Using Screen Printing to Print the RFID Tag by Different Drying Temperatures

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Abstract

Printing is one of the best solutions to mass manufacture the RFID tags of reducing the unit cost. It is a great challenge and opportunity for printing industry to have a feasible operation of workflow in four printing methods. The screen printing is the low entry-barrier printing method and it also enjoys the highest ink thickness of four printing methods which it is a major concern of the performance of the RFID tags.

By using what we have learned from previous experience, we used the screen printing to produce the RFID tags with different drying temperatures with the conductive ink. We did test and examine the density, resistance, and reading/writing distance of the RFID tags to see the overall performance. We used high drying temperatures to enhance the productivity of the RFID tags. Basically, low drying temperature does have long range of reading/writing distance but with a longer drying time. We should not focus on the manufacturing but also focus on the balance between temperature and time efficiently and effectively.

Introduction

It is very surprised that the so called old technology, RFID (Radio Frequency Identification), has been developed many new applications tremendously. Wal-Mart made an announcement in 2003, asking his top 100 suppliers to use RFID to facilitate the internal control since RFID tag may replace the bar-code because of its advantages. This action made those suppliers really pay attention on RFID because they cannot ignore the buying power of Wal-Mart. Not only those suppliers but also other competitors need to think thoroughly about the strategies and how to face this new changes, challenges, and opportunities. We definitely can smell this unstop trend that lots of money, people, and time will go into this business.

Since the RFID technology has been widely applied to many applications already. For such logistics and retail industry like Wal-Mart, they would think the key point is how to adopt the low cost RFID tags properly, effectively, and efficiently. Every item for sale in the store is unique and should have "one" RFID tag. Therefore every item needs a unique RFID tag to attach on it. Can you imagine that how many RFID tags will be enough to fulfill the need for Wal-Mart? How big this business could be if RFID tags have been widely used by Wal-Mart? If other competitors follow the step of Wal-Mart, the quantity of RFID tags' usage will be very hard to calculate. This definitely shows that the unit cost of the RFID tag itself becomes so critical in this business.

Actually, all of us are looking and searching for a solution to produce the low cost RFID tags. For the economical and mass manufacturing point of view, printing is playing the key role in logistic and retail industry for RFID tags. It is believed that the printing is one of the best solutions to provide the low unit cost RFID tags than any other ways, such as etching or galvanic processes [1]. Screen printing is much easier for us to build the mass manufacturing procedures to produce RFID tags.

Statement of the Purpose and Research Questions

By knowing the background and bright future of the RFID, we do realize that we can take action to do this study in reality. As one of the printers, we do have several purposes by doing this true experimental research:

1. To investigate the performance of the RFID tags by using the screen printing.
2. To understand the performance of the RFID tags by using different drying temperatures.
3. To know the differences about the SID (Solid Ink Density), resistance, and the writing and reading distance among different tags of drying temperatures.

Statement of Need

General public normally get used and spoiled to use new technologies and applications without paying to much attention. This RFID technology has dramatically entered our daily life silently for years. Sensitive people may notice the convenience that the RFID has been brought to them. We absolutely believe that the needs of the RFID will increase rapidly and eagerly. The related RFID applications can be widely used and adopted or not, the unit cost of the RFID tag is playing the most significant role, especially for disposable RFID tags. Unfortunately, by using the current manufacturing methods, the unit cost of RFID tags can not be dropped efficiently. We do care about this issue of trend and we can conclude the needs of this research:

1. It is a great opportunity for us to open a window for printing industry to synergy and integrate with other industries.
2. There is a great need for us to train and educate professional printers and students to do the research and development.
3. It is a great challenge and need to experience and study the ways of printing the RFID tags' antenna by establishing the manufacturing procedures of using screen printing.
4. It is also an excellent opportunity to promote the research into practical manufacturing for printing industry.

Limitations and Assumptions

There are some limitations and assumptions needed to be considered in order to conduct this research and interpret the results smoothly and appropriately. They are:

1. The thickness of every printed antenna will be the same.
2. Every strap-IC is stable and precisely attached onto the antenna and does not affect the performance of the RFID tags.
3. The oven is stable to meet the desired drying temperatures.
4. The plate-making and printing processes were stable and consistent by the researchers.
5. All the printing facilities and measuring equipments are consistent in this study. They will not affect the results.

6. The distance we measured in the anechoic chamber will be the best results basically. The performance of the RFID tags may not as good as in the lab in the reality.

Literature Review

RFID is an old technology that was used since the World War II. We better not underestimate its influence and its value. For mass usages of RFID technology, control the unit cost down to a reasonable price (maybe 3 to 5 cents) does occupy extreme important role in producing the RFID tags. Without the low cost tags, the logistic and retail industry can not expand and spread its power to provide the quality service and to increase quality life to the general public. Therefore, we need to analyze the cost of the RFID tags thoroughly. In the cost analysis, the antenna takes 40%, IC takes 30%, and packaging takes 40% of total cost of one tag [2]. Apparently, there is only 30% of the cost in manufacturing tags that printers can involve with. We could think smartly enough to combine part of the packaging into our processes. This might increase the role we are playing in the whole productions. More importantly, we can print the paper battery onto the RFID tags [3]. The added value will be tremendous and uncountable. Although the antenna design is not our profession, we can ask professional experts to deal with it.

There are several classifications we can think of RFID. As the working frequency of the RFID tags are: Low Frequency with 125-134 KHz, High Frequency with 13.56 MHz, and Ultra High Frequency with 860-930MHz, and Microwave with 2.45GHz and 5.8GHz. What kind of tags should use depends on the applications. As the power of the RFID tags are: active RFID tag, passive RFID tag, and semi-passive RFID tag. For the logistic and retail industry, the passive tag is the most suitable one that can fulfill the need for disposable and low unit cost tags.

In the report of ARC Advisory Group in 2004, there are 24 companies who invested on the manufacturing the RFID tag, their benefit was even worse than the retail industry who were their customers. These unstable and immature tags made bottleneck of RFID applications [4]. This also makes us need to study the technology more complete and in detail in order to survive well in the crucial reality.

In the printing technology, there are four major printing methods have been widely applied already. Every method does have its own advantages and disadvantages. Since the ink thickness (by using the same ink) plays the critical issue for the performance of the RFID tags, we should pay attention on this issue seriously. The ink thickness of four printing methods is: Lithography: 1-2 μm, Flexography: 6-8 μm, Gravure: 8-12 μm, and Screen Printing: 20-100μm [5].

In our study, we chose to use the screen printing method to produce the RFID tags for several reasons: (1) high ink thickness; (2) low cost of the conductive sliver ink (comparatively); (3) low entry barrier; (4) one layer could get enough thickness; and (5) easier to control the operations and processes.

Methodology and Research Design

Actually, we are very familiar with these kinds of researches since we do have certain experience of similar researches and pilot studies already. We need to print a 5-mm square test target next to the antenna for the convenience of measuring in order not to damage the printed antenna itself.

There were total 200 RFID tags were printed by using the screen printing. We categorized them into 4 groups of different drying temperatures, therefore there are50 tags in each group. Tags in the Group A were using room temperature to dry them. Tags in the Group B, C, and D were completely dried first. After this waiting time, tags in the Group B will put into the oven with 50°C, Group C with 70°C, and Group D with 90°C. There were total printed 150 tags (from Group B, C, and D) were put into the oven for 30 minutes for its totally drying. After heating these tags up, we also needed to wait until the tags were completely cool down. The all 200 printed tags were measured of the solid ink density, resistance, and reading/writing distance.

Research Equipment and Materials

The major equipments and material were used in this experimental research listed below:

1. Reader: AWID PI-2000, for measuring the distance of the tag.
2. Scanner: Creo iQsmart 3 for scanning the antenna of the tag.
3. Spectrometer: X-Rite 528, for measuring the SID of the tag.
4. Printing press: Sheng-Tai’s semi-auto screen printing press for printing the antenna.
5. Passive RFID tag: Alien Technology UHF-915MHz Gen II ALN-9540 Squiggle tag with size of 95 mm x 8.15 mm (see Figure 1).
6. Conductive Ink: Flint Ink’s Precisia’s CSS-010A.
7. Screen ruling: 300 threads of 90 degree with squeegee speed of 800 per hour.
8. Blade hardness/angel: 70 degree of hardness and 75 degree of the angle.
9. Substrates: coated and uncoated paper of 100 lbs. from YFY.
10. Strap IC: Alien H2 UHF RFID IC, this based on the Alien Gen2 EPCGlobal Certificated IC.

Figure 1. *The Alien Technology’s ALN-9540 Squiggle tag*

Experiment Setting and Data Collection Procedure

The research procedures for the screen printing were:

1. Scan the Alien Technology’s Gen II ALN-9540 tag by using the scanner with line-art of 600 dpi.
2. Using Photoshop to do the image retouching to make a certain correction and modification.
3. Arrange the antennas’ pagination in the QuarkXpress.
4. Output the file to CTF.
5. Do the plate making onto the metal frame.
6. Ink preparation and print the total 200 RFID tags.
7. Let the printed RFID tags dried completely.
8. Put the RFID tags of Group B, C, and D into the oven with different temperature settings and cool them down later.
9. Measure the RFID tags of SID and resistance of all Groups.
10. Attach the strap-IC onto the correspondent position of the RFID tag (see Figure 2).
11. Measure the RFID tags of the reading/writing distance for all Groups in the anechoic chamber.

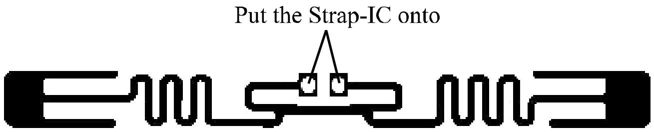

Figure 2. *The Position to put the Strap-IC onto the tag*

Results, Findings, and Discussion

According to the purposes and the research questions, we do discuss the SID, resistance, and the writing/reading distance of the RFID tags. This could help us to evaluate whether the performance of the printed RFID tag is acceptable or not. We printed the antenna onto the 100 pounds of coated and uncoated papers. We will discuss the result as followed:

Descriptive Statistics

Table 1 shows the results of the SID with coated and uncoated paper; the means for Group A is .1751 and .1246, Group B is .1773 and .1229, Group C is .1720 and .1293, and Group D is .1716 and .1242 respectively; the values of SD are from .0036 to .0061 and from .0054 to .0088. You can easily tell from the coated paper when we increase the temperature for drying the tags, the mean score is decreased. But the uncoated paper is not that obvious. Practically, the SID for coated paper is higher than uncoated paper for about 40% generally.

The resistance on the coated paper: Group A is 2.04 Ω, Group B is 1.58 Ω, Group C is .99 Ω, and Group D is .77 Ω; and for uncoated paper: Group A is 3.92 Ω, Group B is 2.03 Ω, Group C is 1.17 Ω, and Group D is .93 Ω from Table 2. The SD for coated paper is lower than uncoated paper. We realized that the resistance becomes lower when increasing the drying temperature for coated and uncoated papers. The resistance of coated paper is generally lower than he uncoated paper.

We care most on the performance of the writing and reading distance of the RFID tags. Table 3 shows the distance on the coated paper: Group A is 570 cm, Group B is 267 cm, Group C is 87 cm, and Group D is 65 cm; and on the uncoated paper: Group A is 467 cm, Group B is 211 cm, Group C is 112 cm, and Group D is 91 cm. The distance for coated paper is longer than uncoated paper in Group A and B only. Coated paper does have lower SD than uncoated paper except Group B.

The SID and the resistance play the reference roles in this study that has been challenge. It is very surprised that after so much trouble of settings and long processes, it came out with the opposite results. This shows that after increasing the drying temperature of the RFID tags the characteristics of the antenna has been changed. Lower resistance does reflect shorter distance in the study. This gives us an idea for increasing the productivity, the drying temperature needs to be considered carefully in order to maintain the stable and consistent quality of printed RFID tags.

It is also surprised that the outstanding performance of Group A for its long writing/reading distance since it is very close to the Alien Technology's ALN-9540 tag. It is very obvious that as increasing the drying temperature, the distance is getting shorter. It seems that the high temperature does not help to increase the reading and writing distance at all. For a better performance of the RFID tag, we should keep the tags dried naturally with the room temperature. This strategy is not appropriate for mass manufacturing since the drying time will be increased for a longer processing time. From this result, the higher the temperature is and the shorter the distance of the RFID tag is.

We need to emphasis strongly that the performance of the RFID tag is the major consideration in the mass manufacturing. The drying time better be short because the heater may occupy too much space. As the fact that the higher the temperature and the shorter the drying time. In order to increase the productivity of printed tags, it is necessary to use high temperature to dry the tags to save the drying time. But this may sacrifice the writing and reading distance. Therefore we might either reduce the drying time or decrees the drying temperature in the real production. The trade off between the drying temperatures and drying time must consider thoroughly of figuring a way to balance it.

Table 1: The SID of the Tags with Different Paper

	Min	Max	Mean	S.D.
Coated-Group A	.1603	.1891	.1751	.0061
Coated-Group B	.1518	.1902	.1773	.0066
Coated-Group C	.1629	.1792	.1720	.0036
Coated-Group D	.1640	.1786	.1716	.0039
Uncoated-Group A	.1136	.1359	.1246	.0058
Uncoated-Group B	.1035	.1389	.1229	.0088
Uncoated-Group C	.1174	.1395	.1293	.0054
Uncoated-Group D	.1078	.1372	.1242	.0077

Table 2: The Resistance (Ohm) of the tags with Different Paper

	Min	Max	Mean	S.D.
Coated-Group A	1.70	2.50	2.04	.21
Coated-Group B	1.70	2.70	1.58	.30
Coated-Group C	.80	1.40	.99	.15
Coated-Group D	.60	1.00	.77	.11
Uncoated-Group A	3.10	5.10	3.92	.51
Uncoated-Group B	1.50	3.50	2.03	.42
Uncoated-Group C	.90	1.80	1.17	.20
Uncoated-Group D	.70	1.30	.93	.17

Table 3: The Distance (cm) of the tags with Different Paper

	Min	Max	Mean	S.D.
Coated-Group A	362	590	569.7	52.9
Coated-Group B	100	540	266.8	133.9
Coated-Group C	55	140	87.0	20.6
Coated-Group D	43	102	65.0	14.8
Uncoated-Group A	180	590	467.2	111.8
Uncoated-Group B	80	550	210.5	117.1
Uncoated-Group C	80	350	111.5	43.5
Uncoated-Group D	60	280	90.7	35.0

Hypothesis Tests

We used the one-way ANOVA to test the difference of the SID, resistance, and the reading/writing distance among Groups for the Hypothesis 1, 2, and 3 of the coated and uncoated papers.

H1$_0$: $\mu_{\text{Group A-SID}} = \mu_{\text{Group B-SID}} = \mu_{\text{Group C-SID}} = \mu_{\text{Group D-SID}}$

H1$_1$: $\mu_{\text{Group A-SID}} \neq \mu_{\text{Group B-SID}} \neq \mu_{\text{Group C-SID}} \neq \mu_{\text{Group D-SID}}$

H2$_0$: $\mu_{\text{Group A-Ohm}} = \mu_{\text{Group B-Ohm}} = \mu_{\text{Group C-Ohm}} = \mu_{\text{Group D-Ohm}}$

H2$_1$: $\mu_{\text{Group A-Ohm}} \neq \mu_{\text{Group B-Ohm}} \neq \mu_{\text{Group C-Ohm}} \neq \mu_{\text{Group D-Ohm}}$

$H3_0$: $\mu_{\text{Group A-Dis}} = \mu_{\text{Group B-Dis}} = \mu_{\text{Group C-Dis}} = \mu_{\text{Group D- Dis}}$

$H3_1$: $\mu_{\text{Group A-Dis}} \neq \mu_{\text{Group B-Dis}} \neq \mu_{\text{Group C-Dis}} \neq \mu_{\text{Group D-Dis}}$

The data of the ANOVA tests show on Table 4, 5, and 6. The significance of ***P*** values all are < .05 (α). The $H1_0$, $H2_0$, and $H3_0$ need to be rejected. This concludes that there is at least one group of the mean is significantly different from others. Furthermore, it is necessary to test the difference between each other by doing the LSD test. For the SID: Group A and D, Group A and D, Group B and D are no different from each other of uncoated paper and Group C and D are no different of coated paper. For the resistance: all Groups are different from each other no matter they are the coated or uncoated papers. For the distance: Group C and D are no different between each other of uncoated and coated papers.

Table 4: The Data of Analysis of Variance for the SID

Uncoated	SS	DF	MS	F	P
Between	.0012	3	.0004	7.965	.000
Within	.0097	196	.0000		
Total	.0109	199			
Coated	SS	DF	MS	F	P
Between	.0011	3	.0004	13.158	.000
Within	.0054	196	.0000		
Total	.0065	199			

Table 5: The Data of Analysis of Variance for the Resistance

Uncoated	SS	DF	MS	F	P
Between	277.339	3	92.446	722.322	.000
Within	25.085	196	.128		
Total	302.424	199			
Coated	SS	DF	MS	F	P
Between	49.655	3	16.552	395.651	.000
Within	8.190	196	.041		
Total	57.854	199			

Table 6: The Data of Analysis of Variance for the Distance

Uncoated	SS	DF	MS	F	P
Between	4485153	3	1495050	203.930	.000
Within	1436918	196	7331		
Total	5922071	199			
Coated	SS	DF	MS	F	P
Between	8163805	3	2721268	509.643	.000
Within	1046553	196	5339		
Total	9210358	199			

Conclusions and Recommendations

We can conclude the results of this research as followed:

1. The performance of the printed RFID tags by using screen printing is not bad as we can expect. Using the conductive ink to print the antenna onto different kinds of papers, it does have different performance on the distance of the RFID tags.
2. Different drying temperatures do influence the performance of the RFID tags. The higher temperature of the tag was heated, the shorter distance of the tag was wrote/read even with different kinds of papers. If we do have enough time, the printed RFID tags drying with the room temperature with a longer time, the reading and writing distance is terrific enough near the ALN-9540 tag of Alien Technology.
3. The SID and the resistance do provide certain information to allow us to evaluate the performance of the RFID tags. The results showed that the lower SID and higher resistance do have better performance on the distance of the RFID tags by different drying temperatures which it is a big surprise.
4. From our previous studies, we also realized that the different antenna design for different usages of the RFID tags do have different performance of using different drying temperatures and drying time.

After doing these studies, we believe that we have the obligation to make some recommendations for further studies in the related industries:

1. The different variables can be investigated more, such as different substrates, screen angel, blade hardness, and so on.
2. There is always an urgent need to invent new materials in producing the RFID tags. Material science industry does have a room for helping us in printability and productivity.
3. We could use the test target to measure the resistance and SID as a reference to evaluate the performance of the RFID tags in the production line for saving the cost of waste.
4. Feasible solutions of drying temperature and drying time to the reading and writing distance of RFID tags for specific applications need to be studied further.
5. When designing the antenna, it is better to understand what the dielectric constant of substrate is. This will help printers to increase efficiency and effectiveness as well as to save the try-and-error time since different substrates do have different dielectric constants when manufacturing the RFID tags.

In the end, we highly recommend that the industry can work with academia as a team to develop the workable and economical tags to fit in different applications. More importantly, even there are cheap tags can be used, if there is no killer applications can adopt the RFID tags, all the efforts will be in vain. The usages and the applications of the RFID tags are the key we should focus.

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