Surface Topography Contribution to RFID Tag Efficiency Related To Conductivity

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ABSTRACT

A Radio Frequency Identification Device (RFID) is a new technology oriented to the distribution and storage industries. RFID technology is used to identify, track and store information about groups of products, individual items, or products components using radio waves. An RFID device needs an antenna in order to receive a signal and transmit information. The conductivity of the ink directly controls the read range of the RFID tag. The stamping process applied today to produce the RFID antenna works with foil or copper. These etched metal RFID tags offer good read ranges, but the present cost is too high to achieve widespread implementation. However, with the use of conductive ink to print RFID tags, it is expected that production costs will be lower, enabling the broader scale application of this technology. To obtain a suitable implementation of conductive inks in RFID technology, it is important to understand the ink/substrate interactions. For this work, the influence of SBS coated board topography on ink conductivity was studied. The surface topography was altered by using two different coating application methods to apply a coating at different coat weights, then calendering the coated samples at different calendering pressures. A conductive ink was then applied and the resistivity of the ink measured. The results showed the resistivity to be strongly influenced by surface topography.

INTRODUCTION

A radio frequency identification device (RFID) is a technology that can be used to identify, track, and store information about groups of products, individual items, or product components, using radio waves. An RFID consists of three important parts: a tag, reader (antenna) and transceiver with decoder [1]. The reader emits a radio signal that activates the tag and reads and writes data to it. The information encoded on the tag can be read and received by the reader, which is attached to a data collection system, consisting of computers running data processing software, which typically are networked with a larger information management system.

The final cost of acquiring, installing, and maintaining an RFID system will be what determines it's acceptance in the commercial sector. The cost of an RFID system is composed of tags, readers, and processing and supporting information technology hardware and software [2]. Current tag costs range from 25 to 40 cents per tag (higher in some cases, depending upon the type of tag) [3], making it expensive for low-end consumer items. The MIT Auto-ID lab expected tag prices to drop by 15 cents in 2006 for orders of 1 million units [4]. RFID reader costs are also relatively high, due to limited uptake of systems. The Auto-ID Lab also predicted reader costs to come down from about $100 in 2005 to about $70 in 2006 [5]. Finally, RFID transceiver costs include computer hardware, software, data processing, data mining, personnel salaries, and personal training. A product company that ships 50 million cases per year could spend $20 million for RFID implementation, which is extremely costly for some companies [6].

The majority of RFID tags sold to date are based on copper-etched printed circuits boards containing a silicon chip connected to the copper tracks that form the antenna [7]. This conventional electronic assembly method has limitations in terms of speed of production. Current fabrication techniques are moving toward printed antennas using silver or carbon based conductive ink [8]. Antennas are currently being printed onto PE and PET films to which chips are inserted to complete the device. The films are then joined to a paper substrate to form a RFID label that can be adhered to a package, box or pallet. PE and PET substrates offer an ideal printing surface for this application due to their non-conductive, high smoothness, low permeability, and high dimensional stability to moisture. However, increased film costs, the need for a paperbacking with the current tags to carry the film and desire for green and sustainable technologies by large retailers have increased the interest of printing and packaging companies in directly printing complete RFID tags.

The direct printing of tags with conductive inks and other conductive materials would lower the per item production costs of a tag enabling the larger scale implementation of this technology. The printing can take place reel to reel on a rotary screen, lithography, gravure or flexography press at speeds of up to 2,000 ft/min [9]. Screen-printing has the advantage of being able to lay down a thick ink film for better performance, but potentially creating issues with cure time. Flexographic and gravure printing is capable of running at higher speeds than the screen-printing process [10]. Regardless of the printing process used, if RFID tags are going to be directly printed on cellulose based substrates, the influence of the substrate on their performance needs to be better understood. Hence, a better understanding of the influence of basesheet properties on conductive ink resistivity is needed.

The main objective of this investigation was to study the influence of roughness and topography on conductive ink resistivity. These properties were altered by applying a coating at different coat weights to an SBS board, using two different coating application methods, and then calendering at different pressures. Like any wired circuit, there must be sufficient continuity in the conductive path for the circuit to work. Unlike PE and PET films, cellulose based substrates can be rough which may not allow the conductive ink particles to touch and thus not provide a good substrate for conductive continuity without increasing the ink film thickeness to a point where cost benefits are lost. Good printability of conductive inks on any substrate is all about how well the printing method, substrate surface, and inks yield a conductive circuit.

MATERIALS & METHODS

A commercial coating formulation was applied to the SBS board, using the coating pilot facilities at Western Michigan University. The coatings were applied using a roll applicator and metered using both an air knife and blade coater. Preliminary trials were run to establish the blade run-ins and air knife pressures that would be required to obtain similar coat weights without adjusting the coating formulation. Once the conditions were established, the coatings were applied at 400 ft/min and hot air-dried. The coatings applied were prepared according to the formulation given in **Table 1**.

Table 1. Coating formulation

Ingredients	Parts
Engelhard, Ultrawhite 90	50
Omya, Hydrocarb 90	50
Dow, PB6620	16
Alco Gum 265	0.05
Ciba, Dispex	0.25

Three different coat weights were applied for each method; high, medium and low. After being coated the samples were calendered at two different calendering pressures, **Table 2**.

The topography and roughness of the coated boards were measured using a Verity measurement system and Emveco profilometer. Recent work has shown a good correlation between the Verity and Emveco instruments [11]. Surface topography is known to impact ink transfer, hence print quality. Surface roughness is usually divided into microscale and macroscale components. By using the Emveco and Verity profilometer, different scales of microroughness in both the MD and CD directions could be measured. Research groups studying roughness and its effect on surface properties like gloss have agreed upon the fact that common roughness numbers are insufficient to predict the properties accurately. For printing conductive inks, a better understanding of the correlation between surface topography and required ink film thickness and conductivity is needed.

The Verity-Topo is a non-contact measurement system. It consists of a scanner and topography software system used to numerically rank surface roughness [12]. The Verity IA topography measurement software produces a numerical ranking proportional to the relative severity of the surface roughness. A perfectly smooth surface yields a zero (0) and as the surface roughness increases it also increases in value. The maximum value, which in practice in never reached, is theoretically greater than 2^{24} ($\sim 16 \times 10^{6}$). With proper adjustment of the instrument, a practical high is 200 for a very rough surface.

The area scanned for each sample was 10 cm * 10 cm, using a resolution of 600 ppi, the image was analyzed, presenting a number that represents the roughness of the entire surface. The board samples were scanned in the same area before and after coating, calendering and ink application in both the machine (MD) and cross (CD) directions.

A solvent based flexographic silver ink, provided by Acheson Colloids Company, Port Huron, MI, was applied to the uncoated and coated board using a 0.5 mil Byrd applicator. The viscosity of the silver flake ink used was 3000 cps as measured with a Brookfield RVT viscometer, No 5 spindle, at 100 rpm at and 25^{O}C.

Table 2. Treatment conditions

Air Knife		Blade	
Coat Weight (g/m^2)	**Calendering (pli)**	**Coat Weight (g/m^2)**	**Calendering (pli)**
10.86	Uncal, 600 and 1200	9.61	Uncal, 600 and 1200
14.42	Uncal, 600 and 1200	13.87	Uncal, 600 and 1200
23.92	Uncal, 600 and 1200	22.54	Uncal, 600 and 1200

The thickness of the ink film was measured using an Emveco Profilometer by measuring the unprinted and printed areas. A total of 700 measurements were recorded, 200 for the unprinted and 500 for the printed boards [12, 13]. The data from the Emveco profilometer were plotted. From this graph, two distinct regions were identified. The first region represented the height of the unprinted area and the second region represented the height of the printed area. Subtracting the two enabled the ink film thickness to be obtained.

The silver conductive ink was applied to the coated boards using a 0.5 mil Byrd ink applicator. After drying, ink resistivity was measured. Resistivity was measured using a digital multimeter, by applying a voltage of 0.1 V to -0.1 V to a sample of 5 cm x 0.25 cm in length and width. The film thickness for each sample was measured and found to vary between 5 to 6.5 µm. Ink resistivity was calculated using the following equation:

$$\sigma = L / (R * A)$$

where L= Length of gap, A= (film thickness * sample width) and R=potential difference/electric current. The ink film thickness values obtained from the Emveco profilometer were used in this calculation.

RESULTS AND DISCUSSION

The roughness and topography of the uncoated and coated boards before and after calendering are shown in **Tables 3** and **Figure 1**. Properties were measured in the MD direction.

Table 3. Uncoated board properties

Uncoated SBS Board Properties		
Thickness (m)		3.56×10^{-4}
Emveco Roughness (micron)	Avg.	4.89
	StDev	0.28
Verity Number	Avg.	3.49
	StDev	0.21

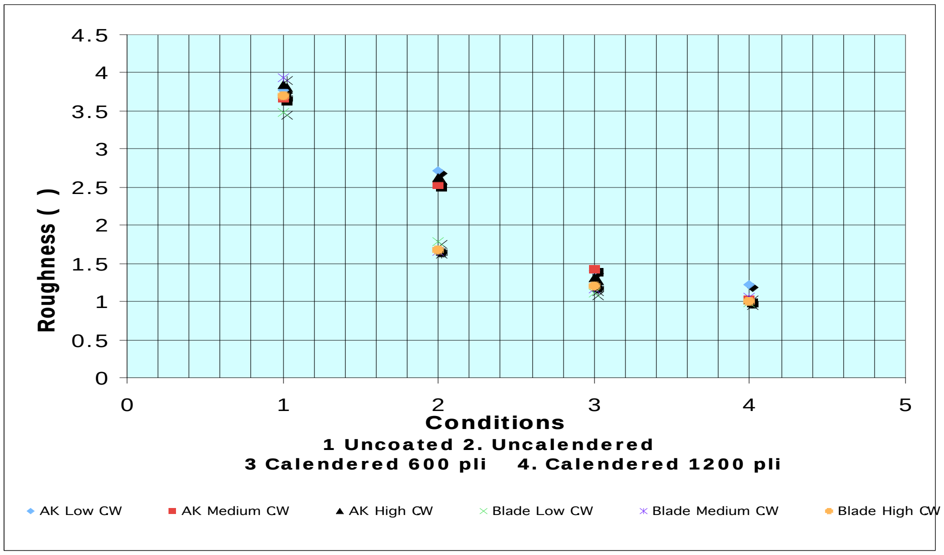

Figure 1. Influence of coating method and calendering on Emveco roughness.

The two different coating methods and calendering of the boards enabled surfaces of varying roughnesses to be obtained for the resistivity studies. As expected, the roughnesses of the air knife coated samples were higher than the blade coated boards. Calendering not only reduced the roughness, but also reduced the surface variability as evident by the reduction in standard deviations. The Verity topography values of the coated boards are compared in **Figure 2 and 3**, for MD and CD.

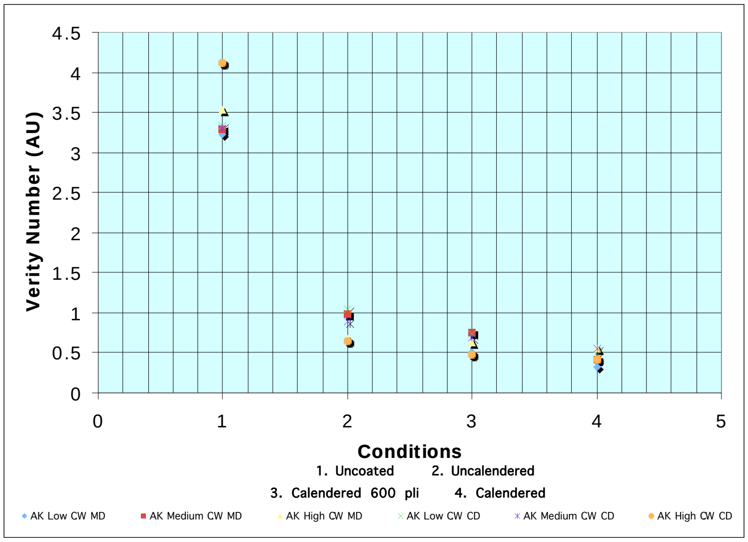

Figure 2. Influence of coating method and calendering on Verity topography (Air knife MD and CD).

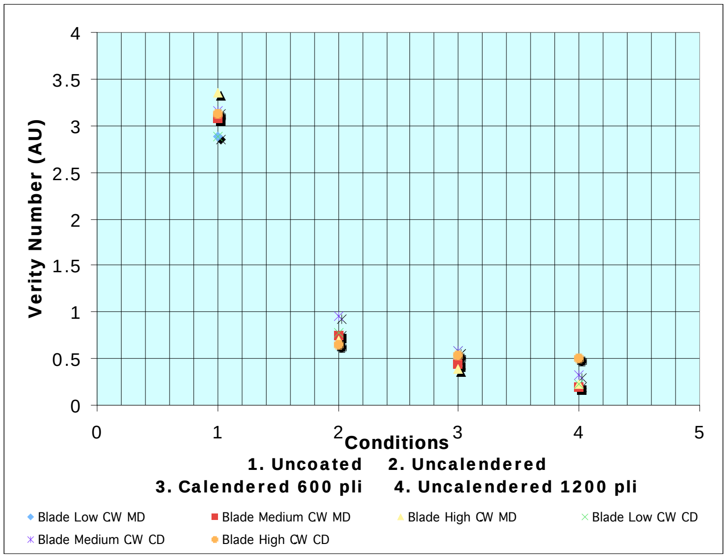

Figure 3. Influence of coating methods and calendering on Verity topography (Blade MD and CD).

The Verity values show a similar trend for both the machine direction and cross direction measurements. The topography values for the air knife coated samples were higher than the blade coated samples at all coat weights, due to it being a contour coater. The effect of surface topography on resistivity is shown in the **Figures 4, 5 and 6**. The surface topographies of these samples were altered by calendering the samples at different pressures. The higher the resistivity, the lower the conductivity, hence a low resistivity is desirable for RFID tags. As shown in the figures, resistivity decreased with decreasing Verity topography value, increased calendering pressure, and increased coat weight and the Verity value decreased with calendering. The lowest resistivity was obtained by printing the smoothest 1200 pli-blade coated board. The resistivities of the blade coated samples were all below that of the air knife coated samples.

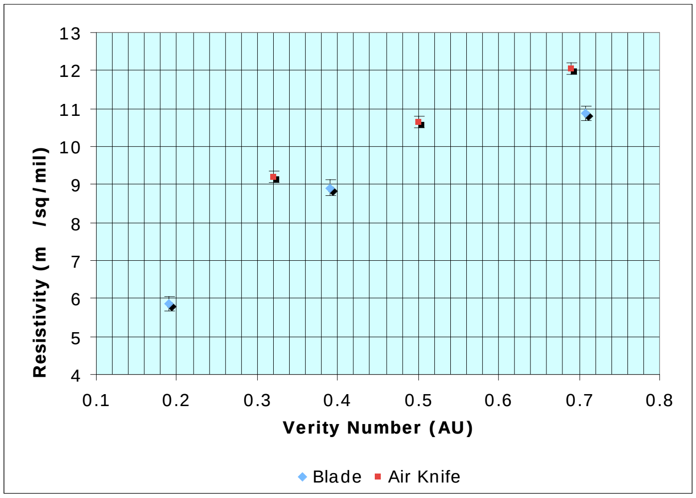

Figure 4. Influence of surface topography on resistivity (calendered and uncalendered high coat weighted samples).

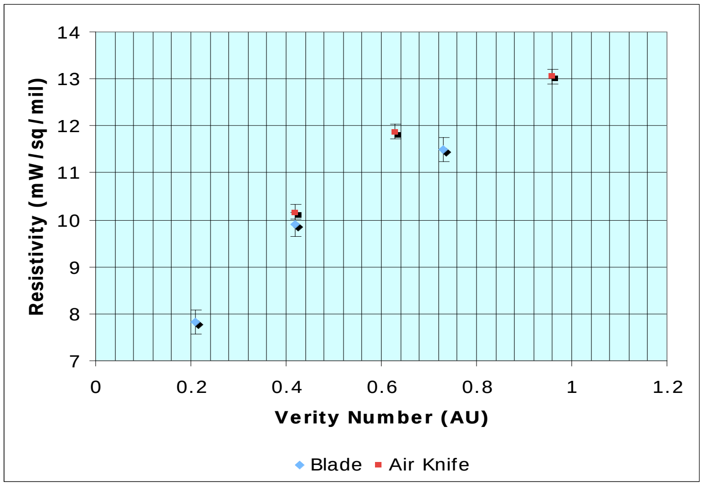

Figure 5. Influence of surface topography on resistivity (calendered and uncalendered /medium coat weight).

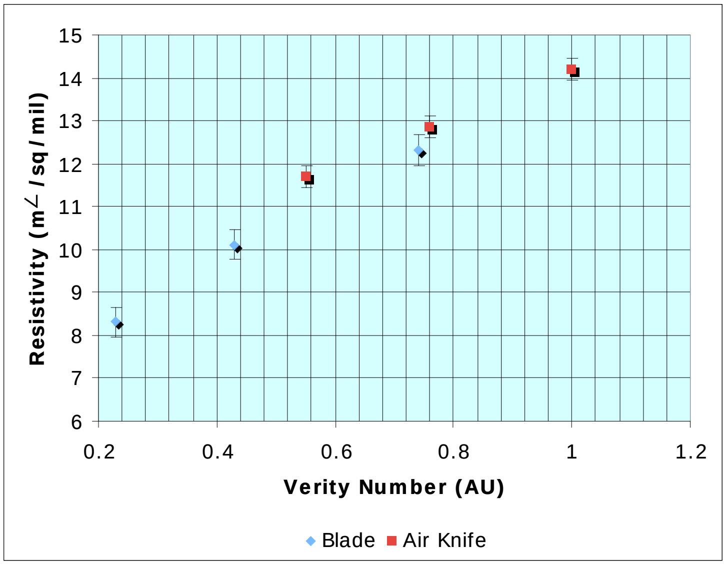

Figure 6. Influence of surface topography on resistivity (calendered and uncalendered/low coat weight).

The effects of coat weight, coating application and calendering on CD and MD resistivity are shown in **Figures 7 and 8.** As coat weight increased the resistivity values decreased. The samples calendered at 1200 pli had lower resistivity values than those calendered at 600 pli.

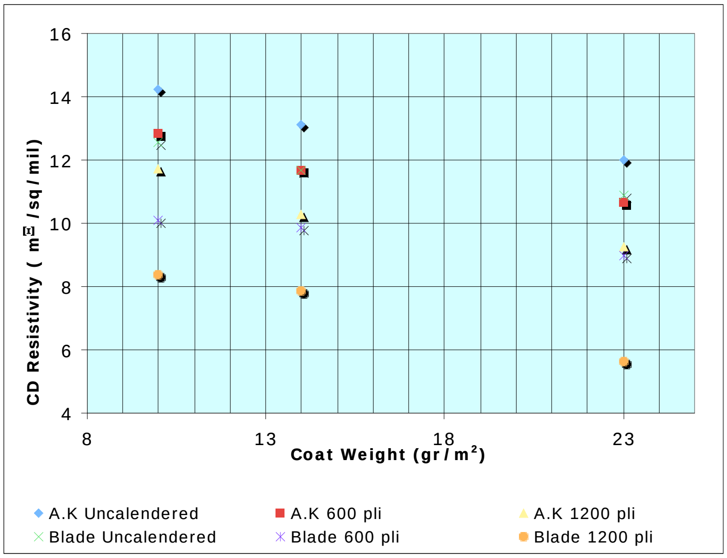

Figure 7. Influence of calendering and coat weight on CD resistivity.

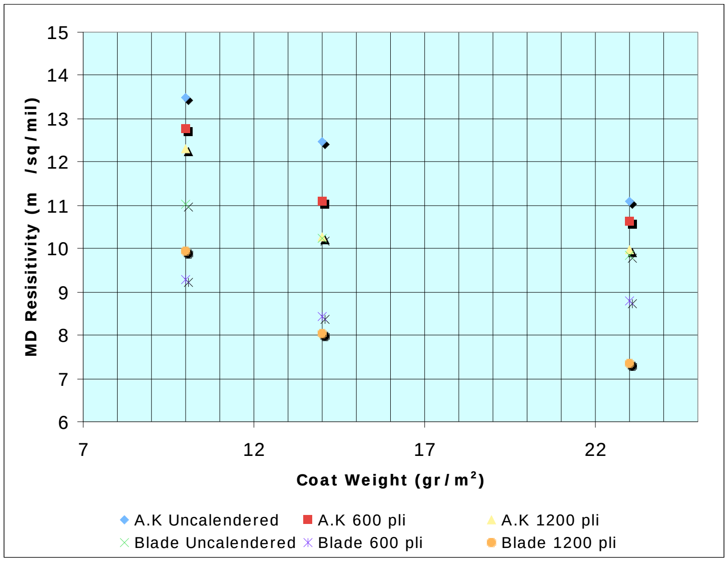

Figure 8. Influence of calendering and coat weight on MD resistivity.

CONCLUSIONS

In this project, SBS board was coated using two different coating devices, three coat weights, and three calendering pressures. A conductive ink was applied to the uncoated and coated samples using a 0.5 mil Byrd applicator. The printed samples were evaluated to obtain the correlation between the coating method, coat weight, calendering and ink resistivity.

It was observed that a decrease in roughness caused a decrease in resistivity. The samples calendered with high pressure, showed lower resistivity. The resistivities of the air knife coated boards were higher than the blade coated boards due to differences in coating topography.

An increase in coat weight caused a decrease in resistivity due to the relation between coat weight and roughness. In this case at higher coat weight the substrate roughness decreased.

Paper as a substrate in the printed electronic industry plays an important role; the characteristics of it can increase or decrease the quality of the final product. To obtain a suitable implementation of paper as a substrate it is necessary to understand each of the variables that affect the conductivity of the ink. This research can provide interesting conclusions to lead future projects to produce substrates with special characteristics for the electronic industry.

ACKNOWLEDGEMENTS

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