24GHz paper based inkjet printed quasi Yagi-Uda antenna with new bowtie director

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Abstract— This paper presents a 24 GHz quasi Yagi-Uda antenna with a new bowtie director. The new bowtie director shape is introduced to improve the bandwidth of a typical Yagi-Uda antenna using a straight director by 240%. In addition to the enhanced impedance bandwidth, it makes its gain-bandwidth three times that of a standard Yagi-Uda antenna and demonstrates a measured 4 dBi gain. The presented inkjet printed paper based antenna operates at 24GHz which is one of the highest reported operating frequencies for an inkjet printed antenna on this lossy substrate. The paper substrate has been characterized for these frequencies. The measurement results indicate that the proposed design is highly suitable for low cost, environmentally friendly and flexible wireless applications.

Index Terms—Inkjet printing, Printed antennas, Yagi-Uda, enhanced bandwidth

I. Introduction

With the increasing demand of accessing information everywhere and all the time, a new generation of wearable wireless communication devices is being envisioned. These devices must be small, light-weight, cost effective and conformal. An attractive approach is to use cheap, environmentally friendly and flexible organic substrates such as polymers or papers and employ low cost inkjet printing which is highly suitable for up-scaling production process [1].

Although literature shows some antenna designs for ISM [2] or WiFi [3], most of the antenna designs using the inkjet printing process are for disposable RFID tags or sensors and mainly operating below 2 GHz [4]. The requirement of high data rates and new communication standards necessitated the use of higher frequency bands. To date, only few papers have demonstrated inkjet printed antennas operating at higher frequencies mainly due to fabrication limitations such as the minimum feature sizes. Low loss substrates such as polyethylene terephthalate (PET) [2] or liquid cristal polymer (LCP) [5] are generally preferred. This paper presents one of the highest reported frequencies for paper based inkjet printed antennas.

Simple structures such as monopoles or dipoles are usually preferred because their geometries are easy to print, use less ink and are not dramatically affected by small bends of the substrate. A new director shape is introduced here to hugely improve both the gain and the bandwidth of a typical Yagi-Uda antenna.

II. Stackup and Topology

The substrate chosen for this work is a simple photographic paper, an organic and low cost material. Its electrical parameters (dielectric constant ' ϵ_r ' and substrate loss ' $\tan\delta$ ') have been extracted previously up to 12.5 GHz in [6] and here close to the operating frequency of the antenna (Fig. 1). At 21.5 GHz, ϵ_r and $\tan\delta$ are 2.6 and 0.076 respectively.

The commercially available silver nano-particle ink from UTdots and Dimatix DMP-2831 printer are employed. A conductivity of 1×10^7 S/m can be achieved depending on the number of printed layers and processing conditions [6]. The design of the antenna is challenging because of the paper substrate losses [6, 7] as well as the minimum feature size requirements at 24 GHz which is difficult to achieve with the fabrication process used. For instance, in this work, the minimum possible fabricated line and slot widths are 50 μm .

A Yagi-Uda design has been chosen since it provides high directivity, it is easy to implement in a planar format and it has a lower concentration of fields in the substrate as compared to single ended antennas [8]. To feed the antenna with a typical SMA connector, a wideband microstrip to slot transition has also been designed [9] using two 220 μm thick sheet of paper glued together. ϵ_r and the thickness of the glue are considered to be 4 and 50 μm respectively based on [6].

III. Antenna Design

The antenna geometry and its critical design parameters are shown in Fig. 2. The top and bottom metal layers are

Fig. 1. Extracted ϵ_r along with the previous published data.

Fig. 2. Microstrip fed quasi Yagi-Uda antenna (dimensions in mm). Top layer in light gray and bottom layer in dark gray.

distinguished through light and dark gray shades respectively.

The design comprises a microstrip to slot transition feeding a differential bowtie antenna through coplanar strips (CPS). This feed provides both an impedance matching and a mode transformation over a wide frequency range. The quarter wavelength CPS line feeding the bowtie is designed to get the metallic part behind the antenna to act as a reflector. This metallic part also serves as the ground plane for the microstrip line of the EM transition located on the side of the antenna. For a Yagi-Uda antenna, a director is located in front of the driving element. The effect of the director shape on the antenna bandwidth (BW) and the directivity depending on the ratio between W_{direct} and W_{dirin} (Fig. 2) have been investigated. Based on its superior performance, a bowtie shaped director is presented in comparison with the two antenna variations without and with a straight director (typical Yagi-Uda antenna).

iv. New Director Performance

Fig. 3 shows the simulated S_{11} versus the frequency for the three antenna variations mentioned above without the SMA connector. The addition of a director in front of the bowtie antenna does not improve the BW and remains at 20.8 % centered at 24 GHz. However, by modifying the

Fig. 3. Simulated S_{11} (in dB) versus frequency for the three antennas.

shape to a bowtie shaped director, the matching is greatly improved and a much wider BW ranging from 21.2 GHz to 33 GHz (49.2 %) is achieved. The use of a bowtie director improves the BW by 240% as compared to a typical quasi Yagi-Uda bowtie antenna (using a straight director).

The simulated gain along the maximum radiation (z-axis) versus the frequency is shown in Fig. 4 for the three designs. The improvement can be seen when a director is placed in front of the antenna with a simulated gain increasing from 2.9 dBi to higher than 4.1 dBi. But most importantly, the bowtie shape director greatly improves the stability of the gain over the frequency. Overall, a gain higher than 4 dBi is maintained for 7.6 GHz (31.7% gain bandwidth) which is more than three times the gain bandwidth when a typical straight director is used.

v. Small Antenna Measurement Issues

The fabricated antennas are fed through SMA connectors, as shown in Figs. 5a and 5b. As it can be seen, the size of the connector is big as compared to the antenna. The effect of the connector on the antenna performance has to be taken into account with an updated simulation model of the antenna fed through SMA connector. This issue is only pertinent for the characterization of these antennas. In real applications, the antennas are directly integrated with the circuits without the need of such a large connector.

Fig. 4. Simulated gain (z-axis) versus frequency for the three antennas

Fig. 5. Fabricated antennas fed through SMA connector.

- a Without director.
- b With bowtie-shaped director

VI. Measured Results

The antenna impedance behaviour is shown in Figs. 6 and 7. In Fig. 6, the measured and simulated S parameters are presented when the antenna without director is fed through its SMA connector. An acceptable correlation can be observed between simulation model and measured results. The antenna and inkjet printing minimum feature sizes and manual assembly between the two paper layers make the exact values of design parameters such as glue thickness, x and z miss-alignments of the microstrip feed and slot width difficult to know and they may be responsible for the discrepancies between simulations and measurements. In the case of the antenna with the director, the SMA connector located on the side may affect the coupling between the driving and director elements and its effect be more significant than for the antenna without director. It should therefore be taken into consideration at the packaging stage.

As it can be seen in Fig. 7, the concept of the new director is well proven in measurement with a 230% impedance bandwidth increase with the new director as compared to the predicted 240% in simulations. Figs. 8a and 8b show the comparison between measured and simulated radiation patterns (with SMA connector) at 24 GHz in the H-plane. The connector is located in the E-plane. The simulation results demonstrate a close match with the measured patterns. The measured maximum gain for the new director is 4 dBi, which is 1.2 dB lower than the simulated gain. This can be attributed to slightly higher losses of the glue and the surface roughness of the inkjet printed metallization which were not anticipated in the design phase.

Fig. 6. Simulated and measured S_{11} (in dB) of antennas without director.

Fig. 7. Measured S_{11} (in dB) of antenna without (dashed) and with (solid) director.

Fig. 8. Simulated and measured radiation patterns at 24 GHz in H-plane
a For the antenna without director.
b For the antenna with bowtie-shaped director.

VII. Conclusion

An inkjet printed paper-based Yagi-Uda antenna operating at 24 GHz, one of the highest reported frequencies for this substrate, is presented in this letter. Further, the paper substrate has been characterized for this frequency. The proposed bowtie shaped director helps to enhance the impedance bandwidth of typical Yagi-Uda antennas by 240%. In addition, the gain bandwidth is also more stable and is three times larger. Measured results validate the new bowtie concept and indicate its suitability for high data rate, conformal and low cost wireless applications.

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