2022 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (AP-S/USNC-URSI) | 978-1-6654-9658-2/22/$31.00 ©2022 IEEE | DOI: 10.1109/AP-S/USNC-URSI47032.2022.9886082

Fully Additively Manufactured Flexible Dual-Band Slotted Patch Antenna for 5G/mmwave Wearable Applications

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***Abstract*—To keep pace with future 5G mmwave technologies, wearable antennas need to cover higher frequencies and maintain flexibility. This paper presents a fully additively manufactured flexible wearable dual band antenna for 5G/mmwave biomedical applications. The patch antenna is inkjet printed with silver ink and SU8 buffer layers onto a 3D printed Polypropylene substrate. The operational frequency is designed at 28GHz and 38GHz in 5G NR band. The measured S11 and radiation pattern match well with simulation. The reliability of the proposed fabrication on flexible substrate is also discussed.**

I. INTRODUCTION

The development of 5G communication and internet of things (IoT) have brought wearable devices into a new era. As the operational frequencies step into mmwave bands, larger data volume can be transmitted in wider spectrum, which results in much lower latency and higher speed for wireless communications. For wearable devices, this means real-time response, more precise diagnosis and systematic health information. Higher frequencies can also enable miniature and light-weight devices that can be easily integrated with other systems. Recent study suggests that future health solutions will be data-based and 25 billion to $40 billion may be saved on healthcare. 5G connectivity can solve this large demand for wearables by providing more computing and less charging, as well as the most up-to-date features [1].

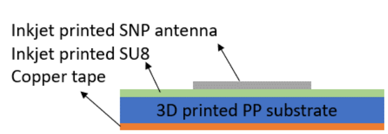
Wearable antennas are the essential parts of Wireless body area networks (WBAN). The most basic design requirement for wearable antennas is flexibility. Many research have investigated the utilization of electro-textile for antenna design[2]. However, for mmwave frequencies, the difficulty in fabrication will increase as the antenna size becomes smaller. In addition, fabric may not be a good option since both dielectric loss from substrates and conductor loss caused by surface roughness has more prominent influence on RF performance at higher frequencies. Therefore, it is significant to find a flexible material that has low loss tangent and good surface properties in a low-profile fabrication method. Additive manufacturing techniques such as 3D printing and inkjet printing can address this issue by creating novel customized structures with low cost and less waste in a quick turnaround time. It has also been reported that additively manufactured “smart” packaging can achieve highly integrated multichip modules [3].

In this paper, a dual-band patch antenna operating at 28GHz and 38GHz is designed and fabricated by inkjet printing silver ink as antenna pattern onto a low loss 3D printed flexible Polypropylene substrate. The flexible antenna can be worn on body for future health monitoring applications and communicate to on-body devices or off-body networks. The dual band design is also a more efficient and compact solution for coverage of multiple 5G NR bands.

II. DESIGN AND FABRICATION

Microstrip patch antennas are especially suitable for wearable applications because they have full ground plane that can largely reduce the back radiation when positioned on human body. A dual band patch antenna is designed and simulated in CST Microwave Studio. The side length of the square patch is 2.952mm and slot width is 0.1mm. A quarter wavelength transformer is used to match the input impedance of 150 Ohm to 50 Ohm. Two L-shape slots at the corners of the patch can be used to tune the desired resonant frequencies.

The substrate material is chosen as Polypropylene, which is a thermoplastic that has been widely used in our daily life for applications such as food containers, automotive devices and many clothes. It is a FDA-approved for food contact and considered much safer than most plastic materials [4]. The dielectric properties of 3D printed PP have been characterized (dielectric constant 2.34, loss tangent 0.001) and it has comparable RF performance with some commercial substrates. The Polypropylene substrate is prepared from an Ultimaker S3 FDM printer. The minimum resolution of the printer is 0.1mm and the substrate thickness is 0.3mm. The printed substrate is first sanded and treated by UVO cleaning for 3mins, in order to improve the surface wetting and printability for inkjet printing. Then 2 layers of SU8 is inkjet printed onto the substrate as buffer layers to cover some surface imperfections and provide better adhesion for silver ink. Finally silver nanoparticle ink (SunTronic, EMD5730, 5-30μΩ volume resistivity) is inkjet printed with antenna pattern onto SU8 layers. The inkjet printer (DMP-2800) and ink cartridge (Dimatix, Samba, 2.4pL) can provide good resolution for thin slots as shown in Fig. 1(b). 10 layers of silver ink is printed in total to ensure enough ink



(a)

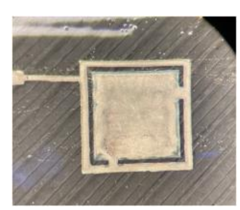

(b)

Figure 1. (a) Cross section schematic of fabrication process; (b) Inkjet printed antenna pattern onto PP substrate with SU8 buffer layer

coverage and good conductivity. Heating is performed after each layer of print to prevent spreading of the ink. The sintering of the fabricated antenna is conducted under 130°C in the oven for 1 hour. Copper tape is used as ground plane for the antenna and the whole material stackup is shown in Fig.1(a). The fabricated sample is shown in Fig. 2, which also demonstrates the good flexibility of the fabricated sample for any conformal wearable applications.

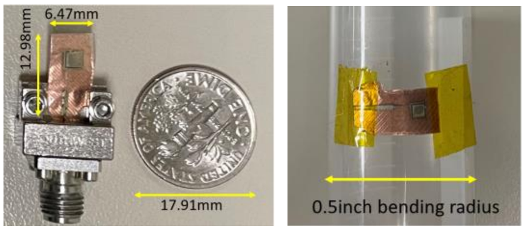


Figure 2. Fabricated antenna prototype and flexibility demonstration

III. RESULTS AND DISCUSSION

In simulation, the designed antenna achieves dual resonant frequencies at 28.02GHz and 37.8GHz and operational bandwidth is 500MHz and 800MHz, respectively. The fabricated dual band patch antenna is measured in an anechoic chamber with VNA. The simulated and measured S11 are shown in Fig. 3. Compared with simulation, there is a slight frequency shift from 28GHz to 28.4GHz that is mainly caused by deviation in fabrication and measurements, for instance, the spreading of the silver ink may alter the antenna size. The second resonance matches well with simulation. The general bandwidth can be further improved by using a wideband impedance matching technique. The side lobe level is smaller than -10dB in both resonant frequencies. Some sharp edges in measured radiation pattern can be caused by the existence of relatively large Southwest connector. Fig. 4 shows the measured radiation pattern of this antenna, which has good consistency with simulation. The simulated realized gain is 5.14dBi at 28GHz and 6.83dBi at 38GHz. Overall, this additively manufactured flexible dual band antenna displays acceptable performance in both simulation and measurements.

In addition, this antenna has been further evaluated under bending condition in CST simulation. A bending radius of 1inch is used for simulation and the resonant frequencies shifts around 200MHz to 27.8GHz and 37.6GHz. The realized gain decreases less than 1dB. This should be considered in wearable antenna design and further optimization is possible by tuning the patch dimension and making larger ground plane. Being worn on human body, the wearable antenna would also undergo different deformation depending on where it is placed on. For a wristband application, the antenna would be uniaxially bent. The bending reliability test has been performed in preliminary research on microstrip lines which are fabricated using the same set of materials and techniques. Cyclic mandrel bending with radius of 1 inch induces the crack initiation and propagation in the printed structure; however, the microstrip lines show reliable performance up to 10000 cycles of bending. The reliability of flexible wearable antenna based on this fabrication method will be further studied under cyclic bending and results will be presented at the conference.

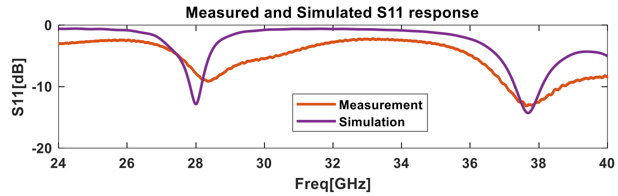


Figure 3. Measured and Simulated S11 response

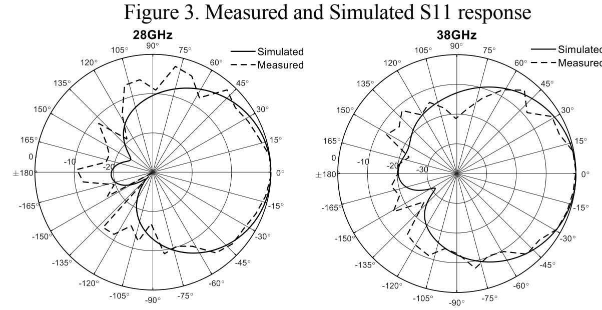


Figure 4. Measured and Simulated radiation pattern

IV. CONCLUSION

This paper presents a fully additively manufactured dual band patch antenna operating at 28GHz and 38GHz for 5G/mmwave wearable applications. It is the first demonstration of antenna design that is fabricated on a flexible low loss 3D printed Polypropylene material. The fabricated antenna prototype shows good performance and matches well with simulation. The proposed low profile fabrication process combing inkjet printing and 3D printing can be adopted in designing flexible wearable electronic systems. Further research can be focused on loss and power evaluation with human body and integration with WBAN. Based on previous reliability evaluation for microstrip samples from the proposed fabrication method, a mechanical testing system can also be developed to evaluate the reliability of this printed antenna.

ACKNOLEDGEMENT

This material is based on research sponsored by Army Research Laboratory under agreement number W911NF-19-2-0345. The U.S. Government is authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation thereon. The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of Army Research Laboratory (ARL) or the U.S. Government.

REFERENCES

[1] https://www.electronics-notes.com/articles/connectivity/5g-mobile-wireless-cellular/5g-nr-new-radio.php.

[2] Almohammed B, Ismail A, Sali A. Electro-textile wearable antennas in wireless body area networks: materials, antenna design, manufacturing techniques, and human body consideration—a review. Textile Research Journal. 2021;91(5-6):646-663. doi:10.1177/0040517520932230

[3] X. He, B. K. Tehrani, R. Bahr, W. Su and M. M. Tentzeris, "Additively Manufactured mm-Wave Multichip Modules With Fully Printed “Smart” Encapsulation Structures," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 68, no. 7, pp. 2716-2724, July 2020, doi: 10.1109/TMTT.2019.2956934.

[4] M. E. de Cos and F. Las-Heras, "Polypropylene-Based Dual-Band CPW-Fed Monopole Antenna [Antenna Applications Corner]," in *IEEE Antennas and Propagation Magazine*, vol. 55, no. 3, pp. 264-273, June 2013, doi: 10.1109/MAP.2013.6586683.