George H. Seward,[1] M.S.

Practical Implications of Charge Transport Model for Electrostatic Detection Apparatus (ESDA)

REFERENCE: Seward GH. Practical implications of charge transport model for electrostatic detection apparatus (ESDA). J Forensic Sci 1999;44(4):832-836.

ABSTRACT: The practical implications are described for a previously reported charge transport model of the electrostatic detection apparatus [Seward GH. J Appl Phys 1998;83(3):1450–6]. Several steps within the ESDA process are theoretically evaluated by the model: humidification of specimen, duration of charging, and duration of discharge prior to application of toner. Recommendations for improved sensitivity are derived from the theoretical models as well as experimental observations.

KEYWORDS: forensic science, questioned documents, electrostatic imaging, ESDA, indented writing, fingerprints

A model has been developed for the electrostatic detection apparatus (ESDA) (1). This model describes the discharge of the electric potential in ESDA as it depends upon the electric perturbations of the paper specimen. This model indicates several methods for increasing the sensitivity of the process. Three of these methods are: application of sufficient charge, adequate water content of the specimen, and temporal decay prior to application of toner. The first two methods are already well known, but the third is a previously unreported method for increasing sensitivity of the ESDA process. This article briefly reviews the model developed by Seward (1), and then describes the practical implications of the model. The present article assumes a working knowledge of the ESDA process. References are provided for those who want more information on the operation of ESDA (1-3).

The ESDA system creates an image of such things as fingerprints and indented writing. The ESDA process involves the following basic steps. First, the paper specimen is placed on top of a grounded platen and beneath a thin sheet of Mylar. The stratified structure is held in place by a partial vacuum beneath the porous platen. Second, a negative charge is applied to the Mylar sheet by passing a charged corona-wire over the Mylar. And third, charged toner particles are applied to the Mylar. These charged toner particles create a visible image of electric perturbations in the paper. Humidification of the specimen prior to the ESDA process can greatly enhance the sensitivity.

Past work on ESDA includes both models and methods for ESDA. Foster and Morantz attributed the ESDA image of indented writing to a change in capacitance of the Mylar-paper-platen structure (2). This change in capacitance was theoretically due to the compression of the paper. Seward, however, identified surface-charge created by paper-to-paper friction as the ESDA-detectable effect of indented writing (1). The experimental proof of this statement is briefly reviewed in the present article. Ellen, Foster, and Morantz described the application of ESDA to several pieces of forensic evidence such as a bank robber's note (2). Noblett and James studied the beneficial effects of humidifying the specimen (3). Baier studied the effects numerous parameters: paper type, writing instrument, number of overlaying sheets, humidification of specimen, and local relative humidity (4). Specifically, Baier indicated the significant benefits of specimen humidification while operating the ESDA system in a dry climate. In the present article, the effects of increased water content of the specimen are mathematically modeled, and these theoretical results concur with the experimental results of Baier. Horan and Horan concluded that indented writing by pencils or ballpoint pens can be successfully imaged by ESDA at least 50-60 (sic) years after creation (5). However, their conclusion erroneously surmises their own reports in the same article: their earliest example of an impression by a ballpoint pen was from 1948, which is 39 years prior to their experimental work; and their earliest example of an impression by a pencil was from 1933, which is 54 years prior to their experimental work.

The model developed by Seward is based upon charge transport through the Mylar-paper-platen structure (1). The mathematical expression for this discharge is

$$\frac{\mathrm{d}\left|V_M\right|}{\mathrm{d}t} = -\alpha \exp(\beta \left| - V_M + V_{\mathrm{pert}} \right|^{1/2}) \tag{1}$$

in which: V_M is the voltage of the Mylar with respect to the grounded platen; α and β are parameters of the Mylar and specimen; and V_{pert} is the electric potential of the perturbation. This mathematical model correlates extremely well with experimentally acquired data. An equivalent circuit was developed for the present article. It is displayed in Fig. 1. Both the charging and discharging are affected by the perturbation potential. As the perturbation potential increases, the effective resistance of the Mylar decreases.

Methods

The model is briefly described in order to highlight the effects of certain parameters. The reader is referred to a previous article for more detail if necessary (1). The discharge of the Mylar is controlled by Poole-Frenkel conduction of the electrons trapped in surface states of the Mylar. The parameters of temporal relation for Mylar voltage are simplified for this article as

$$\alpha = \frac{\alpha_0}{c_{\mathrm{MS}}} \quad \text{and} \quad \beta = \beta_0\, c_{\mathrm{MS}}^{1/2}. \tag{2}$$

[1] Associate corporate scientist, IISI Corporation, 19 Sterling Road, North Billerica, Massachusetts.

Received 27 Aug. 1998; and in revised form 2 Nov. 1998; accepted 20 Nov. 1998.

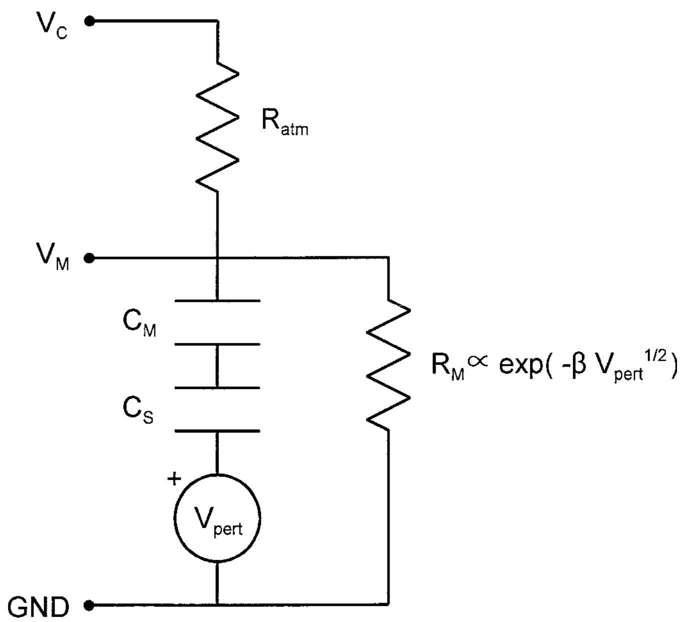

FIG. 1—*Equivalent Circuit for ESDA. V_C, voltage of corona; R_{atm}, resistance of atmosphere; V_M, voltage of Mylar; C_M, capacitance of Mylar; C_S, capacitance of specimen; V_{pert}, voltage of perturbation; GND, ground potential; R_M, resistance of Mylar; B, conduction parameter.*

The terms α_0 and β_0 express the contributions of parameters which are beyond the control of the operator of the ESDA system. The remaining term, c_{MS}, is the capacitance per area of the Mylar-specimen structure. This parameter is expressed as

$$c_{\mathrm{MS}} = \left(\frac{d_S}{\varepsilon_S} + \frac{d_M}{\varepsilon_M}\right)^{-1} \tag{3}$$

in which: d_S is the thickness or dimension of the specimen; ε_S is the permittivity of the specimen; d_M is the dimension of the Mylar; ε_M is the permittivity of the Mylar. The permittivity of the specimen is extremely dependent upon water content. Consequently, humidification of the specimen greatly affects the ESDA process. This parameter is easily modified by the ESDA operator, while the others are not.

In a previous work (1), this theoretical model was applied to measured voltage data. The correlation between the theoretical and experimental data was excellent. The model parameters α and β were determined in this study as 1.37 volt per year and 0.37 inverse square-root volt, respectively. The perturbation potential for an indented writing was circa 30 volts. The relative humidity of the controlled space of the experiment was 70–75%. For the purpose of modeling within this article, the permittivity of the specimen at 75% RH (relative humidity) was estimated as $10\varepsilon_0$ in which ε_0 is the permittivity of free space. Furthermore, the resistivity of the air was adjusted to create a charging curve that resembled experimental observations. The corona wire potential was set at –8800 volt.

An experiment was conducted to establish the electrostatic effect of indented writing as creation of surface charge by means of friction (1). The specimens were created by dragging the spherical tip a stainless steel rod across the structure shown in Fig. 2. The specimens were quantified by scanning a voltage probe across the stroke of each specimen. This measurement was repeated every minute for 30 min. The specimens were measured in both erect (upside up) and inverted (upside down) orientations. The model was fit to the experimental data. A perturbation potential was established for all three specimens in both the erect and inverted orientations.

Results

Application of the charge transport model in three different situations reveals some important dependencies. First, the model is applied to the charging of ESDA as displayed in Fig. 3. This is based upon a specimen permittivity of $10\varepsilon_0$. Second, the discharge is modeled for a moist specimen of permittivity $10\varepsilon_0$ as displayed in Fig. 4. And third, the discharge is modeled for a relatively dry specimen of permittivity $5\varepsilon_0$ as displayed in Fig. 5. Both discharge plots were based upon equal initial voltages for the ordinary and perturbed regions of a specimen.

Discussion

Several perturbation potentials were derived in the previous article (1), but only one has significant relevance to the present discussion. This perturbation potential created by a surface charge. It is expresses as

$$V_\sigma = \frac{z_\sigma}{\varepsilon_S} \tag{4}$$

in which z_σ is the elevation of the surface charge above the platform. The elevation of the surface charge is normally equal to the thickness of the specimen, but this is not true when the specimen is inverted. An inverted specimen can display no perturbation potential, and consequently, no image of that perturbation in ESDA.

In the previous study (1) on the specimens of Fig. 2, only two specific orientations created an ESDA image of the indentation. These orientations were an erect P_2 and an inverted P_1. In these two orientations, the elevated surface of the paper possessed an indentation created by paper-to-paper contact. Inverting either one of these orientations eliminated the image. This inversion asymmetry indicates a positive surface charge as the electric perturbation cre-

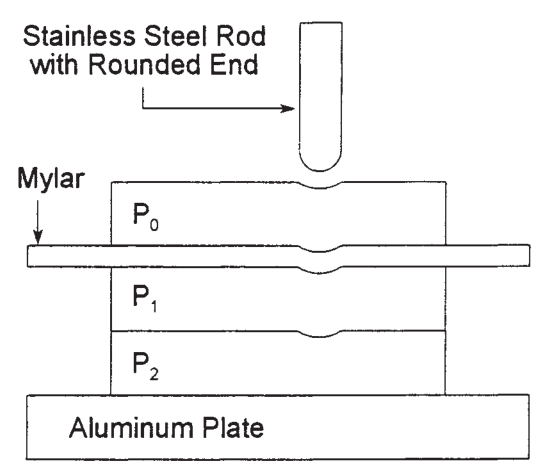

FIG. 2—*Indented writing throughout paper-Mylar-paper-paper stack. Reprinted with permission from G. H. Seward, "Model for electrostatic imaging of forensic evidence via discharge through Mylar-paper path,"* Journal of Applied Physics, *1998:83(3); 1450–6, Copyright 1998 American Institute of Physics.*

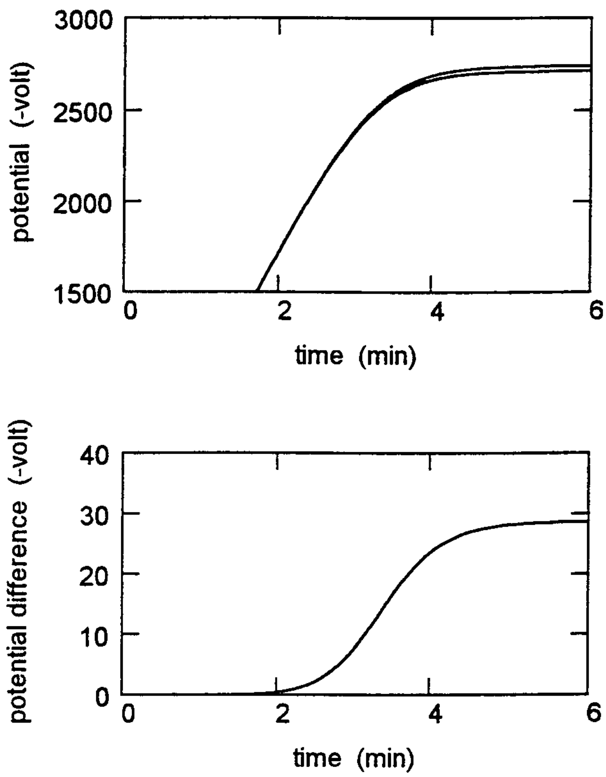

FIG. 3—*Theoretical charging of ESDA (estimated $\varepsilon_S = 10\varepsilon_0$). Lower curve in plot of potential belongs to indented writing. Time scale is speculative. Magnitude of potential is consistent with experimental observations.*

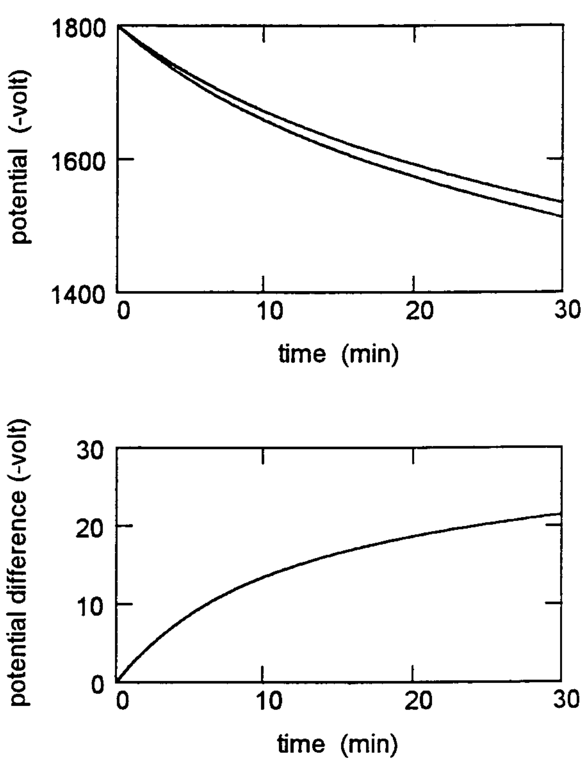

FIG. 4—*Theoretical temporal decay in ESDA for a humidified specimen (estimated $\varepsilon_S = 10\varepsilon_0$). Lower curve in plot of potential belongs to indented writing. Theoretical curves correlate strongly with experimental data for both time and voltage.*

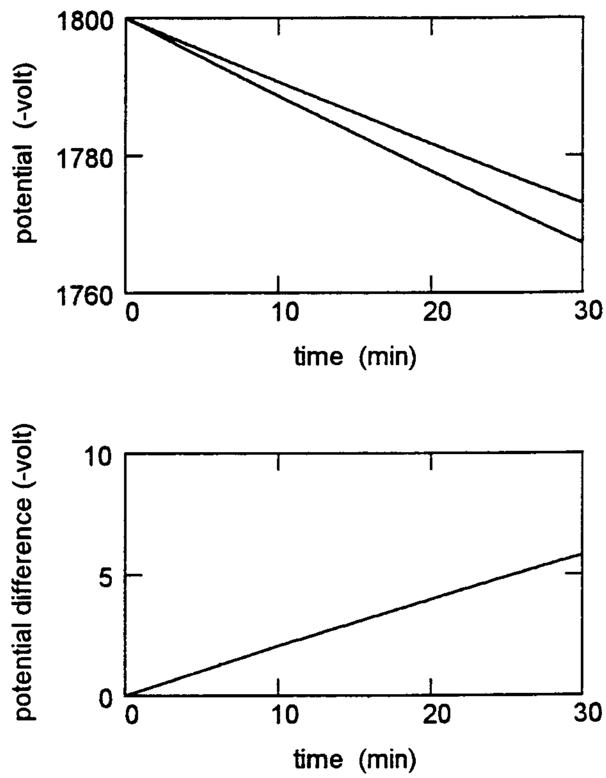

FIG. 5—*Theoretical temporal decay in ESDA for a specimen with ambient water content (estimated $\varepsilon_S = 5\varepsilon_0$). Lower curve in plot of potential belongs to indented writing. Magnitude of potential difference is much smaller than that of humidified specimen in Fig. 4. This reduced magnitude is consistent with experimental observations for dry specimens. Magnitude of this reduction is speculative.*

ated at a paper-to-paper indentation. The friction between the paper fibers is probably responsible for creating sites at which positive ions from the atmosphere can bond to the paper. Other indentations created by frictionless compression did not create an electric perturbation. Thus, the experimental evidence indicates that friction, and not compression, creates a positive surface charge which is detectable by ESDA. Compression without friction has no noticeable effect in ESDA.

The perturbation potential of a surface charge is directly proportional to the thickness of the specimen. Consequently, deep indentations and thin specimens might not create strong ESDA images. Elevating either one of these specimens might improve image quality. Elevation can be achieved by placing another sheet of paper beneath the specimen being examined.

Fingerprints were also discussed in the previous work (1), and they usually do not display inversion asymmetry. The electric perturbation of a fingerprint is an increased capacitance due to the addition of a dielectric film to the specimen. It does not involve a net charge. Fresh fingerprints (less than 4 h in age) on the top of a specimen do create strong ESDA image (1). However, fresh fingerprints might not create an image while in contact with the platen because of the electrical conductance associated the water and salt content of the fingerprint. Inversion of the specimen is required to detect such a fresh fingerprint on the bottom of the specimen. Recent fingerprints (one to three days in age) are usually detectable in ESDA regardless of location on the specimen (top or bottom). Old fingerprints (more than three days in age) typically do not create a strong image in ESDA. Additional experimental work is needed to document the effects of recent and old fingerprints. The effects of fresh fingerprints were documented in the previous work (1).

In regards to the theoretical data of this article, the temporal decay of the potential is very accurate, while the charging curve is more speculative. The charging process is extremely variable because of variations in both atmospheric conditions and charging techniques. However, both curves do effectively display the correct dependencies upon the duration of charging, duration of decay, and water content of the specimen. These dependencies are discussed as follows.

Examination of Fig. 3 reveals that an observable contrast requires an adequate charge. Based upon this particular time axis, the time to achieve an adequate charge can be on the order of minutes. After such time, additional charging does not significantly increase the magnitude of the voltage difference. Thus, it is possible to under-charge the ESDA, but it is not possible to over-charge it. Due to the vagaries of modeling of the charging process, it is difficult to establish a minimum duration for charging. Some sort of process control is warranted here. An initial potential of 1800 volts should be sufficient, but the duration of charging required for this potential is dependent upon many variables such as: atmospheric humidity, elevation of the corona wire, and diameter of the corona wire. A voltage monitor applied to Mylar sheet would be an excellent device for process control during the charging procedure.

Examination of Fig. 4 reveals the development of the image after the charging has ceased. The magnitude of the potential difference increases steadily over time. The time domain of this curve accurately resembles the experimental data of the previous article (1). Therefore, implementing a 30 min decay prior to application of the toner should enhance the ESDA image contrast. The specimen permittivity employed for this figure accurately resembles that of a humidified specimen. According to this model, additional discharge beyond 30 min does not produce significant benefits for a properly humidified specimen.

Examination of Fig. 5 reveals a similar dependence to that of Fig. 4, but the voltage difference evolves more slowly. This reduced rate of development is due to the reduced permittivity of specimen which is proportional to the water content of the specimen.

Comparison of Figs. 4 and 5 reveals a striking dependency upon water content of the specimen. A reduction by one-half in the permittivity of the specimen results in a reduction of approximately one-fourth in the voltage difference after 30 min of decay. Additional reduction in the moisture content of the specimen can render the image unrecoverable by ESDA. Such an event is common in an extremely dry climate. Therefore, humidification of the specimen is essential in a dry climate. Furthermore, moisture is essential only within the specimen, and not within the local atmosphere. Thus, the operator does not have to function within a tropical climate.

Preservation of specimen moisture is another issue to consider when employing a lengthy duration for either charging or discharging. The vacuum beneath the platen of the ESDA expedites drying of the specimen. To preserve the water content of a humidified specimen, the vacuum should be terminated after a brief 10-second charge of the system. After such a brief charge, the electrostatic force should be sufficient to hold the Mylar in place. A subsequent completion of the charging process will yield the benefits of a lengthy charge without the detrimental effects of removing moisture from the specimen.

Based upon presently available empirical and theoretical knowledge, the author recommends the following steps for ESDA processing: One, place the specimen in a humidification tray for 2 to 3 min (this tray is provided by Foster and Freeman). Two, place the humidified specimen on the platen of the ESDA machine. If it is a thin specimen, such as newspaper, then place a sheet of ordinary writing paper (circa 100 μm in thickness) beneath the thin specimen. This sheet of ordinary writing paper must also be humidified. Three, turn on the vacuum. Four, apply the Mylar sheet. Five, charge for 10 seconds. Six, shut off the vacuum. Seven, apply charge for two additional minutes. Eight, allow 30 min for decay of the surface charge. And nine, apply the charged toner. Based upon the present knowledge of the author, this should insure adequate sensitivity in the ESDA process.

A voltage monitor of some sort would be an effective process control for ESDA. An operator would simply charge until a specified voltage is achieved, and then, after a sufficient decay is observed through the voltage monitor, the operator would apply the toner. Implementing such a monitor would insure adequate sensitivity of the ESDA process. At the present time, this author knows of only one option for a such a voltage monitor: it is called an electrostatic high-voltage probe. Two manufactures of this device are: Monroe Electronics Incorporated of Lyndonville, NY; and Trek Incorporated of Medina, NY. These devices are rather expensive, and consequently, IISI Corporation is exploring the development of a more economical device which is designed specifically for the ESDA system.

Conclusion

A model for the ESDA process has been reviewed. Practical implications of the model include the effects of specimen humidification, duration of charging, and duration of discharging. Methods of enhancing the sensitivity of ESDA have been presented. Adequate charging as well as adequate discharge are both essential for maximizing sensitivity. Specimen humidification is confirmed as an essential part of the process when operating in dry climate. The ESDA detectable effect of indented writing has been identified as a surface charge created by paper-to-paper friction. The magnitude of this effect is dependent upon the elevation of the surface charge above the platen in ESDA.

Acknowledgments

The author would like to acknowledge the contributions of numerous people. A vast amount of knowledge regarding ESDA phenomena was provided by: Benjamin M. Locke, David E. Willoughby, George Antonopoulos, Gershon M. Goldberg, Michael S. Poirier, Todd N. Tsakiris, Edmund L. Bouché, and Peter F. Mueller. Their past observations of ESDA phenomena provided the foundation for the development of the ESDA model presented herein.

Also, the author would like to acknowledge the people who designed the electrostatic imaging system of the previous article (1): Benjamin M. Locke, Robert P. Jurgilewicz, Nelson D. Tarr, and Gerard J. Murphy. This system provided quantitative voltage data which was essential for the development of the author's model for the ESDA phenomena.

Any finally, the author would like to express special thanks to Antonio A. Cantú of both the United States Secret Service and the Journal of Forensic Sciences. His invitation for writing this article and his commentary regarding appropriate content for the intended audience were essential for the creation and development of this article.

References

1. Seward GH. Model for electrostatic imaging of forensic evidence via discharge through Mylar-paper path. J Appl Phys 1998;83(3):1450–6.
2. Foster DJ, Morantz DJ. An electrostatic imaging technique for the detection of indented impressions in documents. Forensic Sci Int 1979;13:51–4.
3. Foster & Freeman Ltd. ESDA Operating Instructions. Grays Essex, UK: Fostter & Freeman Ltd. (Any year of publication).
4. Ellen DM, Foster DJ, Morantz DJ. The use of electrostatic imaging in the detection of indented impressions. Forensic Sci Int 1980;15:53–60.
5. Noblett MG, James EL. Optimum conditions for examination of documents using an Electrostatic Detection Apparatus (ESDA) to visualize indented writings. J Forensic Sci 1983;28(3):697–712.
6. Baier PE. Application of experimental variables to the use of the Electrostatic Detection Apparatus. J Forensic Sci 1983;28(4):901–10.
7. Horan GJ, Horan JJ. How long after writing can an ESDA image be developed? Forensic Sci Int 1988;39:119–25.

Additional information and reprint requests:
George H. Seward
Associate Corporate Scientist
IISI Corporation
19 Sterling Road
North Billerica, Massachusetts 01862
e-mail: GHSeward@aol.com