of sensitivity. After the test was over, the data on the supervisor's sheet was compared to the test subject's data sheet to determine whether the LifeGuard Model 2.0 being used as an autonomous device had correctly determined the human target subject's location for these test conditions.

DOUBLE-BLIND TEST RESULTS

The data from the human test subject and the supervisor was compared after the completion of the 25 trials. It was found that the "DKL LifeGuard Model 2.0" was accurate in 25 out of 25 trials. In fact, observing the "chart recorder output signal I was easily able to discern each individual step that the test subject took on the way to the marker line at the "in-range" position. After viewing the test videotape, one was also able to correlate the turning around motion of the test subject with a large signal from the sensor that appeared on the computer screen.

DEVICE PERFORMANCE SUMMARY

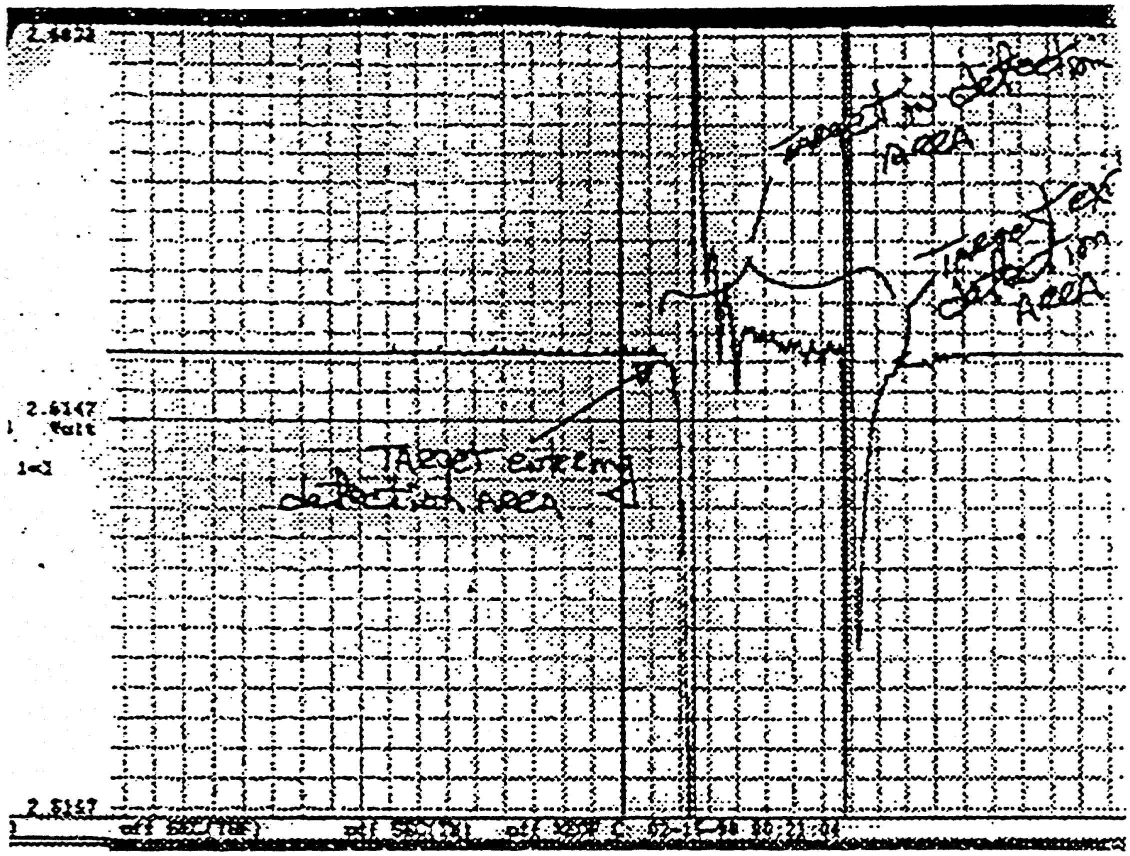
In my judgment the "DKL LifeGuard Model 2.0", being used as an autonomous device, has excellent sensitivity. Again, it was possible to correlate the sensor signal with the individual steps taken by various test subjects. The correlations were quite clear and distinctive. In fact, it was demonstrated that at about 15 feet, it was even possible to detect a single big toe (mine) being raised within a shoe. The "DKL LifeGuard Model 2.0" being used as an autonomous device detected human test subjects behind electrically insulating walls by sensing the charge perturbations created by their movements The circuits used in the device are proprietary to DKL. I inspected the interior of the Model 2.0 and found it consistent with the attached DKL block diagram.

REPORT DISTRIBUTION

This report should be distributed and used by any and all sources only in its entirety. It is not to be excerpted, abbreviated, quoted, or summarized.

Signed: Dr. Joseph P. Dougherty
Advanced Materials Technologies

Date: May 28, 1998



Target in detection AREA
Target exiting detection AREA
TARGET entering detection AREA
2.6147
Volt

Appendix B: Output of the DKL LifeGuard™ Operated as an Autonomous Charge Perturbation Sensor (Provided by DKL)

223D.WDQ

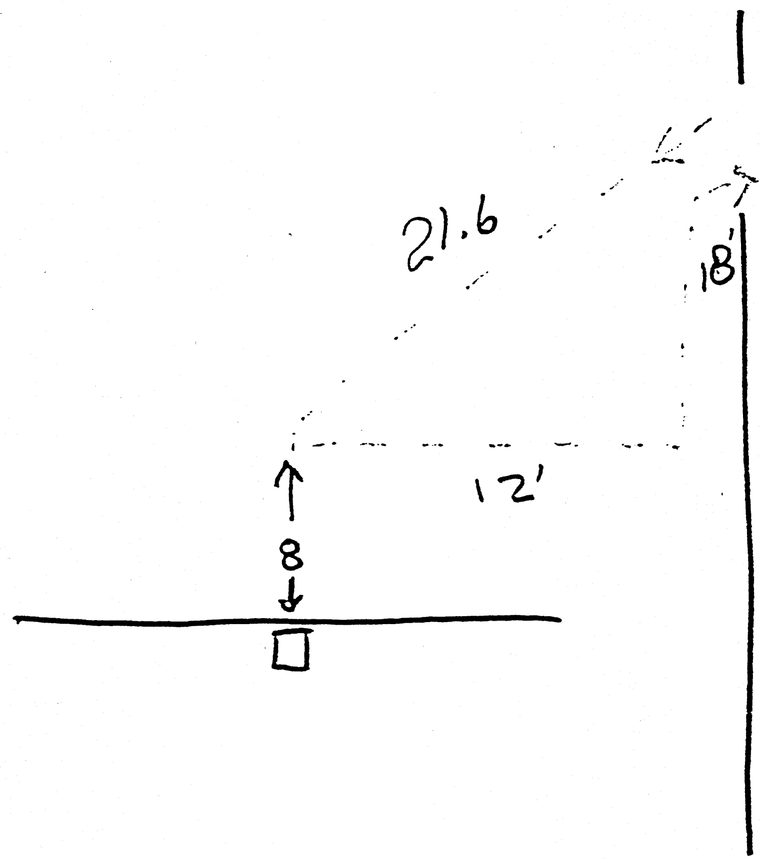
Bob VanDine (250 lbs.) walking on linoleum from doorway to spot 8' in front of wall, traversing wall for 12' and exiting doorway. Geometry created — right-hand right triangle.

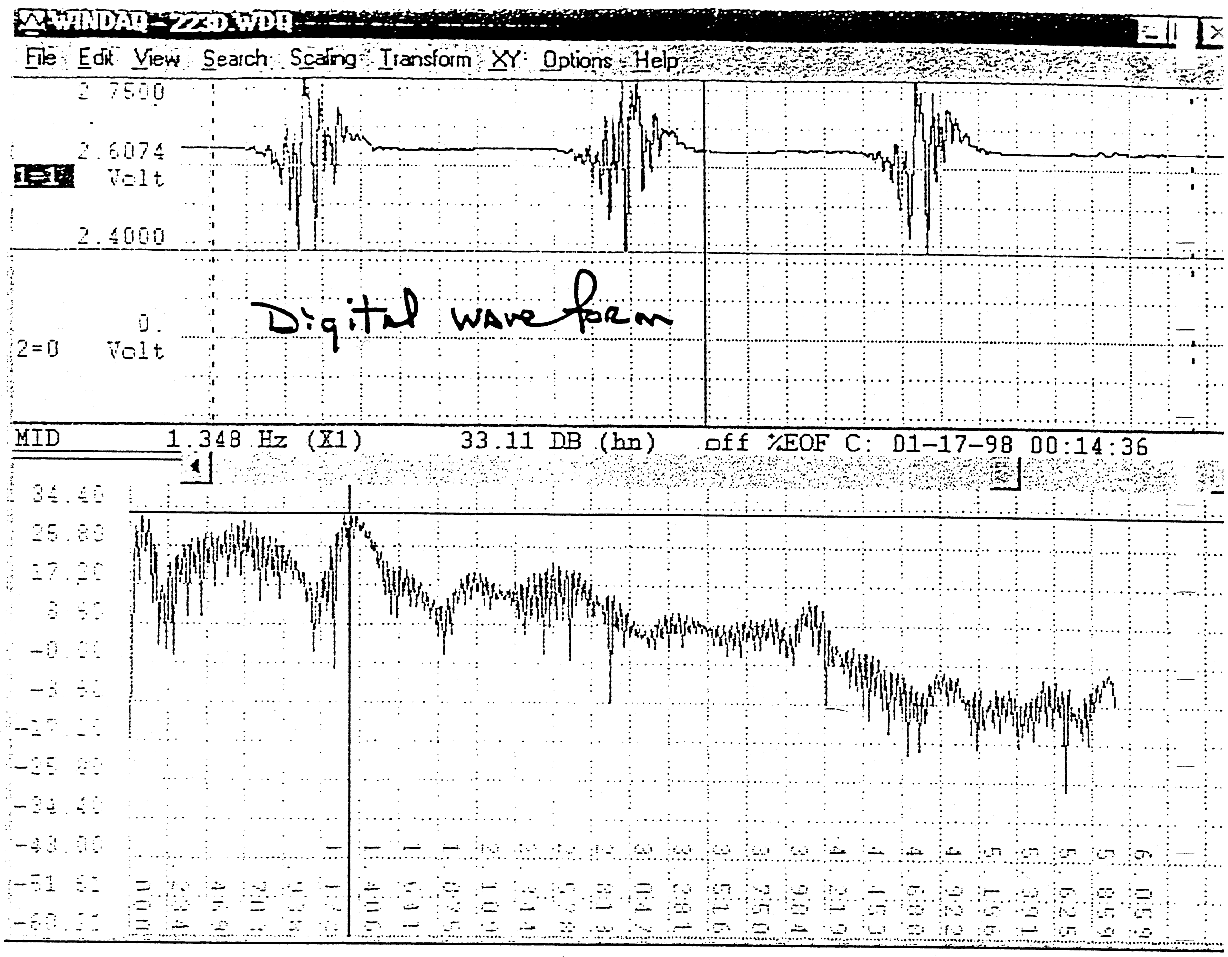
223A.WDQ

Sherry Diehl walking on linoleum from doorway to spot 8' in front of wall, traversing wall for 12' and exiting doorway. Geometry created — right-hand right triangle.

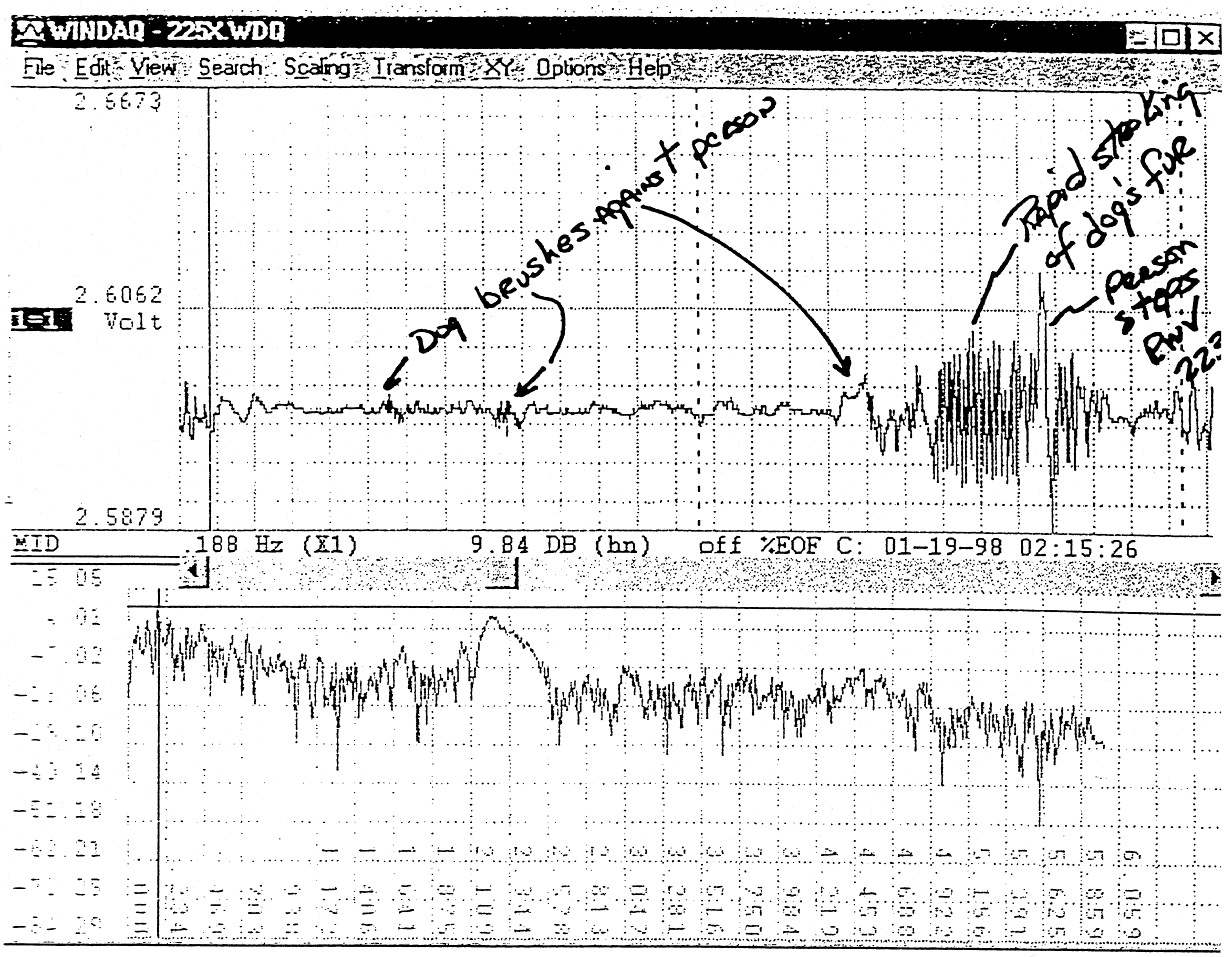
225X.WDQ

Dog (150 lbs.) w/petting at 4 Hz, range 16', through 3/4" particle board.

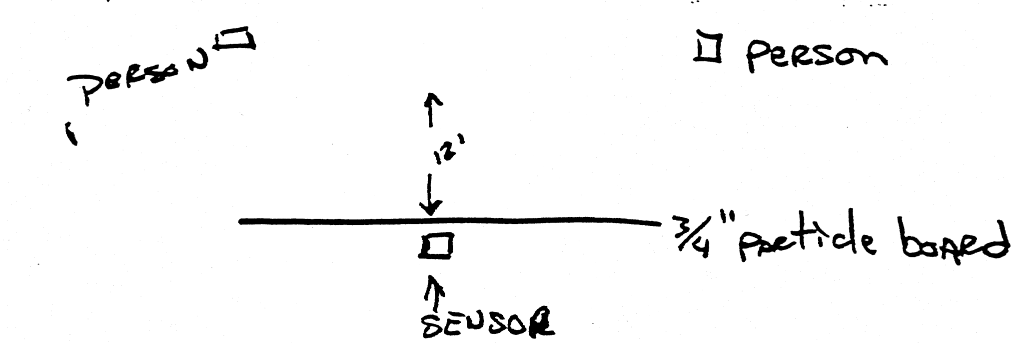


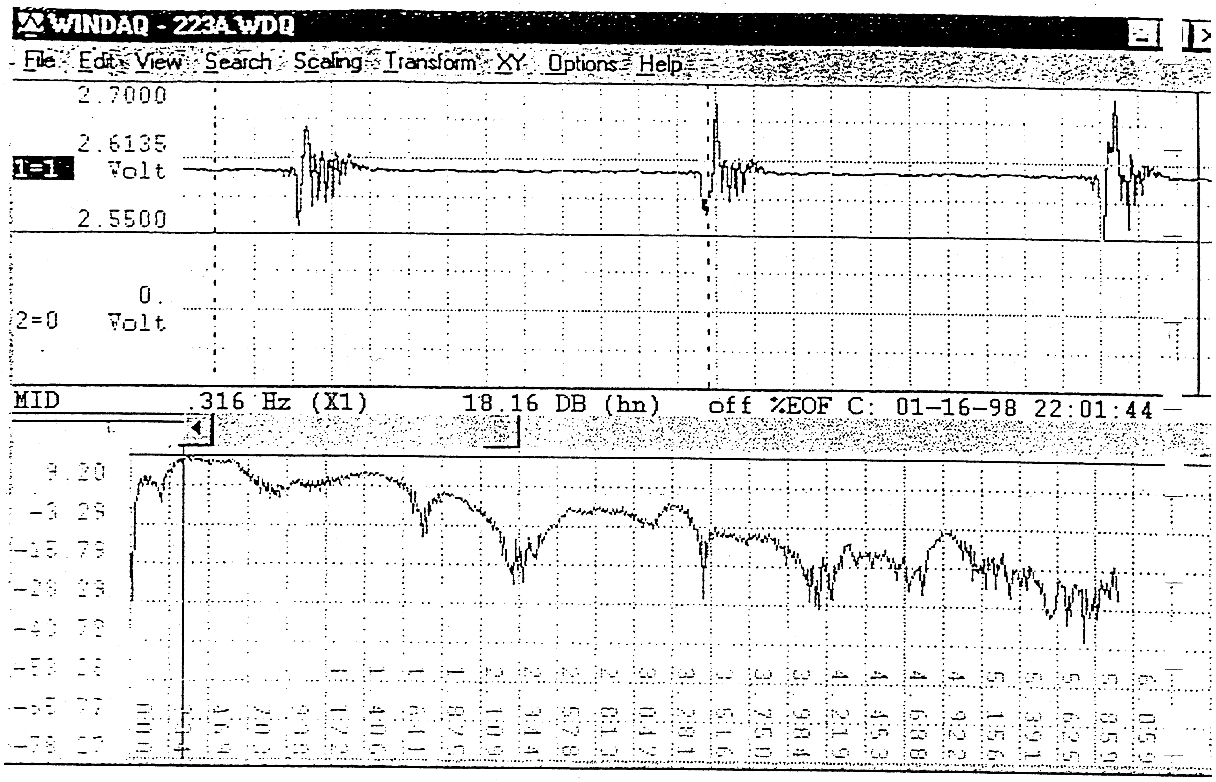


FFT - NO POWER AVERAGING

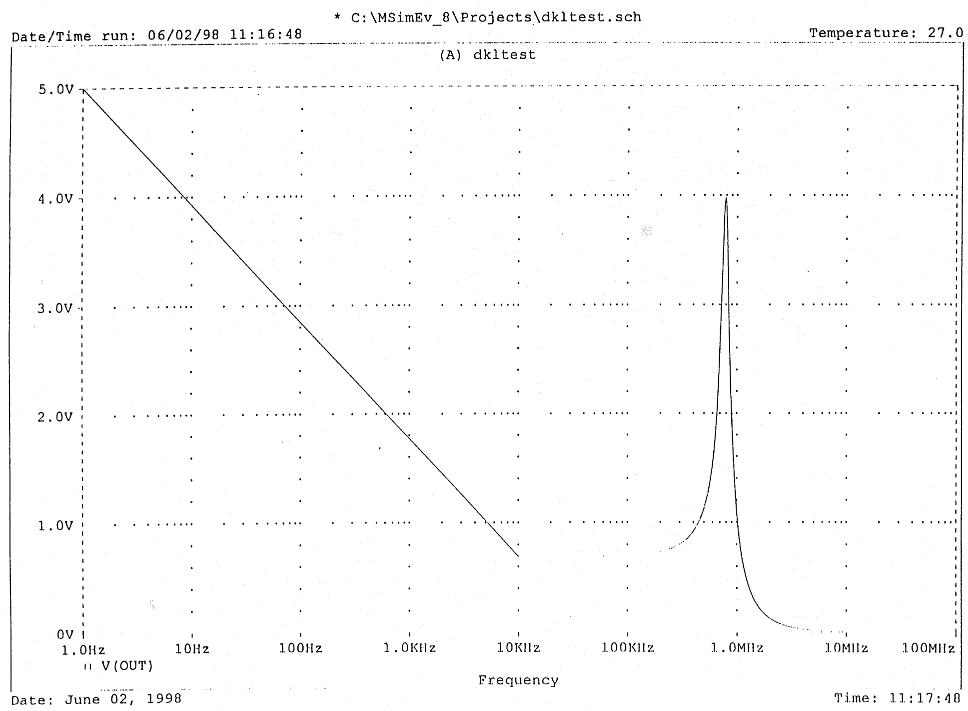


Great Dane walking at 12' from wall

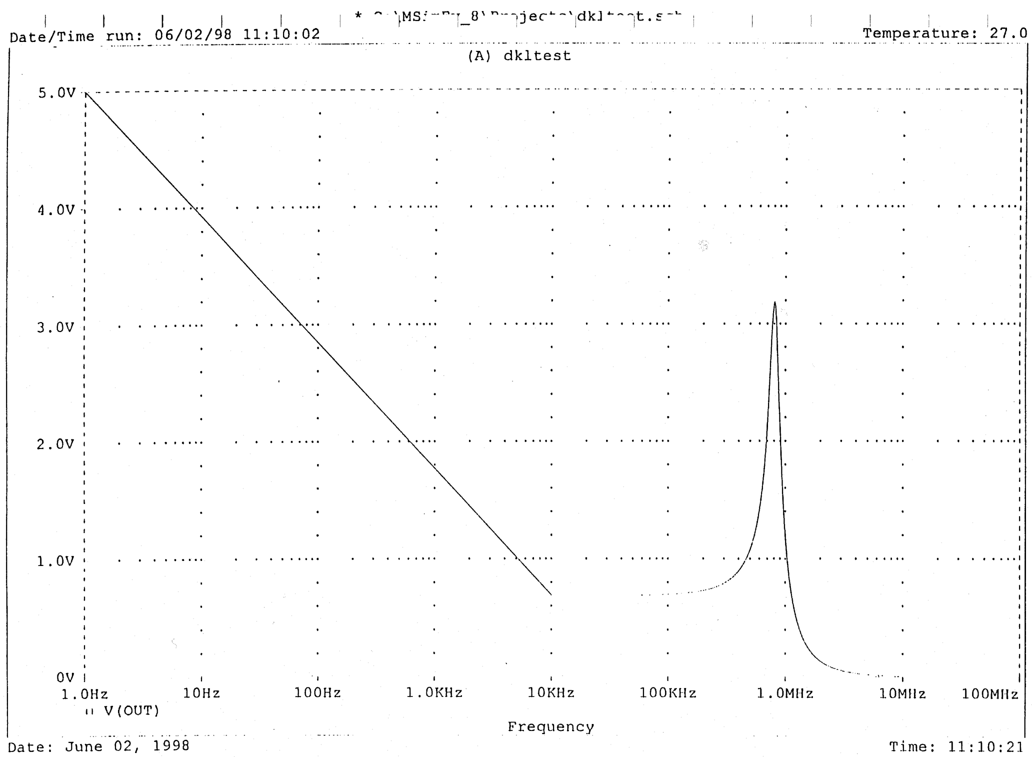



WINDAQ - 223A.WDQ
File Edit View Search Scaling Transform XY Options Help
2.7000
2.6135
1=1 Volt
2.5500
0.
2=0 Volt
MID .316 Hz (X1) 18.16 DB (hn) off %EOF C: 01-16-98 22:01:44

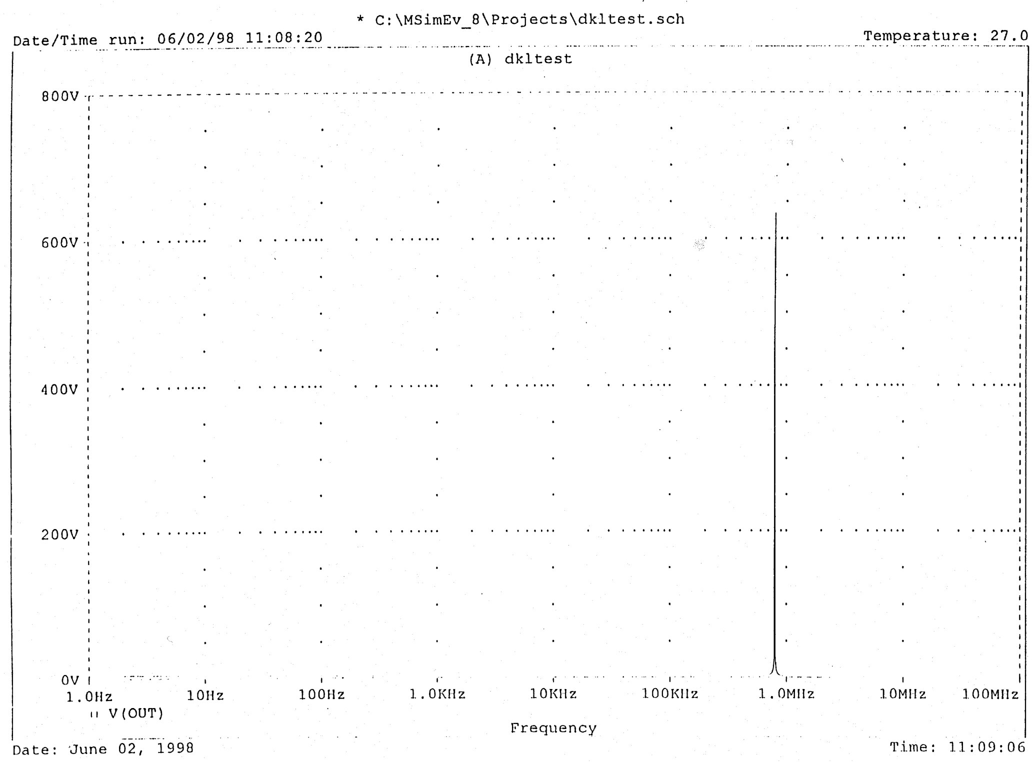
Appendix C: PSPICE Frequency Response Analysis of the Passive Module’s LCR Filter



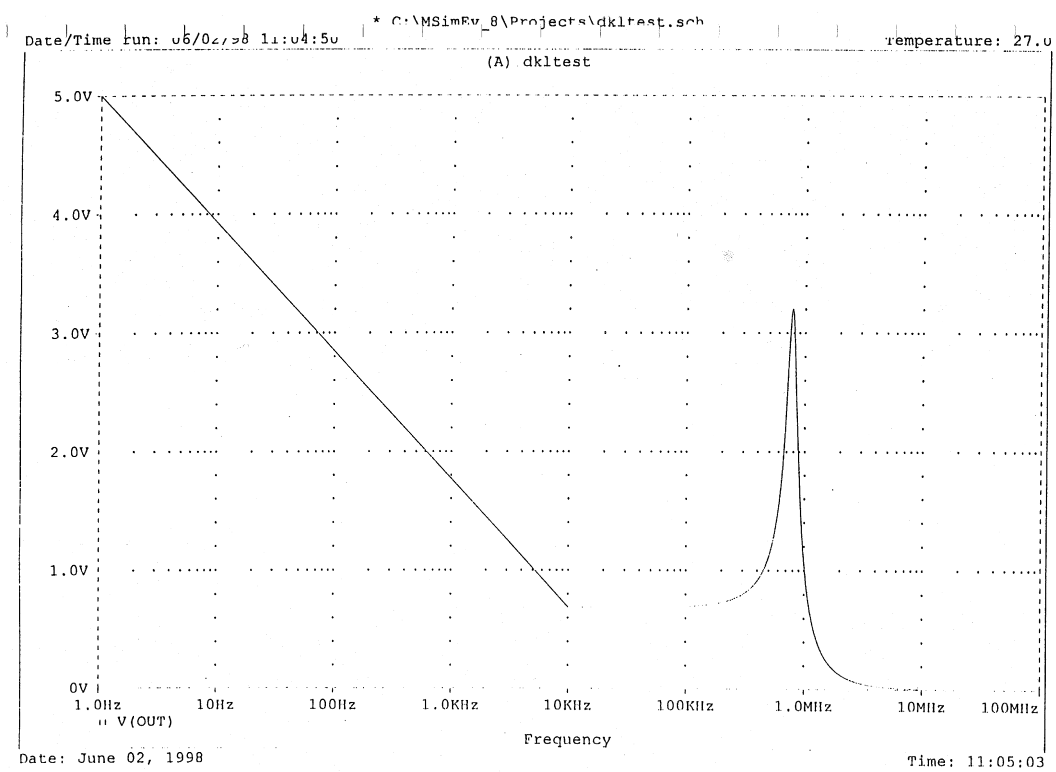
3.3 kΩ Resistor



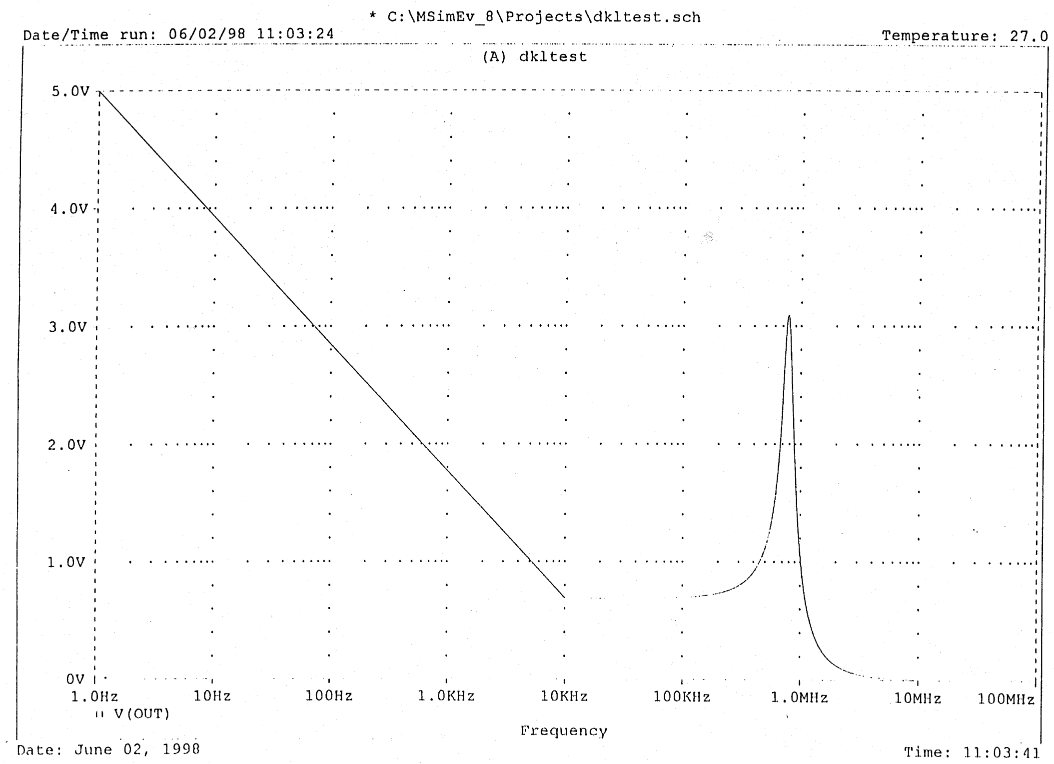
Diodes



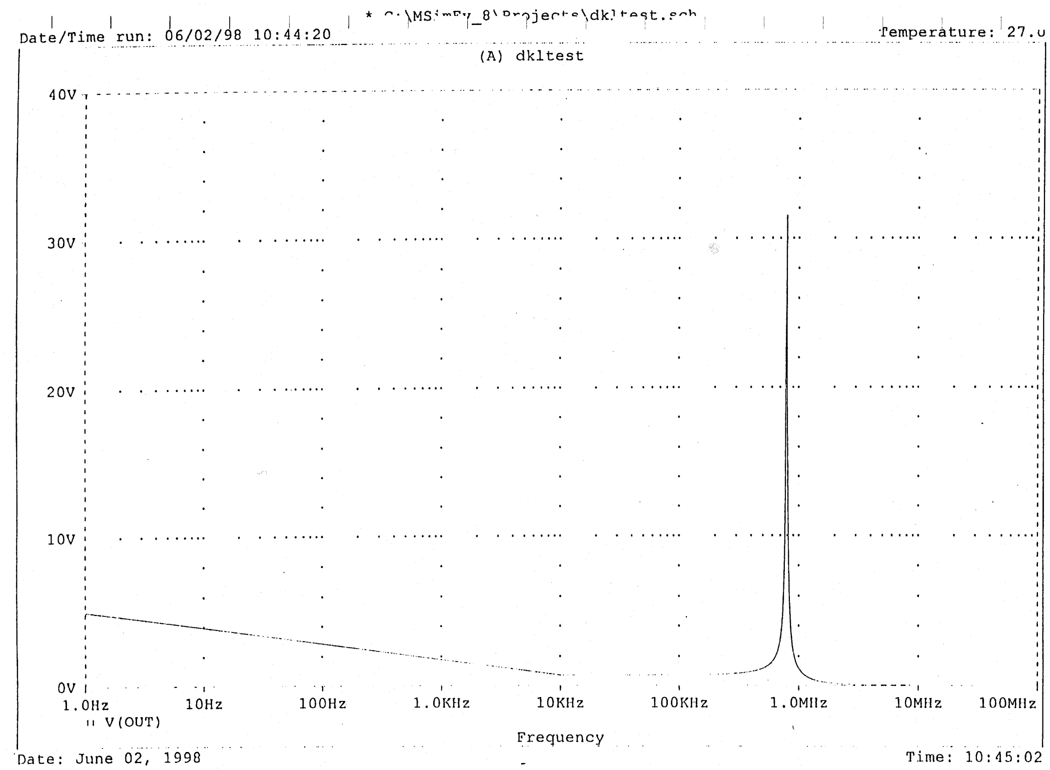
Capacitor



22 kΩ Resistor



100 kΩ Resistor



100 Ω Resistor

Appendix D: Analysis of the Hair-Like Fibers Performed by the Albuquerque Police Department Crime Laboratory

ALBUQUERQUE POLICE DEPARTMENT
SUPPLEMENTARY
OFFENSE REPORT

OFFENSE None Given CASE NO. SNL 9/98
OFFENSE LOCATION None Given
VICTIM None Given

CRIMINALISTICS TRACE EVIDENCE REPORT
Hair Examination

ITEMS EXAMINED:

No Card: Two (2) apparent square plastic disks, with apparent hair attached.

RESULTS:

Microscopic examination revealed numerous human head hair fragments ranging in size from approximately 2 millimeters to 5 millimeters in length. The hair fragments showed a wide color range from dark brown to white (grey).

REMARKS:

Apparent hair was removed from the above described items and mounted on microscope slides for examination and identification.

Hair does not possess a sufficient number of unique, individual, microscopic characteristics to be positively identified as having originated from a particular person to the exclusion of all others.

The results and interpretations in this report are meant to be used as an aid to understanding the significance of the results of analysis. They do not reflect a complete interpretation of all results, and further discussion is encouraged.

SEND RESULTS TO: Dr. Dale Murray, Sandia National Labs

PAGE 1 OI

EXAMINER: Donna Arbogast Dona Arbogast 2054 DATE 9/4/98
ID NO.

PD-1?

CITY OF ALBUQUERQUE

ALBUQUERQUE, NEW MEXICO

INTER-OFFICE CORRESPONDENCE

REF. NO.__________

September 14, 1998

TO: **Dale Murray, Sandia National Laboratory**

FROM: **Donna Arbogast, Forensic Scientist, SED, Criminalistics**

SUBJECT: **Hair Examination Request**

Please find attached a report generated regarding the specimens you brought to me for preliminary examination and identification. I thought it would be helpful for you to have a physical copy of my findings for your file.

I have also included the microscope slides that I generated when examining specimens. I send them to you as I have no means to store them here, and I felt you may need them as part of your file. Each item (report, notes, and microscope slides) is labeled as SNL 9/98, along with my signature or initials and the date.

If I can be of further assistance, or if you have any questions, please feel free to contact me. I can be reached at (505) 769-2261 between 0900 and 1500. Thank you for the opportunity to be of assistance to you.

Appendix E: A ^{13}C NMR Analysis of the Dielectric Material

Sandia National Laboratories

Operated for the U.S. Department of Energy by
Sandia Corporation

Albuquerque, New Mexico 87185-1407

date: September 9, 1998

to: Dale Murray, Org 5844, MS 0782

from: Roger Assink, Org 1811, MS 1407

subject: Analysis of Encapsulant Material in DKL LifeGuard

The ^{13}C NMR spectrum of the encapsulant material taken from a DKL LifeGuard unit was recorded. This spectrum along with the spectrum of Polystyrene-Divinylbenzene purchased from Polysciences catalogue #04696 are shown on the following page.

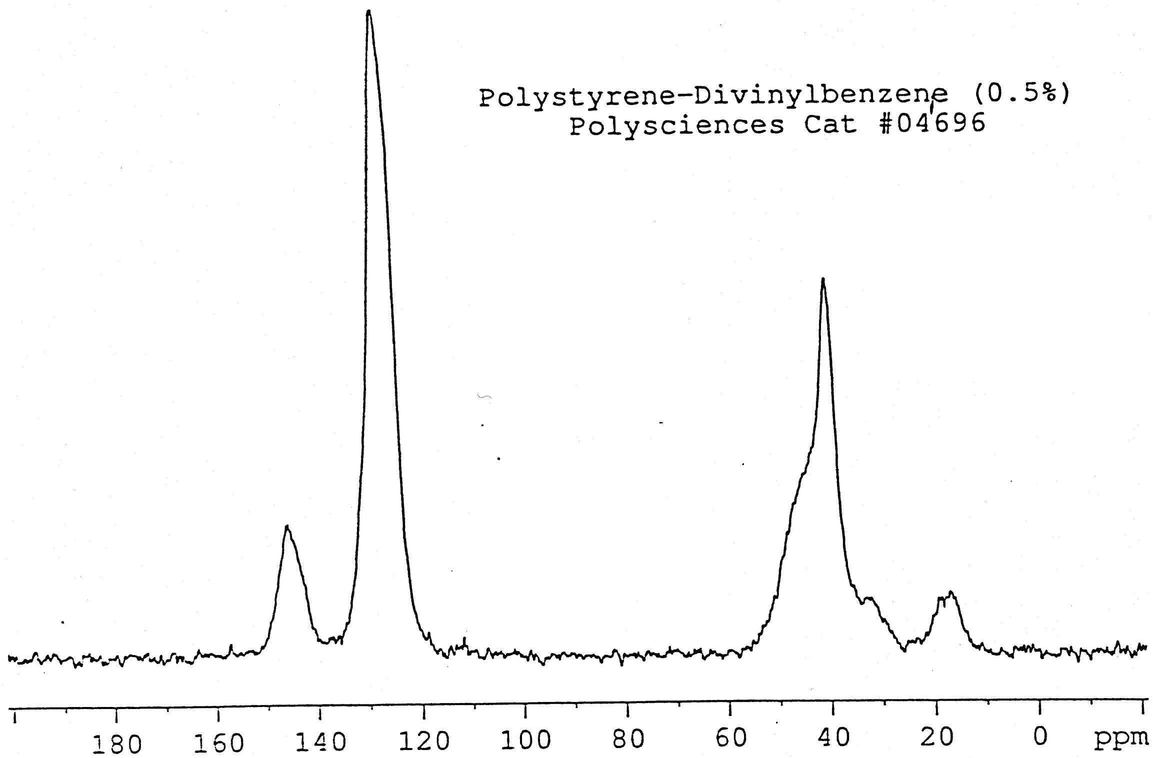
Each spectrum consists of aromatic carbons in the range from 110 to 150 ppm and aliphatic carbons in the range from 10 to 50 ppm. Although these spectrum are similar, there are two noticeable differences: (1) the resonances near 40 ppm have different shapes and (2) the DKL LifeGuard encapsulant has several additional resonances.

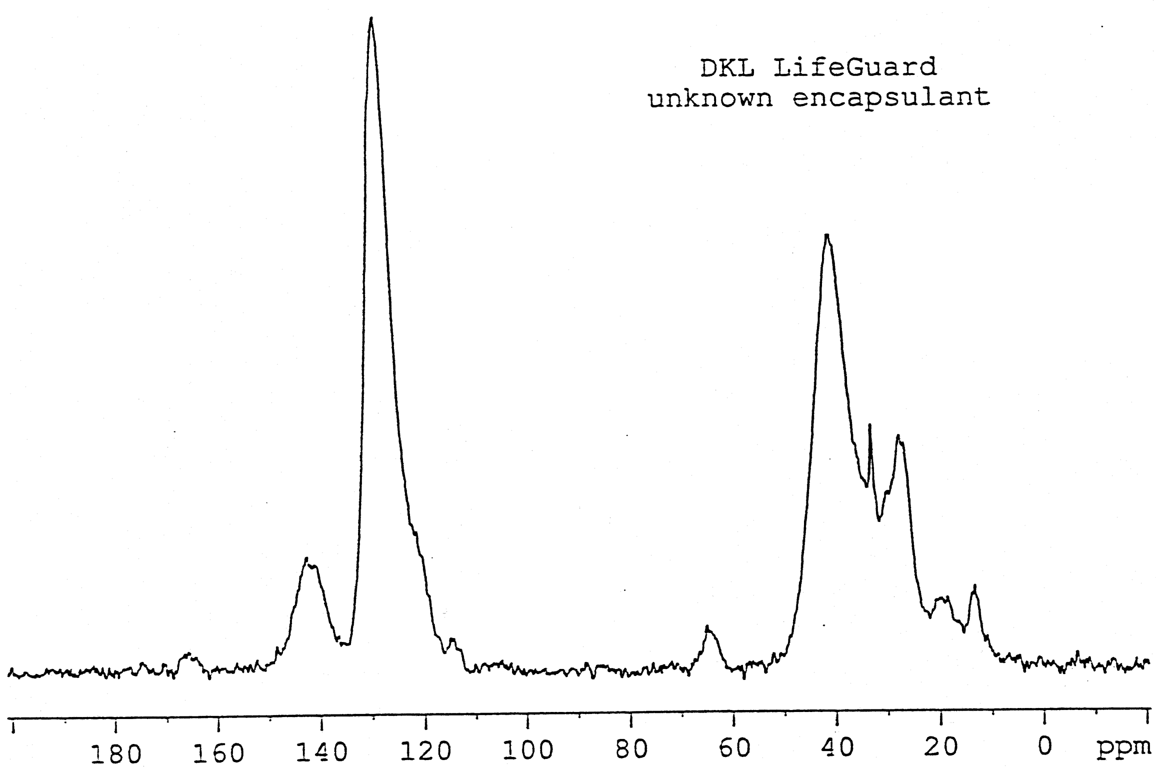
The difference in shape of the resonances at 40 ppm can be attributed to differences in the microstructure of the two materials. The resonance at 40 ppm corresponds to both the methylene and methine carbons. Their exact position depends on the tacticity of the chain which in turn depends on the method of preparation. Chain tacticity can also affect the position of the C1 carbon in the phenyl ring which is seen to be shifted to lower ppm. The crystallinity, which depends on both chain tacticity and thermal history can also affect the exact shape and location of the resonances. I've attached a figure from the literature which shows the kind of changes which can be seen in an isotactic polystyrene which has been subjected to different thermal treatments.

The additional resonances in the encapsulant are at 13, 28, 33, 65, 114 and 166 ppm. These spectral features are closely matched by a standard spectrum of polyvinyl stearate (attached) which is often used as an impact modifier. The resonance at 114 ppm, which is seen in both the stearate and encapsulant spectra, corresponds to unreacted vinyl groups. The resonance at 33 ppm, which corresponds to interior CH_2 repeat units, is much smaller in the encapsulant sample than in the standard sample. The reduced size indicates that the side chain of the impact modifier is shorter than 15 repeat units.

The number of carbons in the polymers is in the ratio of 0.80 polystyrene to 0.20 polyvinyl stearate. The mass fraction ratio would be similar since most of the mass of each polymer is attributed to the carbons.

Exceptional Service in the National Interest


Polystyrene-Divinylbenzene (0.5%)
Polysciences Cat #04696
180 160 140 120 100 80 60 40 20 0 ppm


DKL LifeGuard
unknown encapsulant
180 160 140 120 100 80 60 40 20 0 ppm

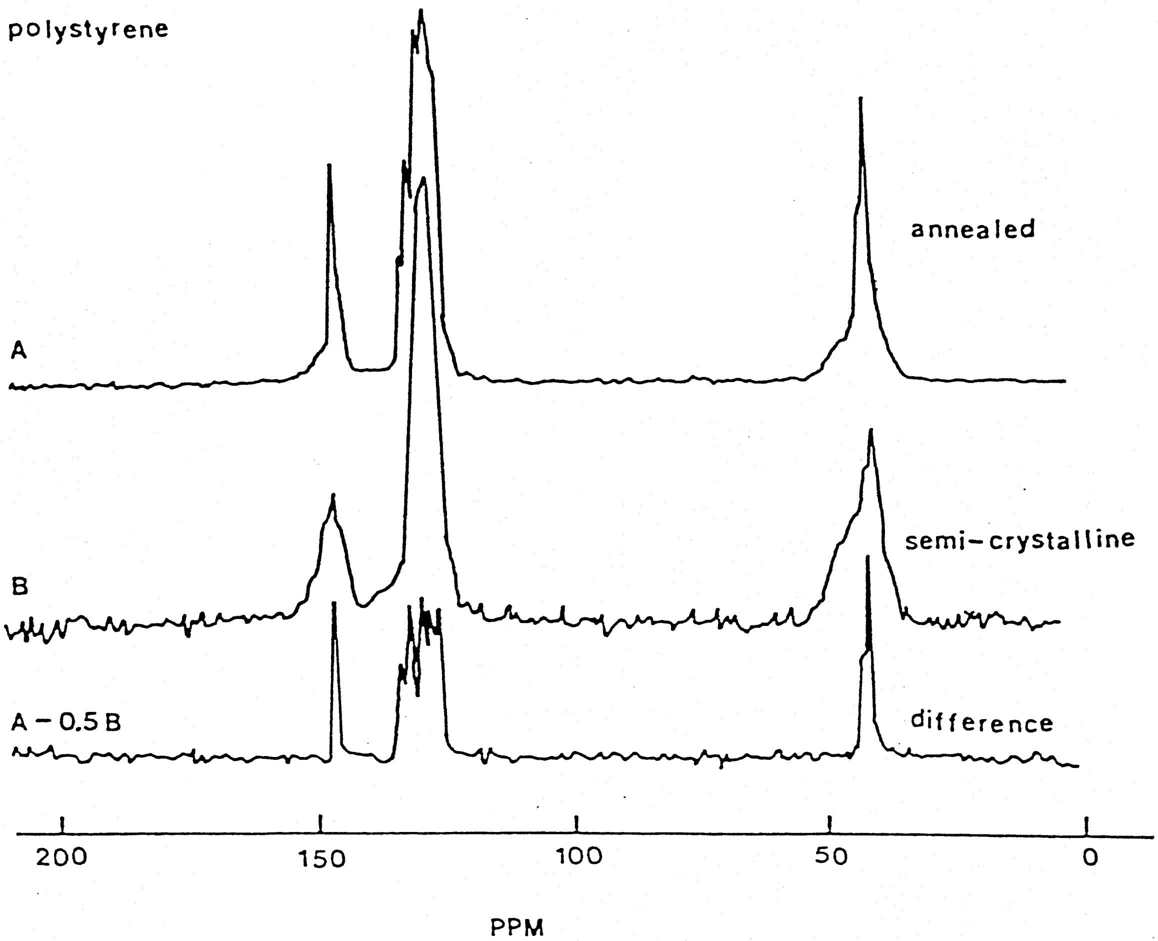


Figure 5-9. Spectra of isotactic polystyrene as a function of crystallinity (A) sample annealed for 3 h at 180°C: (B) same material but with no annealing. both spectra plotted with the same total area: (C) difference spectrum. (A) – 0.5 × (B). to effectively remove signal attributable to noncrystalline carbons giving very nearly the spectrum of purely crystalline polystyrene. (Reprinted from Earl. W. L.: VanderHart. D. L. *J. Magn. Reson.* 1982. *48*. 35. by permission of Academic Press. Inc.)

POLY(VINYL STEARATE)

^{13}C CP/MAS

CHARACTERISTICS

Formula: $C_{20}H_{38}O_2$
Unit MW: 310
T_g: 52°C
T_m:
Source: Scientific Polymer Products
CAS Registry #: [9003-95-6]

ACQUISITION PARAMETERS

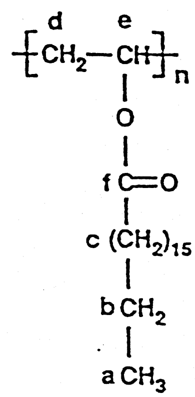
Frequency: 50.32 MHz
No. of Scans: 160
Temperature: 300 K
Hz/Pt: 3.699
Rotation Rate: ca 4.0 kHz
Line Broadening: 20 Hz
Comments: Powder

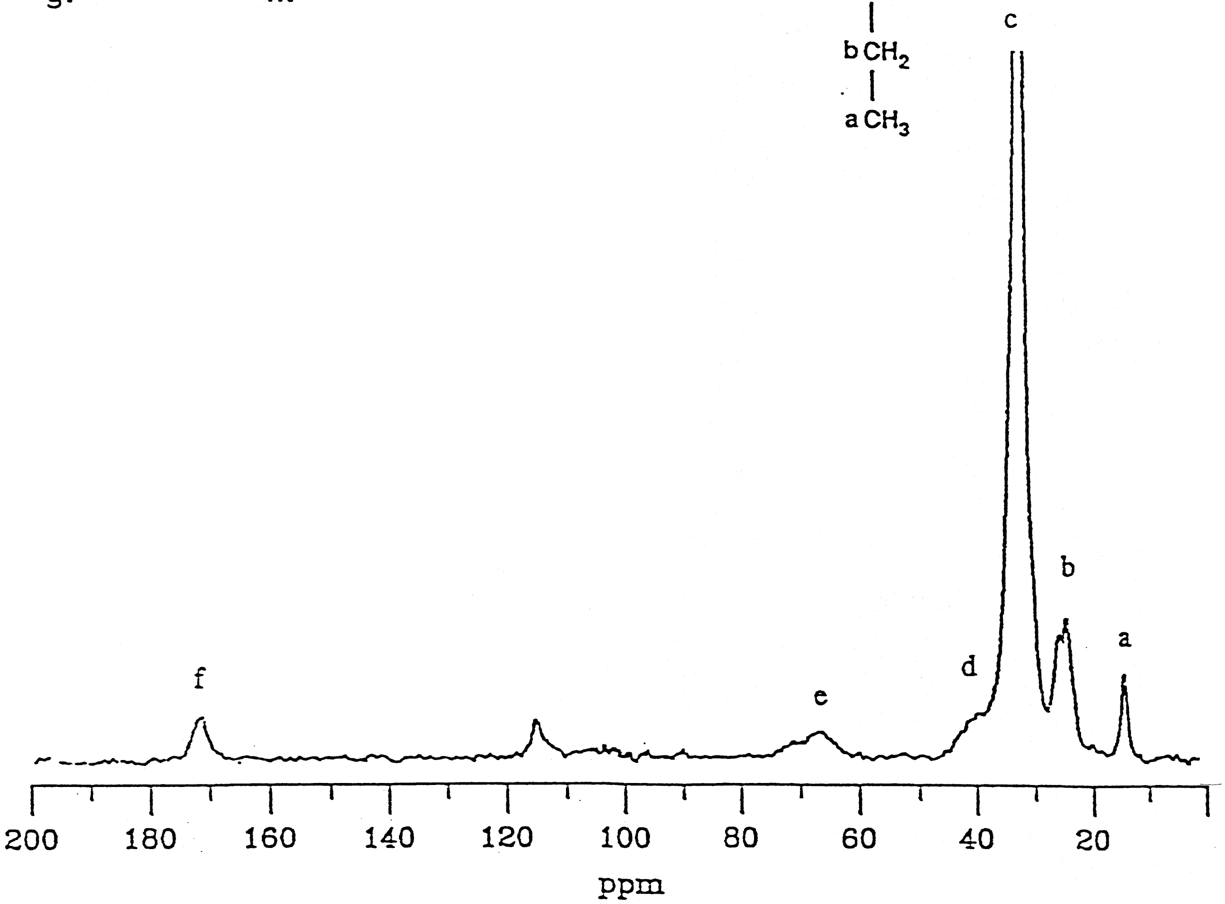
^{1}H 90° Pulse: 5.0 μs
Mixing Pulse: 5 ms
Ringdown:
Recycle Time: 3.0 s
Acquisition Time: 35 ms
Reference: Adamantane (29.5 ppm)

PEAK ASSIGNMENTS

a:	13.9	h:	
b:	24.1	i:	
c:	32.5	j:	
d:	ca 40	k:	
e:	66.2	l:	
f:	171.6	m:	
g:		n:	

STRUCTURE





Appendix F: Calculations of Fields and Forces Based on Pohl's Equation

DEP Theory

Can the DKL design function as stated based on the principle of dielectrophoresis, known laws of physics, and the principles of electrical engineering? To begin to answer this question, we start with the governing equation for dielectrophoresis—Pohl's equation. Pohl's equation states that for a sphere, the dielectrophoretic force can be calculated by:

$$\vec{F} = 2p\ a^3 e_m \operatorname{Re}\left\{\left[\frac{(e_p - e_m)}{(e_p + 2e_m)}\right]\nabla \vec{E}_0^{\,2}\right\}$$ [38]

where $\vec{F}$ is the force, a is the radius of the sphere, e_m and e_p are the complex permittivies of the medium and the material respectively, and $\vec{E}_0$ is the applied electric field. The Re symbol means the real part of the complex expression within the braces. By making some conservative assumptions the equation can be reduced to a scalar expression:

$$F = 2p\ a^3 k_m e_0 \left[\frac{(k_p - k_m)}{(k_p + 2k_m)}\right] \left|\nabla \vec{E}_0^{\,2}\right|$$

where k_m and k_p are the dielectric constant of the surrounding medium and the dielectric material respectively and e_0 is the permittivity constant of free space ($8.85 \times 10^{-12}\, F/m$). The term $\frac{(k_p - k_m)}{(k_p + 2k_m)}$ is a scalar real variation of the Clausius-Mosotti factor. This factor is a measure of the polorizability of the dielectric material. The dielectric constant of air (which is the surrounding medium) is 1.00054. Notice that as the dielectric constant for the material grows very large, the Clausius-Mosotti factor approaches and is bounded by 1. Even if a material had an infinite dielectric constant, this factor would never exceed 1.

Before solving this equation several approximations must be made. Many of the values that are required for this calculation cannot be determined precisely. Each approximation is made with a conservative approach (in the device's favor). The magnitude of the human heart's electric field and its spatial flux density gradient are based on well-established electrocardiogram (ECG) measurements. The dielectric constant for the materials of the DKL LifeGuard™ is assumed to be infinite. The size of the dielectric material within the dielectric component is known, however the size is exaggerated in order to provide the most conservative analysis. While these approximations are not precise, the combination of using conservative values and basing approximations on well-established values make this analysis reasonable.

The first step in the analysis is to determine an estimate for the magnitude of the human heart's electric field. The human heart is a dipole, not a monopole (having a single positive or negative pole). A monopole's electric field decreases with the square of the distance; whereas, as the distance from a dipole increases, the electric field decreases with the cube of the distance. For this analysis we will use the average electric field strength that is measured during electrocardiograms, which is about 15 millivolts per cm, or 1.5 volts per meter. We will assume

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[38] http://www.elec.gla.ac.uk/groups/bio/Electrokinetics/theory/theory.htm (a web site maintained by the University of Glasgow, Electrical Engineering Department, Scotland, UK).

that this is the value at 1 meter distance from the human heart (another conservative estimate because the ECG measures the field at the surface of the chest). At 500 meters, the heart's electric field is approximated as 12 nanovolts per meter : $\frac{1.5 V/m}{(500)^3} = 12 \times 10^{-9} V/m$.

The second step in the analysis is to determine the spatial flux density gradient of the electric field at a distance of 500 meters. Moving one meter closer to a distance of 499 meters results in a field-strength of 12.072 nanovolts per meter. This means that the spatial flux density gradient between 499 and 500 meters is 0.072 nanovolts (0.072×10^{-9} volts) per meter per meter.

To solve Pohl's equation we must make some further assumptions. The company claims that the antenna, the body of the device, and the operator's body become part of the "dielectric array". While there is no basis in scientific principles to support this claim, we will assume this is true. Since the dielectric constant for any such array would be difficult to determine, we will assume the dielectric array's dielectric constant is infinity (the most conservative estimate possible). These assumptions will make the Clausius-Mosotti factor equal to one (its maximum). The device is not spherical but in order to perform a very conservative calculation of the DEP force, we will assume a spherical "dielectric array" with a radius of one meter (a sphere of this radius would contain the entire "dielectric array" claimed by DKL). Any DEP force resulting from the human heart's electric field on the dielectric component would be directed at the dielectric component. However, to perform a very conservative calculation, we will assume that the force is directed at the antenna tip (the best location for the force to act) and is perpendicular to the axis of the antenna assembly (the most favorable direction). We will also assume that the antenna assembly is perfectly horizontal and balanced and we will neglect all friction. For a distance of 500 meters (remember the published range for the Model 3 is 600 meters), the equation yields a solution of 29×10^{-32} Newtons for the DEP force.

Resulting torque, angular acceleration and time for angular displacement calculations

Continuing with the analysis, we now determine the moment of inertia for the antenna assembly. The plastic body of the antenna assembly has a measured mass of 186 grams. The shape of this part is roughly a parallelepiped. The moment of inertia for a parallelepiped rotating around an axis at one end is given by: $I = \frac{1}{12} m w^2 + \frac{1}{3} m l^2$, where *m* is the mass (0.186 Kg), *w* is the width (0.029 m), and *l* is the length (0.146 m). This calculation results in a moment of inertia of 0.0013 $\mathrm{Kgm^2}$.

The antenna is approximately a slender rod with a measured mass of 18 grams. The moment of inertia for a slender rod rotating about an axis at one end is given by: $I = \frac{1}{3} m l^2$, where *m* is the mass (0.018Kg) and *l* is the length (0.61 m). This results in a moment of inertia of 0.0022 $\mathrm{Kgm^2}$. The total moment of inertia for the assembly rotating about the same axis is the sum of the moments of inertia. This results in a total moment of inertia of 0.0036 $\mathrm{Kgm^2}$.

Now that we have the moment of inertia and the force that is assumed to be directed at the tip of the extended antenna, we are ready to calculate the time it would take to rotate the antenna assembly 15° (0.262 radians) in 1 second. Since the force is assumed to act perpendicular to the axis of the antenna, the magnitude of the torque $\boldsymbol{t}$ is given by: $t = r \times F$, where r is the radius from the axis of rotation to the point where the force is directed. The calculated force directed perpendicular to the antenna at the extended tip results in a torque of 18×10^{-32} mNewtons. The magnitude of the angular acceleration is given by: $a = t/I$. The calculated angular acceleration is 49×10^{-30} radians per second per second. The angular displacement for a body initially at rest and with no initial displacement is given by: $q = \frac{1}{2} a t^2$. Solving for $\boldsymbol{t}$ (the time) for a 15° rotation results in a total time of 3.27 million years. Despite all the efforts to use the most conservative estimates, the calculated force and resulting torque, there is no possibility that the DEP effect is responsible for the rotation of the antenna assembly. The calculations for force, torque, angular acceleration, and time for the 15° displacement at total distance of 2 meters were performed using identical procedures.

Using the equation for angular displacement, we can calculate the torque required to rotate the antenna assembly 15° in 1 second, which can then be used to calculate the needed force at the antenna tip to produce this torque. The result of these calculations is 3.1 milliNewtons. We can now ask the question how large must the spatial flux density gradient be to produce this force. As stated before, we have assumed a material dielectric constant of infinity making the Clausius-Mosotti factor equal to its maximum of one. The dielectric constant of air is 1.00054. And the volume of a sphere of radius one meter. Using these values in Pohl’s equation and solving for the required spatial flux density gradient yields 7.5 thousand volts per meter per meter.

Appendix G: Excerpts from a Fax sent to Sandia from Dr. George Johnson, Chief Scientist from DKL

3-23-1998 1:41PM FROM THE CECON GROUP INC 302 994 8837 P.1

The CECON GROUP Inc

242 N. James St., Suite 202
Wilmington, DE 19804
302-994-8000
FAX: 302-994-8837
888-263-8000

TELEFAX COMMUNICATION

To Telefax No. 505-844-5318
505-844-5569

PLEASE DELIVER THIS PAGE (and the following 17 pages) TO:

Name: Dale Murray and John Molloy

Location: Sandia Nat'l Laboratory

Sender: George Johnson (Chief Scientist; DKL)

Date: 3/23/98

(if for any reason you do **NOT** receive ALL the pages noted above, PLEASE CALL us at 302-994-8000)

MESSAGE: Some summary Technical charts that may provide some insights for you on DKL Technology

Reference List Keys are
ref #1
ref #28 and 27

Call me with questions or comments
888-263-8000

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