Feasibility of Printing RFID Antennas on Corrugated Paperboard

A major limitation of RFID technology has been the implementation cost. It was the intention of the researcher to study whether the new method, "printed-RFID-antenna", could be used to reduce the cost of RFID applications in the corrugated packaging industry. Although the study showed success of conductive antennas on kraft and corrugated, the conductivity achieved was still far from that of the antennas on commercial labels. This leads the researcher believe that, with an additional treatment on corrugated material and the process, this method can be feasible in the real production.

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The demand from the world leaders in retail business - such as Wal-Mart (USA), Tesco (UK), and Metro AG (Germany) - and the U.S. Department of Defense (DoD) has made RFID (Radio Frequency Identification) increasingly popular for product tracking applications. As noted in *Wall Street Journal* (2003), RFID “will be in every product imaginable”, and will replace barcodes and magnetic strips. June, 2003, Allied Business Intelligence (ABI) forecasted that the global RFID market will possibly grow to more than 3.1 billion dollars by 2008 (Pianoforte 2003). This situation has been driving both product manufacturers and packaging suppliers to be ready for RFID implementation. While RFID technology was being developed to satisfy its rapidly growing market, the application cost turned to be a serious problem. At the moment, “many consumer product companies are applying (RFID) tags by hand, but that’s not a viable solution in the long run because it costs too much,” said Mark Roberti, founder and editor of *RFID Journal* (Durkalski and Stephanie 2004). That author believed that the responsibility for RFID tagging application wruld, sooner or later, be shifted to packaging suppliers because of its complication and additional cost. As Mr. Roberti said, “If you’re thinking far out, the company would like to pass the application responsibility onto the packaging company - put it in, save me the cost of the label and save me the trouble.” (Durkalski and Stephanie 2004). Packaging manufacturers should be aware. Once being asked by customers for RFID, an efficient way was to provide it with an affordable cost at a minimal price. At the moment, many technologies have been studied to overcome the cost barriers. One among them was “printed RFID” technology. An innovation in conductive ink allowed RFID tag providers to print RFID antenna on tagging substrates, such as a label, instead of using a conventional, solid-copper antenna which was more expensive and less flexible. January 2004, Dan Lawrence, director of Technology and Commercialization, Precisia, presented that the printed antenna had 93-96% of the radiation efficiency of a copper antenna (depending on the design), while it cost only 24-44% (Figure 1, Lawrence 2004a). He also introduced the concept of RFID integrated with packaging - printing RFID antenna directly on packaging substrates and attaching microchips in-line (Lawrence 2004b). Ideally, RFID integration would significantly reduce the cost of RFID implementation in mass production because it would eliminate the needs for labels and the manual “slapping” (attaching) process. Figure 1 shows an early sample of an RFID printed

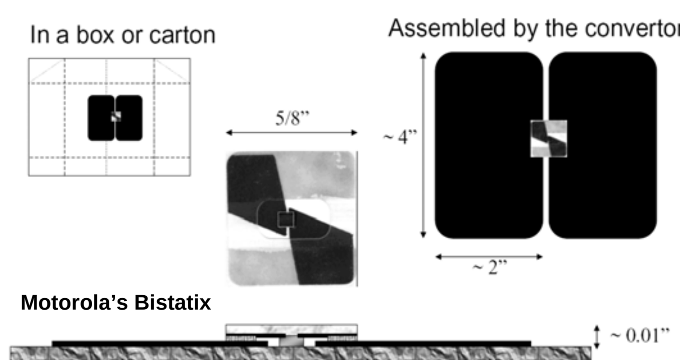

Figure 1. RFID printed antenna on packaging (Lawrence, 2004b)

antenna on packaging presented by Mr. Lawrence.

Although one could believe that the integrated RFID concept was possible, no research of this technology on corrugated substrates was found. April 2005, with a kind invitation from Mr. Michael Petersen, founder of Xink Laboratory Ltd., the author had a chance to visit the company in Ottawa. Xink develops and provides conductive ink, RFID labels, and smart packages. Mr. Petersen stated that his researchers used to test Xink's conductive ink on kraft paper. Although the printed antennas showed conductivity, a problem was found due to small cracks of an ink-film, and the antennas lost their conductivity later on. The researchers suspected that it might be an issue of humidity attacking the thin-film traces. However, there was no further study on this.

From the above background, this research was intended to study low-cost RFID for the corrugated packaging industry focusing on the possibility to apply RFID-integration in production. To convert corrugated paperboard into packages, sized corrugated sheets will be printed, creased, and cut into designed patterns, then folded and glued for pre-assembly. Ideally, if RFID is requested, the converters will use an additional printing unit to print conductive antennas on corrugated sheets, and then attach microchips on straps to those antennas before (or after) the sheets have been creased, cut, and glued. Considering corrugated materials, corrugated paperboard is composed of kraft liners and corrugated kraft paper in between. Kraft, an industrial-graded paper, is thick and coarse; whereas the corrugated surface is uneven because of its flute-stripes. These two limitations could affect the printability of the process. Therefore the printing quality on corrugated substrates is commonly much worse than the printing quality on labels or paperboard substrates. Functional RFID antennas need to be printed precisely with an optimum ink volume. An incomplete pattern of the antenna will cause an electrical path break, and a thin ink layer will not provide enough conductivity. Consequently, there was a question whether corrugated material, with its poor printability, could be used for printed RFID. This study was to identify the possibility of corrugated materials to provide conductive printed RFID antennas.

The study was done at the RIT Printing Application Lab (PAL). The printing equipment was an IGT F1 Printability Tester, a proofing scale version of a flexographic printer (Figure 3). Precisia's CFW-104, water-based flexographic silver ink, was selected to print conductive antennas on five different substrates: coated paper (label, 10-mil), kraft paper (185 g/sq m or 38 lbs/1000 sq ft), E-flute corrugated (1.5 mm-thickness), B-flute corrugated (3.0 mm-thickness), and C-flute corrugated (4.0 mm-thickness) (Figure 2). The ink was commercially supplied for printing RFID

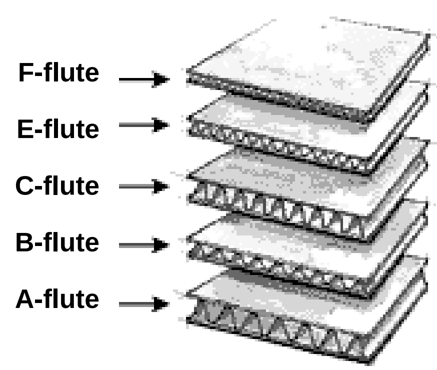

Figure 2. Corrugated paperboard (What is Corrugated? 2004)

antennas and smart packaging. The antenna style used in the study was Alien “I2,” a design for Alien Technology’s ALL-9250 tag (Figure 4). Electrical resistance of the antennas printed on the given substrates was evaluated. Because it could not be measured directly, **the conductivity was identified by a measurement of electrical resistance (Ω or Ohm). Resistance is the inverse of conductivity.** Before the test started, a number of limitations were identified. These limitations included the fast drying of small volumes of conductive ink (high surface to volume ratio), an anilox roller volume (need enough ink-film thickness to provide conductivity), and an incompatibility of printing layout and the tester which caused an incomplete print output during an initial test (Figure 5).

Figure 3. IGT F1

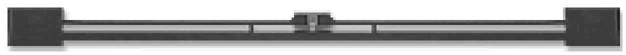

Figure 4. Alien Technology’s ALL-9250 Tag

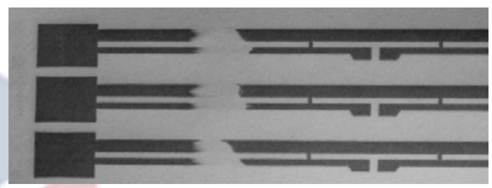

Figure 5. Incomplete Printed Antennas

To acquire the highest printability from the system, a series of tests was conducted to find the optimal printing parameters (printing speed, printing pressure, and inking pressure) for each substrate. For the main test, the antennas were printed and left to dry (ambient) for twenty-four hours, and then the electrical resistance was measured. In order to evaluate the printing efficiency of the test system, a number of commercial I2 antennas printed on coated paper with the same ink were also measured. Figure 6 and Table 1 show that the resistance of the test antennas (on kraft and corrugated) was much higher than that of the commercial samples. Due to the limitations of the tester such as a small inking unit, the printability (for conductive ink) of the test system may not as good as a commercial one. On the other hand, the given substrates to be printed in commercial manufacturing should be able to provide more conductive antennas than those used in this test. Coated paper gave the most conductive antennas, followed by kraft paper, E-flute, B-flute, and C-flute, respectively. Figure 7 and Table 1 show that the conductivity of the printed antennas on coated paper was consistent even though the printing parameters changed; whereas the conductivities on kraft and the three corrugated varied. The largest variation was found from the measurement on C-flute, the largest flute profile, closely followed by B-flute, the second largest used. It should be a concern that, although corrugated substrate could be printed for RFID antennas, its physical properties might be a barrier for high quality prints. In addition, since the conductivity on kraft paper was higher (lower resistance) than that on corrugated, it could be assumed that the manufacturing sequence possibly affects printability of the substrates.

Pre-printing - printing on kraft before converting into corrugated - might be an opportunity for corrugated packaging converters to produce higher quality printed antennas.

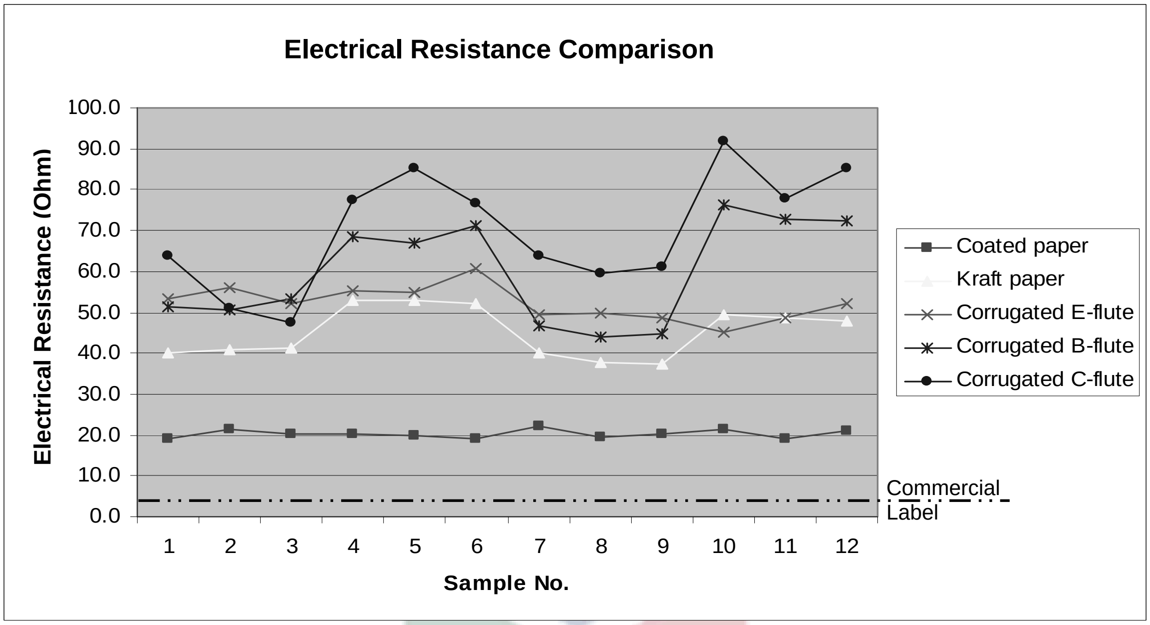

Figure 6. Resistance Comparison of Printed Antennas on Five Substrates

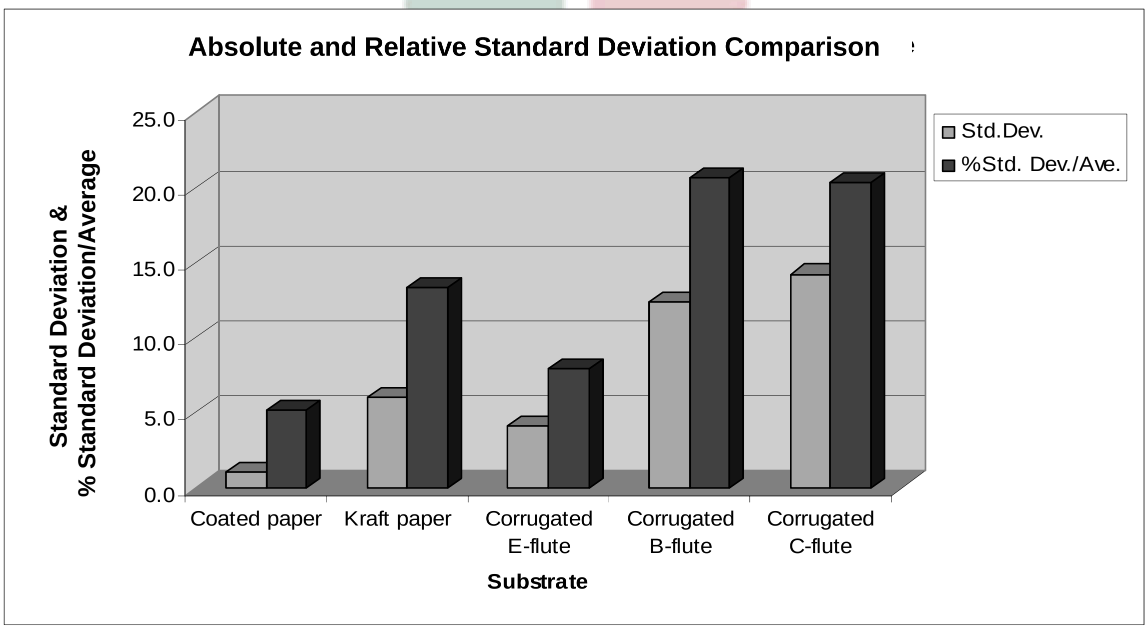

Figure 7. Absolute and Relative Standard Deviation of Printed Antenna Resistance

	Electrical Resistance (Ohm)	
Substrate	**Average**	**σ of Data**
Commercial label	3.31	0.07
Coated paper	20.30	1.04
Kraft paper	45.10	6.03
E-flute	52.20	4.15
B-flute	59.90	12.40
C-flute	70.10	14.26

Table 1. Resistance of the Printed Antennas On different Substrates

Figure 8. Printed antenna

Usually, corrugated packages are used for distribution. The packages can be delivered in many different regions of the world. Thus, it is necessary that the printed antennas maintain their conductivity even in extreme environments. Humidity and temperature-change were two factors that critically affect paper properties; such as moisture content, fragility, and surface distortion, which could possibly cause the antennas efficiencies to change. As a result, an additional study was done to determine the conductivity change under severe environmental conditions compared with those under normal conditions (ambient: 70°F or 21°C, 50% RH). According to ASTM D-4332, the lowest temperature condition was cryogenic atmosphere (-67°F or -55°C), and the highest temperature and humidity was tropical atmosphere (104°F or 40°C, 90% RH). This study continued to use the samples printed from the former study. Samples of the printed antennas on the five substrates were divided into three groups for three conditionings; tropical, cryogenic (or frozen), and ambient. After being printed, two groups of samples were left to dry in an ambient environment for forty-eight hours. Then one group was placed in the tropical condition, and another was placed in the cryogenic condition. After four days, the two groups were moved back to the ambient environment for another three-day observation. The third group of samples was observed simultaneously in the ambient condition for five days. The resistance measurement was done an hour after printing and every twenty-four hours thereafter. Figure 9 and 10 show that for all substrates in the ambient environment, the resistance slightly decreased on the first day, and remained nearly constant after that, confirming that the normal environments have very little impact on conductivity of the antennas. Compared with the ambient environment, the data measured from the tropical conditioning showed lower resistances (higher conductivity). This finding alleviates the concern that high temperature/humidity could change the physical properties of the substrates and reduce the antenna performance; in fact it might even act in the opposite way. In the conditioning of the antennas printed on kraft paper, water inadvertently dropped onto the antennas, causing their resistance to rapidly increase. Although the resistance decreased again after the antennas dried, it should be noted that water (or very high humidity) could considerably obstruct the performance of the antennas. Under cryogenic conditioning, the resistance on coated paper stayed at essentially the same level as in ambient, whereas the resistances on kraft and corrugated increased dramatically. After ambient conditioning following cryogenic conditioning, the resistances on kraft and corrugated were decreased somewhat, but were still not nearly as low as before the cryogenic conditioning. This demonstrates that low temperature conditioning has a deleterious impact on the conductivity of the antennas on kraft and corrugated, but not on coated paper. The two charts below show comparisons of absolute and relative resistance changes under the three conditions on the five substrates. The largest change was found in cryogenic conditioning, followed by tropical and ambient conditionings. The resistance on C-flute had the greatest fluctuation, followed by B-flute, E-flute, kraft paper, and coated paper. Although the antennas on kraft and corrugated had much lower conductivity than those on coated paper (a commercial substrate), there could be an opportunity for corrugated packaging manufacturers to improve material properties to obtain higher printability and better-quality RFID printed antennas.

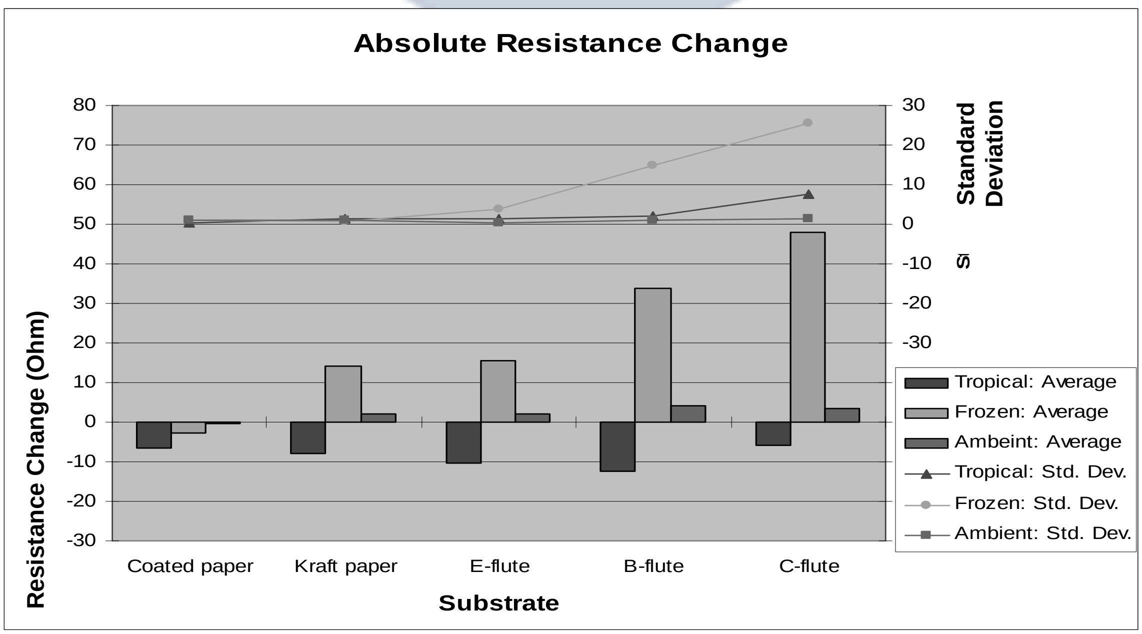

Figure 9. Absolute Resistance Changes Under Three Conditions

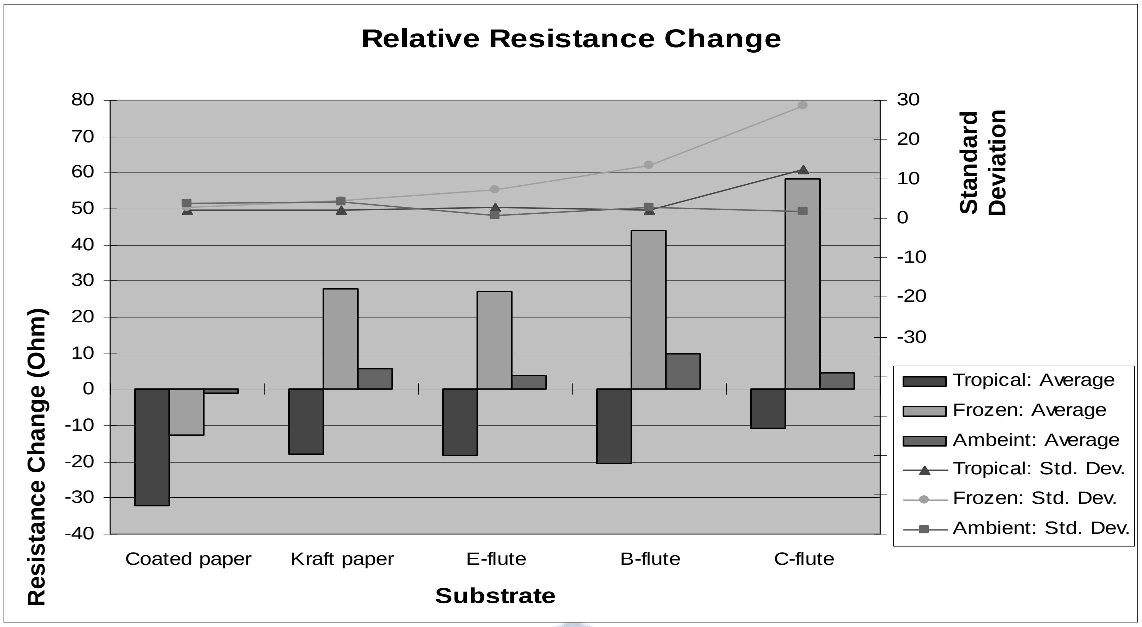

Figure 10. Relative Resistance Changes Under Three Conditions

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