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OVERVIEW OF PRINTING WEARABLE ANTENNA

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ABSTRACT

The usage of wearable textiles in antenna section has been seen increased due to the advanced in miniaturization of wireless devices. A wearable antenna is meant to be a part of the clothing and body used for communication purposes, which includes tracking and navigation, mobile computing and public safety. Printing of conductive ink gives the leisure of flexibility properties on electronics thus allowing it to be used on conformal surfaces such as textiles. However, the current printing techniques mostly suffer from ink incompatibility and limited of substrates to be printed with. Hence, this paper discusses an overview of conventional and current printing techniques of wearable antenna and a potential of automatic syringe deposition system to print electronics structure mainly antenna using conductive ink on conformal substrates particularly textiles.

Keywords: Textile, Printing, Wearable Antenna, Curing, Syringe deposition system.

INTRODUCTION

Wearable electronic devices are becoming very popular in personal communications, computer systems and wireless monitoring of vital functions (Adel et al., 2003). The main advantage of wearable antennas is that they are designed as elements of clothing capable of transmitting or receiving wireless signals (Lim et al., 2014).

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Integrating antennas into clothing can improve the desirability of such systems, and novel methods of fabricating conducting structures on clothing will benefit of diverse applications. Commonly, wearable antennas for all modern application require light weight, low cost, almost maintenance-free and no installation (Rais et al., 2009). In that sense, smart clothes will ensure the ability of wearable devices to escape from the confines of rigid box and hence merge with textile technology. This kind of incorporation of antennas will add the benefit of eliminating clumsy devices that can be entangled to some extent.

Conventional Antenna Fabrication

Spray Technique

Spray technique via Spraylat spraying of conductive paints technique were recognized as promising alternatives for coating antenna surfaces (true metal coatings). These paints are obtainable in silver, copper, and a hybrid system. These materials are commonly used for electro- magnetic inductance (EMI) shielding, electrostatic dissipation, and grounding (Haight et al., 2006). Besides, a more flexible fabrication technique via a conductive spray technique was used which can be applied to any textile material (Santas et al., 2007). The spray, which is a mixture of copper with gases under pressure, can be used to obtain a conductive layer on textile surfaces exposed to the spray. Figure 1 below shows the micro-strip patch antenna fabricated using copper tape, woven copper thread and conductive spray.

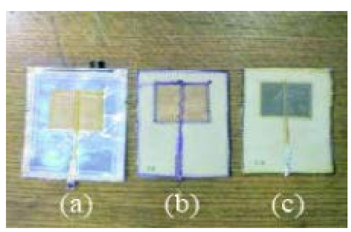


Fig.1. Fabricated textile patch antennas (a) copper tape (b) woven copper thread (c) conductive spray (Santas et al., 2007)

Copper Tape

The used of copper tape was identified as the simplest method and it involves the application of commonly available copper tape that can be directly applied to the substrate of interest with no extra fabrication processes where an E-shaped patch antenna using copper tape was constructed as the conducting element and felt fabric was employed as the substrate (Salonen et al., 2005). The copper tape was cut according to the dimension of the E-shaped patch antenna and mounted on the felt fabric. Figure 2 below shows the measured and constructed dual- band E-shaped textile antenna by copper tape.

Adhesive Sheet

Figure 3 below shows the measured dimension and constructed co-planar waveguide (CPW)-fed textile UWB disc monopole antenna by adhesive sheet (Klemm and Troester, 2006). The textile antenna was connected with a SMA jack using conductive two components glue. It evenly deposits as a thin layer on the conductive textile by ironing. The adhesive only penetrates the surface of the conductive textile such that patch sheet resistance and substrate permittivity are not changed. Another antenna manufactured using adhesive sheet was a fabrication of textile's ultra wide band (UWB) antenna using highly conductive metalized Nylon where the dimension of the antenna must be retained while being attached to the substrate using adhesive sheet.

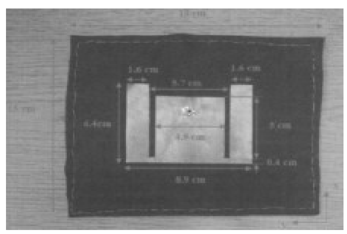


Fig.2. Measured and constructed dual-band E-shaped textile antenna by copper tape (Salonen et al., 2005)

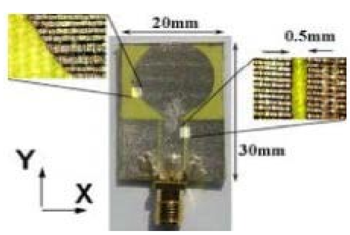


Fig.3. Measured dimension and constructed CPW-fed textile UWB disc monopole antenna by adhesive sheet (Klemm & Troester, 2006)

The manufacturing process using adhesive sheet was difficult and had to be done cautiously. The attachment of the conductive textile to the substrate turns out to be very critical. Wrong dimension measured of the antenna which attached to the substrate can affect the electrical properties of the textile material.

Sewing

Sewing technique was used to fabricate the antenna where the seam spacing in sewing process was smaller than 2 cm to minimize wrinkling problems (Purohit and Raval, 2013). This behaviour is illustrated in Figure 4 (a). A stitch passes through both the patch and the ground plane of the antenna. Electrical measurements revealed shorts between antennas patch and ground plane because the sewing needle pulled small conductive fibres from the patch through the substrate and shorted them with the ground plane. The manufacturing process using sewing technique was difficult and much attention needs to be paid in preventing warpage during the sewing process. If the seam is large, then it resulted with wrinkling as depicted in Figure 4 (b). A wrinkling corresponds to uneven distances between the antenna patch and the ground plane resulting in distortion of the antenna characteristic (Locher et al., 2006). Besides, sewing technique could not be used with the spacer fabric substrate since high pressure of the sewing seam compressed the substrate permanently.

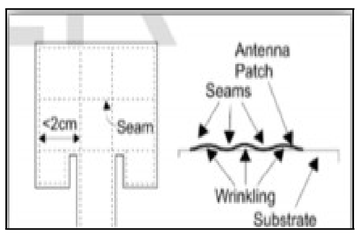


Fig.4. Sewed antenna (a) Sewed patch antenna with seam grid (b) Wrinkling of antenna between seams (Locher et al., 2006)

Printing Technique of Antenna

Silk-screen Printing

A silk-screen printing also known as screen printing is very similar to block printing which is already gained attention because it is flexible, simple (Khirotdin et al., 2016)(Khirotdin et al., n.d.) and low cost technology. It is commonly used in advertisement printing and the methods comprises the printing of a viscous paste through a patterned fabric screen and followed by drying process (Aegerter et al.,2011). It is a feasible printing technique to realize textile antennas as it can easily pattern conductive paste onto fabric to form a flexible strong and suitably thick functional layer as shown in Figure 5 (Kellomki et al., 2012). Beforehand, carbon electrodes, circuits, wearable computers and embedded system for monitoring vital signs had been effectively printed by screen printing conductive silver-based ink on different woven and nonwoven fabrics (Scarpello et al., 2012). The technique was selected to construct the conductive patch and the ground plane of the antennas because with this technique, it is possible to accurately produce any kind of pattern (Kazani et al., 2012). Textile patch antenna was also fabricated with double fabric layers to sustain the steady screen printing of the antenna geometry for wrist- wearable applications (Ha et al., 2010).

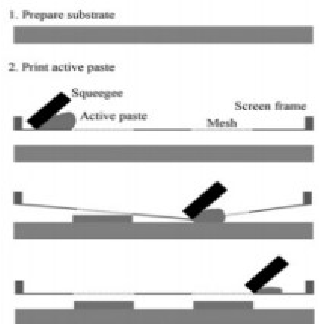
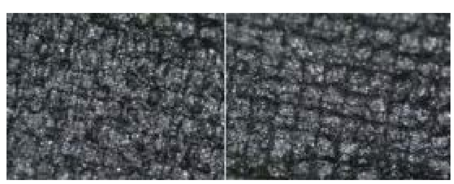


Fig.5. Silk-screen printing process (Kellomki et al., 2012)

In addition, radio frequency (RF) transmission lines and microwave systems were also having been previously screen printed onto a cotton substrate (Locher and Troester, 2007). Silk screen printing is appropriate for fabrication of electronics structure due to its ability to produce patterned, thick layers form paste-like materials (Khirotdin et al., 2016). However, the only drawback of this technique is the surface finish for most screen printed surfaces are rougher due to the reverse image of the silk- screen net (pattern of small square-like) which is undesirable to achieve higher conductivity as illustrated in Figure 6 (a) and (b) (Khirotdin et al., 2016).



(a) (b)

Fig.6. Surface finish for single layer conductive ink using silk-screen printing (a) cotton sample (b) polyester sample (Khirotdin et al., 2016)

Inkjet Printing

Inkjet printers were introduced first in 1976. Among the main contributors for the development of inkjet printing technology are Canon, Hewlett-Packard, Epson, and Lexmark who happen to currently hold the majority of printer sales worldwide. Conductive traces for passive/active circuitry such as antennas, filters, frequency selective surfaces as well as nano-particle micro-electromechanical system (MEMS) have not just been a hot topic in academic research but also been applied in several industry processes (Lakafosis et al., 2010). This new technology of inkjet printing utilizing conductive paste which is can rapidly fabricate prototype circuits (Azucena et al., 2008) without iterations in photolithographic mask design or traditional etching techniques that have been widely used in industry (Rida et al., 2009). This inkjet printing is completely controlled from the designer's computer, and does not require a clean-room environment (Thompson et al., 2004). Inkjet printing technique is different from etching which is a subtractive method by removing unwanted metal from the substrate surface. It jets the ink drops from the nozzle to the desired position. Therefore, it creates no waste, and it results in an economical fabrication process.

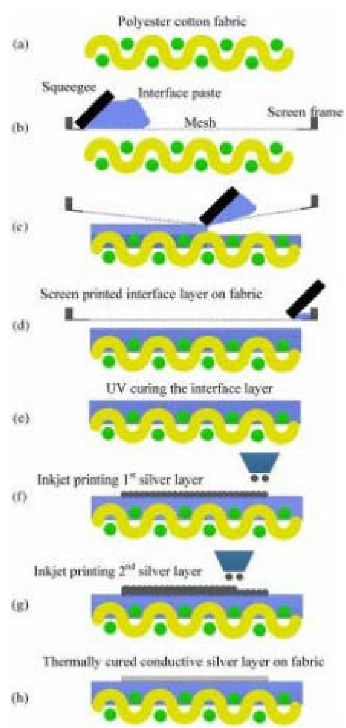


Fig.7. Flow diagram of the inkjet-printed textile antenna fabrication process a) Cross-sectional view of standard polyester cotton fabric (b)-(d) Screen printing stage to deposit the interface layers on top of polyester cotton (e) UV curing stage to harden the printed interface layer (f) and (g) Inkjet printing two deposits of the conductive silver (h) Thermal curing stage to solidify the printed silver layer (Whittow et al., 2014)

A new technique of inkjet printing of antennas on textiles was introduced which is its process flow diagram is shown in Figure 7 (Whittow et al., 2014). The technique can be an advantageous manufacturing technique as the antenna can be created within minutes of finalizing the design, the finish is aesthetic, and it requires minimal material consumption. As no mask is required, there is a flexibility to change the design regularly. Inkjet printing used silver or copper nano-particles in solution to create conducting lines. The process is an additive process which does not require environmentally harmful etching chemicals. Carbon nano-tube inks are also used but typically have lower conductivities than metallic inks. A particular antenna has been printed using inkjet printing technology using silver paste as the conductor. The antenna design was reproduced on paper using inkjet-printing technology (Dimatix DMP-2800 inkjet printer). The antenna and the micro-strip transmission line were printed and cured on paper substrate using silver ink. Sintering process occur in the printing chamber as shown in Figure 8. A close-up picture of the overlap between the printed ink layers using the 10-pL cartridge is shown in Figure 9. A photograph of three printed samples is shown in Figure 10. Besides, the conductivity of the conductive ink resulted has been observed to vary from 0.4 to 2.5 x 10^7 Siemens/m depending on the curing temperature and duration of curing time (Rida et al., 2010).

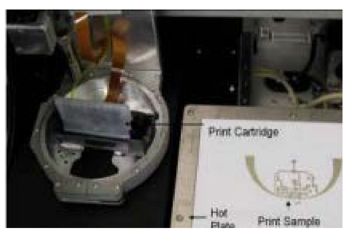


Fig.8. Printing chamber (Rida et al., 2010)

Fig.9. Close up image of an edge of a printed layer (zoom factor: x100) (Rida et al., 2010)

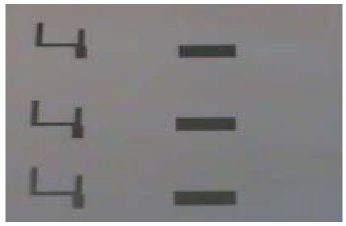


Fig.10. A photograph of three printed samples using inkjet printing (Rida et al., 2010)

The downside of ink jet printing are the conducting layers are very thin, of the order of one micron, hence it is very difficult to print on rough, uneven or porous surfaces such as fabrics (Merilampi et al., 2010). In addition, the challenge is to achieve a connected spot since the nozzle head is easily to clog. In other words, the spots are not connected on the surface efficiently in which it could not form a required continuous ink track. Furthermore, the thickness of the ink tracks is thin and at some stage the tracks were not conductive at all. Printing conductive inks is differed from graphical printing due to the high requirement for layer thickness. Thus, multiple printings are needed on a single track and this consumed time and cost (Khirotdin et al., n.d.).

Flexography Printing

Flexography and gravure printing are implemented due to the limitation in speed and volume for both screen printing and inkjet printing. Flexography and gravure printing have been used for sensors, solar cells transistors, and radio frequency identification (RFID) system components, such as conductors or RFID tag antenna. Flexography is a type of relief printing. An image is produced by a printmaking process where a surface of the printing plate matrix is inked while the recessed areas are free of ink. Image printing is a simple process since it only involves inking the protruding surface of the matrix and bringing it in contact with the substrate (Kattumenu, 2008). Due to its relatively fine resolution, low cost, and high throughput, flexography gained a great interest by RFID antenna manufacturers (Faddoul et al., 2012). Moreover, this technique requires a lower viscosity ink than screen printing inks, and yields imaged (printed) dry films of a thickness of less than 2.5 μm (Vena et al., 2013). Figure 11 (a) below shows a chipless tag based on multiple 3-gap loop resonators and Figure 11 (b) shows a photograph of the tag printed on glossy paper by flexography. On the other hand, flexography inks need to posse higher bulk conductivity than those used in screen printing to compensate for the increase in sheet resistance since the efficiency of printed antennas depends mainly on the electrical conductivity of the traced pattern (Hsieh et al., 2008). For very low ink layer thickness, flexographic lining and halo effects can also appear as severe problems, creating anisotropy in conductivity and can also lead to nonconductive traces for narrow traces printed perpendicular to the direction of the print (Siden et al., 2007).

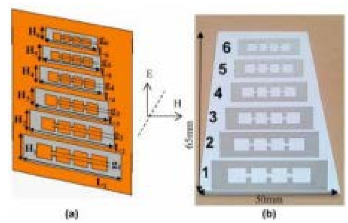


Fig.11. (a) Chipless tag based on multiple 3-gap loop resonators (b) Photograph of the tag printed on glossy paper by flexography (Vena et al., 2013)

Laser Induced Forward Transfer (LIFT)

Bulging is a common problem in most printing techniques, and LIFT is not immune to it (Visser et al., 2015). The problem can be eliminated through a strategy which combines the alternate deposition of two sets of droplets with an intermediate drying step (Fernandez-Pradas et al., 2004). First, a set of equally spaced non-overlapping droplets is printed. In a second step, they are dried (Colina et al., 2005). Finally, the second set of equally spaced droplets is printed, with a shift with respect to the first set which corresponds exactly to half the distance between adjacent non-overlapping droplets (measured from center to center) (Karaiskou et al., 2003). This process allows mitigating the capillary flow along the printed line which is responsible for both bulging and line breakup, thus obtaining continuous stable lines free from bulging (Florian et al., 2015). After a laser sintering process, the printed lines present a conductivity very close to that of the ink after curing in an oven (Xiong and Qu, 2011). Figure 12 below shows a sketch of the experimental setup of LIFT. The only disadvantage of this technique is the utilization of this technique is quite pricey due to the used of laser system.

Automatic Syringe Deposition System

Syringe deposition system is an automatic non-contact fluid dispensing system (FISNAR 3-axis, F4200N.1) equipped with a teach pendant and industry’s leading dispensing software that walks the user through step-by step instructions to create a complex operation in minutes, dispensing controller (FISNAR, JB113N) that supplies air pressure from the compressor to the syringe and utilizes a 3-axis coordinate as its movement system. It is a compact and costeffective priced benchtop machine and designed for manufacturing, medical and laboratory environments requiring a streamlined, robust and easily maintained. The system has been widely used in electronic industries especially in solder paste machine and surface mount technology (Khirotdin et al., n.d.). Figure 13 shows the automatic syringe deposition system.

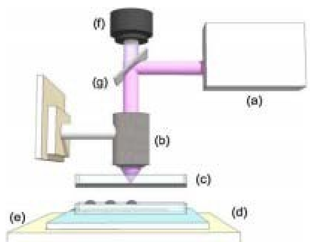


Fig.12. Sketch of the experimental setup of LIFT (a) Laser (b) Focusing objective (c) Ag layer (d) Vacuum Chuck (e) Stages (f) CCD camera and (g) IR mirror (Xiong and Qu, 2011)

Fig.13. Fisnar F4200N automatic syringe deposition system

The technique has shown some potential in printing electronics structure which it was successfully printed a strain gauge on fabric substrates and the strain gauge is proven functional as expected since different strains were induced when bent on variation of bending angles. The average change of resistances was doubled before the strain gauge starts to break. Printed strain gauges also exhibited some excellence elasticity as they were able to resist bending up to 70° angle (Khirotdin et al., n.d.a). Another prospect of this technique is shown in (Khirotdin et al., n.d.b) where the technique has successfully printed a strain gauge on curvature substrates and the strain gauge is proven functional as expected since different strains were induced when bent on variation of curvature radiuses from designated curvature fixtures. The average change of resistances was doubled before the strain gauge starts to break. Printed strain gauges also exhibited some excellence elasticity as they were able to resist bending up to 3 mm of curvature radius.

CONCLUSION

Most of previous printing techniques are only capable of printing on planar substrates and some of these techniques suffer from clogging as well as limited type of materials to be printed with. Currently, there are no reports found on the use of syringe deposition system in fabricating a functional electronics structure particularly antenna and the potential of the system has not been thoroughly explored especially in printing of antenna since it will open up another dimension in communication and might become a life saver. Furthermore, automatic syringe deposition system also capable of coping with variety of materials as well as providing larger building volume due to its nozzle movement that utilize three-dimensional coordinate axis system. It also can deposit wide range of viscosity level of ink, flexible and easy to handle.

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