Curvature-Induced Performance Variations in Conformal Antennas of Wireless Sensing of Smart Jewelry

Wang Cheong
Faculty of Science and Technology
University of Macau
Macao SAR, China
mc35142@um.edu.mo

Yong-Yu Huang
Faculty of Science and Technology
University of Macau
Macao SAR, China
mc35143@um.edu.mo

Huawei Lin
The State Key Laboratory *of Radio Frequency Heterogeneous Integration and the College of Electronics and Information Engineering*
Shenzhen University, Shenzhen
Shenzhen, China
fehuawei@163.com

Chi-Hou Chio
Faculty of Science and Technology
University of Macau
Macao SAR, China
timchio@um.edu.mo

Kam-Weng Tam
Faculty of Science and Technology
University of Macau
Macao SAR, China
kentam@um.edu.mo

Rossana Kong
Gold Touch Macau
info@goldtouch.com.mo

***Abstract*—Conformal antennas are designed to accommodate different special curved surfaces and have shown advantages in areas such as aerospace and the Internet of Things (IoT), including wearables and automation technology of smart Jewelry sensing. In this study, the effect of antenna curvature on radiation efficiency and impedance matching is investigated by measuring the reflection coefficient S_{11} at different curvatures using a vector network analyser (VNA). The results show that although the resonant frequency is stable, the magnitude of S_{11} decreases with decreasing intermediate curvature and then changes with increasing curvature, which is attributed to the enhanced capacitance effect of the compensating inductive reactance. The best performance is achieved when the curvature is between 120 and 150 degrees, with minimal reflection and increased transmission.**

Keywords—Conformal antenna, Antenna curvature

I. Introduction

Conformal antennas fit closely into a variety of curved surfaces, making them particularly suitable for applications that require seamless integration, such as aerospace, automotive, mobile devices, and the Internet of Things. Conformal antennas provide advantages over traditional antennas in terms of aesthetics and concealment, while maintaining good radiation performance and signal coverage. They can be made with flexible circuits, printed circuit boards (PCBs), and 3D printing, providing design flexibility to meet the high-performance demands of modern communication systems [1]. For wearable devices such as smart Jewelry, conformal antennas adapt to the human body's curves and support Bluetooth communication [2,3], enhancing fit and aesthetics. By optimising the curve, engineers can improve radiation patterns and impedance matching to ensure efficient signal transmission and stable connections [1].

This study explores the influence of antenna curvature on key performance metrics such as radiation efficiency and impedance matching. While previous studies have focused on general performance enhancement, the effect of curve angle has been less explored. By measuring the reflection coefficient (S_{11}) of the conformal antenna at different curvatures, the results show that the best performance occurs when the curvature is between 120 and 150 degrees [4], when the reflection is minimised and the transmission efficiency is the highest.

II. The Impact of Curvature on Conformal Antenna Performance

The curvature of a conformal antenna significantly affects its performance across several key parameters:

Radiation efficiency is an important parameter for measuring antenna performance [1], especially in high frequency applications. Excessive curvature leads to radiation loss, which affects the signal quality. In practical applications, an optimal balance between curvature and radiation efficiency must be found to maintain high efficiency. The input impedance of a conformal antenna can lead to impedance mismatch, resulting in reflection loss and reduced signal transmission efficiency. Therefore, good impedance matching is key, and adjusting the curvature during the design process helps to achieve this goal. The curvature also affects its radiation pattern, potentially increasing the radiation intensity in some directions [2] and weakening it in others.

III. Measurement and Analysis

To analyze the effect of antenna curvature on performance, we conducted structured experiments. We quantified the curvature of the antenna, designed sectors with fixed arc lengths, and varied the angle in 30-degree increments to create different radii. The antennas were attached to these sector structures sequentially to ensure a tight fit to each surface. A vector network analyzer (VNA) was used to measure the S_{11} parameters of the antenna at different levels of curvature.

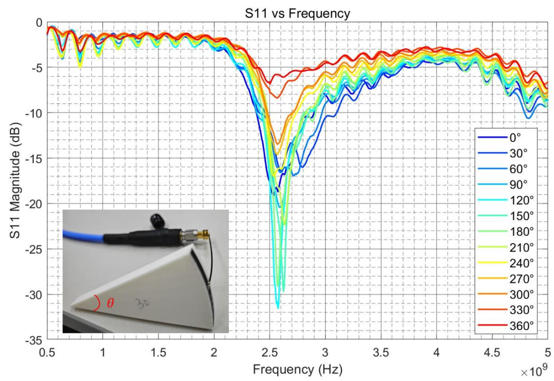

Fig. 1. S_{11} Variation under Different Curvature Conditions

The experimental design enables a systematic investigation of how curvature affects antenna performance metric. Fig. 1 shows the superimposed data from all our measurements. It is evident that the antenna ' s resonance points did not significantly shift due to the curvature (The fixed arc length is 4.5cm and the angle θ is changed every 30° to obtain different curvatures.) only the magnitude changed.

From Fig. 2, we can observe that the resonance frequencies of the antennas fluctuate between 2.5 GHz and 2.7 GHz, without showing a clear pattern. This suggests that the curvature of the antenna does not have a significant or consistent impact on the resonance frequency.

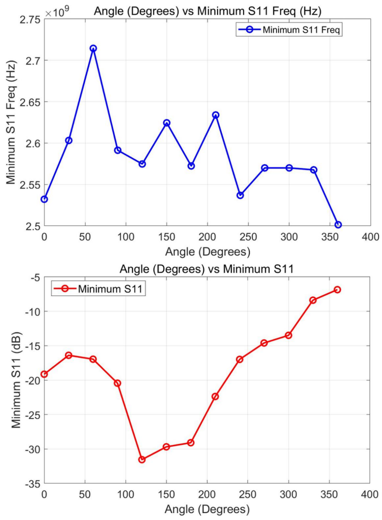

Fig. 2. The resonance frequency and magnitude of antennas with different curvature.

The resonance point of an antenna is primarily determined by its physical dimensions and the wavelength of the signal. Bending the antenna can alter the current distribution along its surface, causing only minor effects on the resonance. The minor fluctuations observed here indicate that the antenna ' s overall electrical length is minimally affected by the curvature. Therefore, the resonance frequency remains largely consistent despite changes in curvature.

For the S_{11} magnitude at the resonance as shown in Fig. 2, we observe an initial decrease and followed by an increase. This behavior has underlying causes. Although the antenna was originally designed to have impedance matched, with a target of zero imaginary impedance should be zero, attaching the antenna to a 3D-printed material caused the imaginary impedance to increase, even without bending.

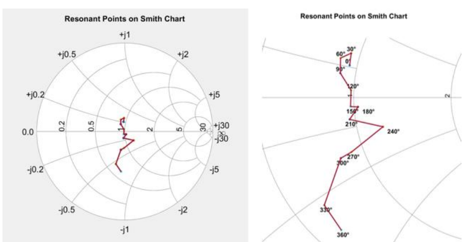

Fig. 3. Smith Chart of the impedance matching for antennas with different curvatures.

As we increased the curvature, Fig. 3 shows that the imaginary part of the impedance gradually decreased, indicating that the capacitive nature of the antenna became more pronounced. Increasing the curvature helps to counteract the inductive effect introduced by the material, tuning the antenna ' s impedance closer to the desired matching point.

In this experiment, the optimal matching point lies between 120 and 150 degrees of curvature. As shown in Fig. 3, he S_{11} performance is optimal in this range, indicating minimal reflection and maximum signal transmission.

The increase in capacitive characteristics with curvature increases may results from two factors:

1. Increase in Distributed Capacitance: Bending brings different antenna sections closer together, especially in dipole antennas or other multi-element antennas, where the coupling effect between adjacent sections is enhanced. This increased coupling leads to a rise in distributed capacitance between the different segments of the antenna. The increase in distributed capacitance directly causes the imaginary part of the antenna impedance to exhibit stronger capacitive characteristics.

2. Change in Electric Field Distribution: Bending changes the distribution of the electric field, especially near the surface and nearby regions of the antenna, intensifying the field in localized areas, further contributing to capacitive effects. This redistribution of the electric field results in the imaginary part of the antenna impedance exhibiting stronger capacitive characteristics.

IV. Conclusion

Optimizing curvature in conformal antenna design is crucial for achieving high performance. Adjusting curvature improves impedance matching, reduces reflection, and enhances transmission efficiency. This study shows that optimal S_{11} performance occurs at curvatures between 120 and 150 degrees, balancing capacitive and inductive effects. These findings provide practical insights for designing conformal antennas that maintain efficient performance on curved surfaces.

Acknowledgement

This work is funded in part by the University of Macau (File no. MYRG-GRG2023-00172-FST), Guangdong-Hong Kong-Macau Joint Laboratory of Millimeter-Wave and Terahertz Fund (2023B1212120002), the Science and Technology Development Fund, Macau SAR (File no. 0012/2023/AMR), and the Jiangsu Province Innovation Support Program Special Fund (File no. BZ2023061).

References

[1] L. Song, S. Fu, Q. Fang and Q. Wu, "Performance simulation and analysis of two kinds of cylindrical conformal microstrip Yagi antennas," 2009 3rd IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications, Beijing, China, 2009, pp. 576-579.

[2] Z. Qingchao, Z. Xiaolin and F. Jia, "The Optimization of Arbitrary-Shape Conformal Array Antenna's Performance Based on CSHPSO," *2019 International Applied Computational Electromagnetics Society Symposium (ACES)*, Miami, FL, USA, 2019, pp. 1-2.

[3] W. Yang, K. W. Tam et al., "Polarization rotation reflective surface based on artificial magnetic conductor," *Electronics Letters*, 50, 21, pp. 1500 – 1502, October, 2014.

[4] C. -H. Chio, K. -W. Tam and R. Gómez-García, "Filtering Angular Displacement Sensor Based on Transversal Section With Parallel-Coupled-Line Path and U-Shaped Coupled Slotline," in IEEE Sensors Journal, vol. 22, no. 2, pp. 1218-1226, 15 January, 2022.