

Ink-jet Implementation of Stacked Planar and Conformal Array Antennas for Wireless Applications

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Abstract—This work addresses a double stacked array antenna with linear and circularly conformal disposition of patch elements. The single patch element is designed in the 5 GHz band based on the inkjet-printing technique. The idea is to generate a microstrip lines using conductive silver ink which is applied on a thin Kapton film. To improve the mechanical stability, a high impact polyester (HIPS) is used as a substrate to fix the Kapton layers which also improves the impedance matching bandwidth. After designing the single patch element with 7.2% impedance bandwidth under -20 dB and 7.7 dBi directivity, the linear array antenna is designed to improve impedance bandwidth to 11.6% and directivity to 11.2 dBi. Due to the possibility of using 3D printing technique, to make HIPS substrate and the flexibility of Kapton layers, the idea of placing eight single patch elements on a 3D printed cylindrical structure is created to achieve the omnidirectional pattern. Therefore, the combination of inkjet-printing and 3D printing techniques will pave the way for manufacturing compact, low cost and light weight antennas for many applications such as wireless local area network or unmanned aerial vehicles.

Index Terms— double stacked antennas, directional radiation pattern, omnidirectional radiation pattern, inkjet-printing method, 3D printing method, Kapton, High Impact Polyester.

I. INTRODUCTION

Over the last decades, printed circuit board (PCB) is often used in array antennas for satisfying low profile and weight [1,2]. Low-profile antennas have wide interest in wireless communication systems such as wireless local area networks (WLANs). These kind of antennas play a significant role in the world Internet of Things (IoT) as implementing antennas in textile or wool material for wearable indoor applications [3] or easy-to-carry wearable personal WLAN hotspots to connect individuals to mesh network [4]. Using this method makes it possible to implement wearable antennas to provide smart fabrics. However, in this environment it is almost impossible to keep the antenna in a designed shape all the time. The performance of a textile antenna under bending and crumpling conditions and its effect on the impedance and radiation effect is presented in [5].

Inkjet-printing antennas as an alternative method to directly print a conductive on a substrate is introduced in [6]. The advantage of eliminating the harmful chemical etching process has made this method more widespread. On the other hand, the possibility of using this method to print on different

materials such as textile [7], paper [8] and Kapton [9] has taken a large share of smart wearables. [10] presents some challenges to print a very thin conductive on a rough surface such as fabric. The issue of non-tolerance of this material to a higher temperature than 150°C as a part of the process of this method has also been discussed. In any case, due to the possibility of using this method on different substrates, it can offer a new route to manufacturing more complex multilayer devices. According to the compared results that are presented in [10] it has been proved that thin Kapton film shows a more acceptable behavior against these challenges.

The initial step of the idea related to the possibility of using Inkjet-printing method to print conductive silver ink on a thin Kapton film has been evaluated in [11]. Using the Inkjet-printing method along with the 3D printing method to manufacture High Impact Polyester (HIPS) substrate, has made it possible to design a double stacked patch antenna. In fact, HIPS increases the antenna bandwidth and its mechanical stability.

Based on this idea, other designs have been presented to investigate its potential for wider applications. After designing a stacked patch antenna (SPA), it has been tried to provide a design of a stacked linear array (SLA) antenna to obtain better response in case of impedance matching and peak gain results. In the next step, it is discussed that this idea is not only applicable to planar designing with directional radiation patterns, but due to the high potential of using the 3D printing method to make more complex designs, it can also be used for cylindrical conformal structures for omnidirectional radiation pattern applications.

Due to the wide use of conformal array antennas [12] in wireless local area networks (WLANs) and new emerging applications such as novel wearable antennas or unmanned aerial vehicles (UAVs), the importance of addressing this concept will increase. An omnidirectional stacked conformal array (SCA) antenna with the same idea of putting the printed Kapton film on a 3D printed HIPS has been presented in the last part of this work.

II. ANTENNA DESIGN

A. Directional Stacked Antenna

Fig. 1(a) shows the proposed stacked patch antenna (SPA). Although using the idea of stacked patch increases the overall

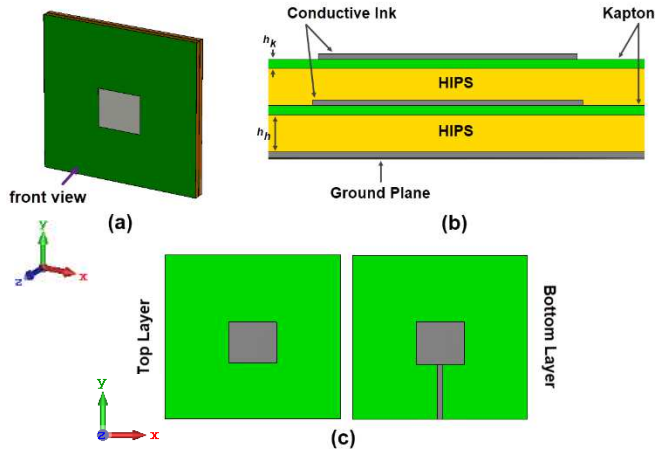


Fig. 1. SPA configuration a) Perspective view, b) side view of the antenna including ground plane, conductive ink, Kapton and HIPS substrate, c) front view of the antenna including the bottom and top layers.

thickness, the significant effect of this idea in increasing the antenna bandwidth in terms of impedance matching is the reason for the interest of using this technique.

In general, stacked patch antennas are designed on two PCB substrates. The feeding network and the resonant patch will be placed on the first substrate while the second patch will be located on the second one. To implement the idea of using ink-jet printing method, two materials are considered, High Impact Polyester (HIPS) as the principle dielectric medium of the antenna, and Kapton to be able to print the microstrip lines on it and then to be placed on the HIPS as is presented in Fig. 1(b). The conductive silver ink will be printed on the Kapton and finally this layer will be placed on the HIPS substrate. The outline of this method is shown in Fig. 1(c) with the top view of the antenna. The bottom layer includes the feeding strip line and the resonant patch and while the second patch will be printed on the top layer. Since the ground plane covers the entire back of the antenna, it will reduce the electromagnetic effect of human body which will make the antenna useful in wearable applications corresponding to the wireless local area network (WLAN) services.

According to the design, the Kapton layer that is used has $75 \mu\text{m}$ thickness (h_k in Fig. 1(c)) with dielectric constant of 3.4 while the HIPS substrate include the specifications of 2 mm for the thickness of top and bottom layers (h_h in Fig. 1(c)) and 2.6 for the electric constant following the information of the manufacturer. To check the accuracy and the quality of the Inkjet-printing method, a sample of the bottom and top layers of the SPA including the conductive silver ink which is printed on Kapton film, is shown in Fig. 2 which indicates its acceptable quality.

Based on the proposed design principles, in a further step the idea of designing a stacked linear array (SLA) has been discussed. Fig. 2. shows the final design of the proposed antenna. In this design, the same idea including two HIPS substrate and two Kapton films for applying the conductive

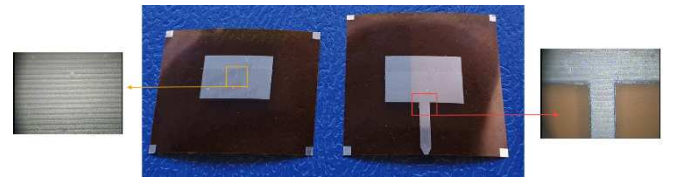


Fig. 2) Sample of the bottom and top layers of the SPA including the printed conductive silver ink on the Kapton film.

silver ink has been implemented. The first layer including the feeding network is shown in Fig. 3(a) which is designed to excite four radiating patch elements. In this feeding network, two steps of T-junction power divider are used while its corners are cut to achieve better impedance matching. In addition to using a quarter-wavelength ($\lambda/4$) transmission line in the T-junction power divider to provide a compact design, in the final step of the feeding network designing, two more $\lambda/4$ transmission line have been used so that despite reaching the desired impedance matching, the possibility of connecting to the (50Ω) SMA load termination is provided. The top layer with four patches is also presented in Fig. 3(b).

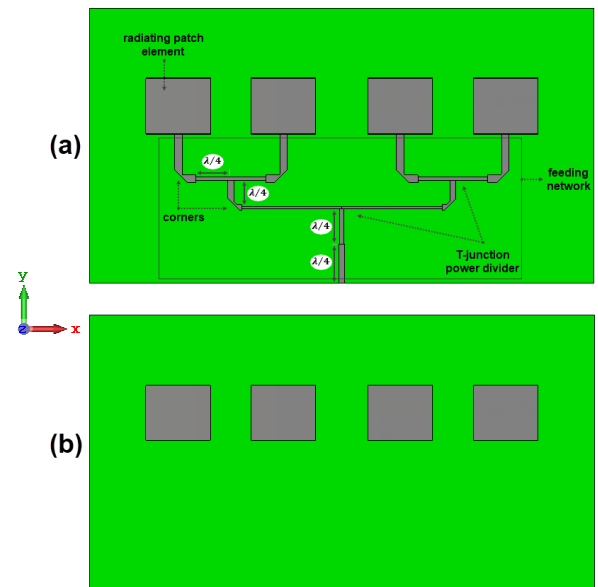


Fig. 3) Front view of the SLA including the a) bottom and the b) top layers.

The simulated impedance matching is presented in Fig. 4. According to the figure, the functional bandwidth (FBW) of the SPA is 11% below -10dB , and 7.2% below -20dB while these values are 15.1% and 11.6% below -10dB and -20dB respectively for SLA. Fig. 5. shows the normalized radiation pattern of the stacked patch antenna and the stacked linear array in E and H planes at the designed frequency of 5.6 GHz. According to the Fig. 1(d) an asymmetry is visible in radiation pattern which can be justified due to the radiation effect of the feeding network of SLA.

The boresight gain has been plotted in Fig. 6 for SPA and SLA designs respectively. According to the figure, the

maximum gain that is achieved is 7.7 dBi for SPA while this value has been increased to 11.2 dBi by presenting the idea of SLA with the same method.

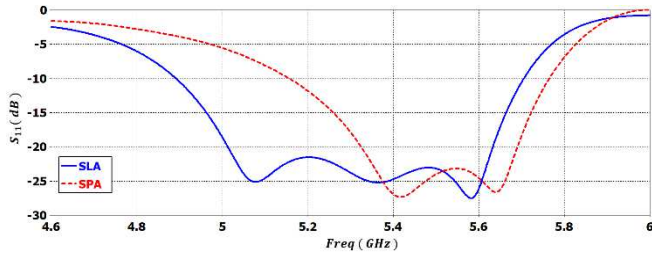


Fig. 4) Impedance matching of the SPA and the SLA.

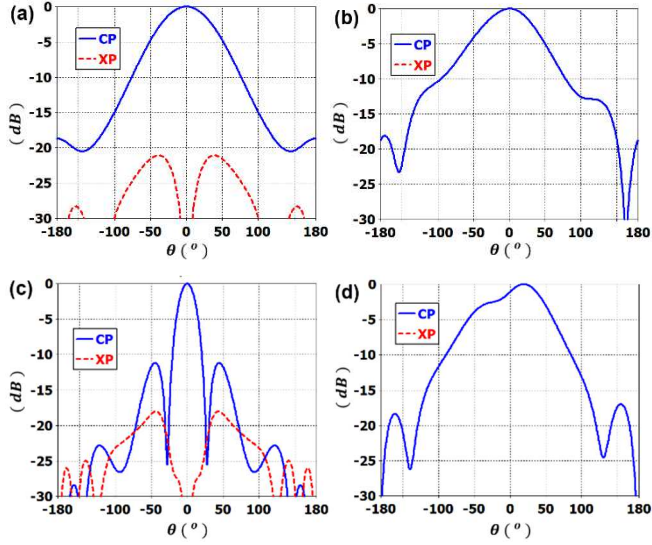


Fig. 5) Normalized radiation pattern of the SPA in a) E-plane, b) H-plane and the SLA in c) E-plane and d) H-plane at 5.6 GHz.

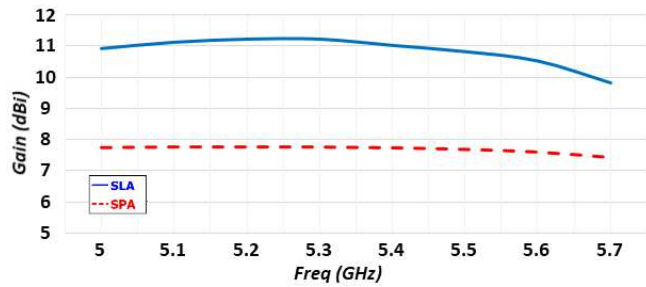


Fig. 6) Boresight gain of the SPA and the SLA.

So far, the idea of directional stacked antenna design using the combination of 3D printing method to manufacture the HIPS and ink-jet printing method to apply the silver conductive ink on Kapton films has been introduced. Due to the high potential of this method, it will be possible to expand it to introduce more complex designs. An idea can be related to omnidirectional antenna design, which is discussed in general in the next section.

B. Omnidirectional Stacked Antenna

The conformal array antennas as a compact and low-cost structures have always been of interest. The array elements orientation in different directions is the main difference between conformal and linear array antennas. This configuration of the radiating elements makes it possible to achieve omnidirectional radiation pattern in the azimuth plane which its formulation for N-faced prism extracted from [12] as follows:

$$\vec{E}_{array}(\theta, \phi) = \sum_{n=1}^N \vec{E}_n(\theta, \phi) I_n e^{j \left[\left(\frac{2\pi}{\lambda_0} \right) a_{prism} \sin \theta \cos(\phi - \phi_n) + a_n \right]}$$

Where $\vec{E}_{array}(\theta, \phi)$ shows the radiated E-field of the conformal array antenna, $\vec{E}_n(\theta, \phi)$, I_n and a_n are the radiated E-field, the feeding amplitude and phase of the n th single radiating element respectively. λ_0 is the free-space wavelength at the design frequency of 5.6 GHz and a_{prism} is the distance between the center of the prism and the center of each element ($a_{prism} = 50$ mm).

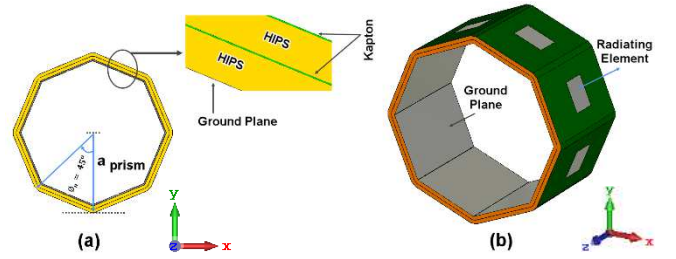


Fig. 7) SCA configuration. a) front view, b) perspective view

According to the given equation, a concept of 8-faced ($\phi_n = 45^\circ$) stacked conformal array (SCA) structure is presented in Fig. 7 to achieve an omnidirectional radiation pattern behavior in the azimuth plane ($\theta = 90^\circ$). In addition, to feed each radiating element of the antenna an equal amplitude and phase has been applied (I_n and a_n).

The final dimension of the whole SCA are $50 \times 50 \times 56$ mm³ ($0.94 \lambda_0 \times 0.94 \lambda_0 \times 1.1 \lambda_0$). the omnidirectional behavior is shown as a normalized radiation pattern in the azimuth plane in Fig. 8(a) at the design frequency. The maximum ripple of 3 dB is visible in this figure. Finally, the simulated radiation pattern in the elevation plane is presented in Fig. 8(b).

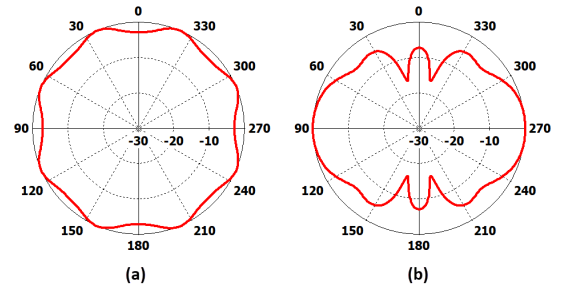


Fig. 8) SCA radiation pattern response. a) normalized radiation pattern in the azimuth plane at 3.6 GHz, b) normalized radiation pattern in the elevation plane at 3.6 GHz.

III. CONCLUSION

In this paper, the use of the inkjet-printing method was introduced for the possibility of printing conductive silver ink on the Kapton film to apply on the High Impact Polyester (HIPS) substrate which can be manufactured with 3D printing technique. This idea was first evaluated in planar structures. A stacked patch antenna (SPA) was designed with a functional bandwidth (FBW) of 7.2% below -20 dB and the maximum gain of 7.7 dBi. In the next step, these values were increased to 11.6% below -20 dB, and 11.2 dBi for the functional bandwidth and the gain respectively, by designing the stacked linear array (SLA) antenna. Finally, a concept of the stacked conformal array (SCA) antenna was introduced with omnidirectional radiation pattern in azimuth plane with the maximum ripple of 3 dB.

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