URSI GASS 2020, Rome, Italy, 29 August - 5 September 2020

Feasibility Study of a Stretchable Antenna Conformed on an Expandable Cylindrical Surface

Rakib Hasan, Reyhan Baktur*
Department of Electrical and Computer Engineering
Utah State University
Logan Utah, U.S.A
rakib.hasan@aggiemail.usu.edu, reyhan.baktur@usu.edu

Abstract

Stretchable antennas are valuable to a wide range of applications, from biomedical field to transportation or weather forecast. The objective of this paper is to present a feasibility study for designing a stretchable antenna that has a better tradeoff between the gain and stretchablity, compared to previous studies. As the antenna under study is conformed to a cylindrical surface, the potential applications include integration with tires or balloons.

1 Introduction

Stretchable antennas are highly desirable in applications such as monitoring tire pressure, integration on balloons, or in biological and medical field such as integration with human or animal joints. Previous studies on stretchable antennas have been mainly focused on utilizing stretchable material such as composite conductor, liquid metal, stretchable ink, and thin film technology [1]-[4]. It has also been shown to achieve stretchablity through relative elastic material and antenna design that can withhold reshaping [5]. Those former studies, however yield either very low gain or limited strechability of no more than 10%.

Recognizing the trade-off between the stretchability and antenna gain as a key design consideration, in a recent study, we reported a cost effective and realistic method to achieve an effective antenna with a high stretch ratio [6]. The study was on a planar stretchable antenna. The objective of this paper is to examine a stretchable antenna conformed to a cylindrical surface. The potential application is for balloon or tire integration where the antenna is placed on a curved surface.

2 Design Philosophy and Antenna Geometry

Although there exist different stretchable conductors such as composite material, the elasticity of those conductors are not acceptable for applications such as balloons that needs much higher stretching ratio. The accessibility of the material is another challenge. In this study, the stretchable antenna is achieved through combing conductive rubber and copper to form a patch antenna. Such a combo-material design was chosen because a conductive rubber alone is normally very lossy and the efficiency of the antenna will not exceed 50% for lower GHz bands. The conductive rubber chosen in this study is Silver Plated Aluminum-filled Fluorosilicone conductive elastomer. It has conductivity of 50000 S/m, stretchability of 350% and the value of ϵ_r is 3.0. The design method in this study is to alternate conductive rubber and copper to form patch antenna. To keep it simple, the geometry of the rubber and copper has been kept rubber grids filled with small copper patches as illustrated in Figure 1.

The geometry of the rubber-copper antenna is shown in Figure 1, where a patch antenna made with rubber grids and copper patches is placed on a cylindrical substrate. As an initial study, we kept the substrate properties the same as a Rogers RT/duroid 5880 (ϵ_r=2.20, loss tangent = 0.0009), and it can be replaced to a more realistic material such as rubber of latex. The rubber grids were made taller than coper and its height reduces when being stretched.

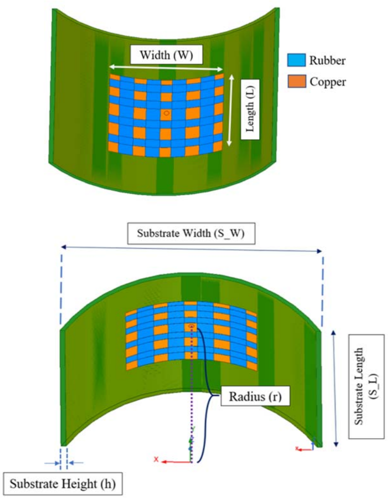


Figure 1. Geometry of the rubber-copper antenna.

The dimension of the antenna before stretching is listed in Table I. These parameters are also marked in Figure 1.

The study only examines the effect of the stretch ratio of the patch antenna on the gain, and therefore the ground is assumed to be copper. Although in the study, we also enlarge the ground proportionally, and this can be not realistic if the ground is made of copper, the examination on the ground will be performed in the follow up work.

Table I. Dimensions (mm) of the Antenna

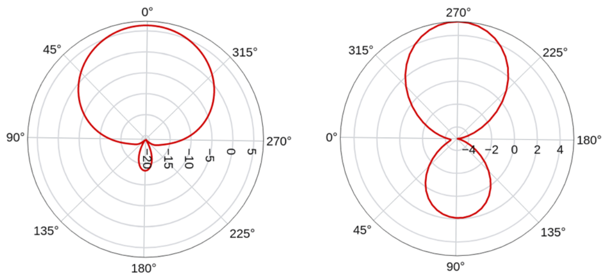
r	S_L	S_W	h	L	W
59.2	80	93	1.575	49.3	40

3 Results and Discussions

The antenna in Figure 1 was stretched proportionally along both length and width, the ground was also proportionally enlarged in order to maintain a constant curvature. The resulting antenna properties v.s. stretching was studied using HFSS and recorded as follows.

3.1 Changes in Radiation Pattern and Gain due to Bending the Antenna

As a baseline, the gain of a patch antenna made of rubber grids and copper patches were examined when it is flat and when conformed to a cylinder by bending as shown in Figure 1. As expected, bending the antenna makes the radiation pattern more omni (Figure 2) and therefore the gain reduces from 6.3 dB to 5.2 dB. The 5.2 dB gain was then taken as the reference for the gain under various stretching.



(a) Flat rubber-copper antenna (b) Antenna bent to conform on a cylinder

Figure 2. Effect conforming the patch antenna to a cylinder from being flat.

3.2 Resonant Frequency and Radiation Pattern V.S. Stretching

The antenna was stretched proportionally in length and width to 10%, 20%, 30%, and 40%. The resonant frequency v.s. stretch is summarized in Figure 3, and the results are reasonable because as the antenna stretches, the resonant frequency is expected to be lower.

The radiation patterns in the principle E plane are plotted in Figure 4 and 5. It is fair to conclude that the distortion in the radiation pattern was acceptable and the antenna functions reasonably well after 40% of stretching in length and width.

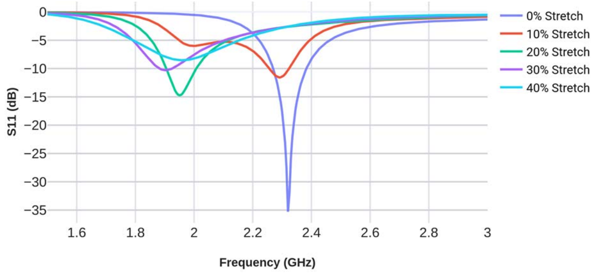
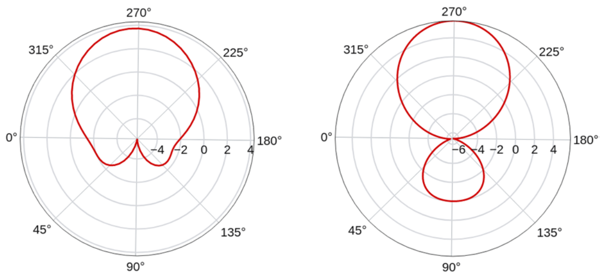
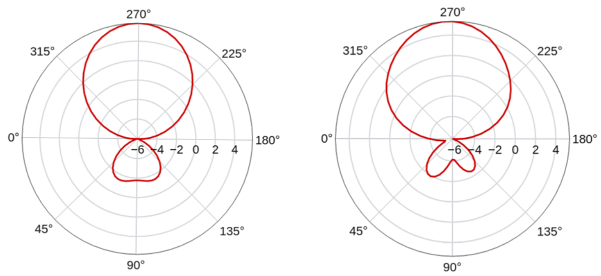


Figure 3. Frequency v.s. stretching.



(a) 10% (b) 20%

Figure 4. Antenna pattern v.s. stretching.



(a) 30% (b) 40%

Figure 5. Antenna pattern v.s. stretching.

3.3 Stretch Ratio Calculation and the Antenna Gain

Since the stretching in this study was performed in two dimensions, it is necessary that we compute the overall stretch ratio. Letting α being the stretch percentage along the length of the antenna (the stretch ratio in width is the same because we stretched the antenna proportionally), then the stretch ratio in area is $2\alpha + \alpha^2$. The antenna gain v.s. stretch ratio in area was summarized in Table II, and the linear stretch ratio α was listed as a reference. The resonant frequencies in Figure 3 was also listed in the table.

Table II. Stretch Ratio and Antenna Properties

Stretch Ratio	α	Frequency	Gain
0	0%	2.32 GHz	5.2 dB
21%	10%	2.29 GHz	4.0 dB
44%	20%	1.95 GHz	5.8 dB
69%	30%	1.90 GHz	5.8 dB
96%	40%	1.955 GHz	5.4 dB

3.4 Discussions

From the results in Figure 2-5 and Table II, it is seen that the antenna consistently functions well after being stretched to 96% in area. The data point for 10% was not quite fit in with the other numbers, and the reasons most likely were due to lack of further tuning. In addition, when the rubber was stretched for more than 20%, the geometry of the antenna differed significantly from the original because only the rubbers were stretched, and the copper remained the same. This could be the reason for the increase of the gain for higher stretch ratio. For the future design and studies, we may consider printing copper patches on a conductive rubber.

4 Conclusions

A feasibility study in achieving highly stretchable antenna was presented. The design, although still reply on the development of conductive rubber that is commercially available, does not require advanced material such as liquid polymer or nanowire, and the conductive rubbers are commercially accessible. Case studies were formed on an antenna conformed to a cylindrical surface by stretching the antenna and the cylinder. The antenna functions reasonably well even when the overall stretch ratio was higher than 90%, promising further investigation on this type of design and to deploy it with applications such as integration with balloons.

5 References

1. S. Cheng, A.Rydberg, K.HjortandZ.Wu, "Liquid metal stretchable unbalanced loop antenna, " Applied Physics Letters,94(14), p.144103, 2009.

2. A. M. Hussain, F.A.Ghaffar, S. I.Park, J. A.Rogers, A.Shamimand M. M. Hussain, "Metal/Polymer Based Stretchable Antenna for Constant Frequency Far‐Field Communication in Wearable Electronics," Advanced Functional Materials, 25(42), pp.6565-6575, 2015.

3. A. Kiourti, J. L. Volakis, "Stretchable and Flexible E-Fiber Wire Antennas Embedded in Polymer," IEEE Antennas and Wireless Propagation Letters, vol. 13, pp. 1381-1384, 2014.

4. Q. Liu, K. L. Ford, R. Langley, A. Robinson, S. Lacour, "Stretchable antennas," 6th European Conference on Antennas and Propagation (EUCAP), 2012.

5. H. Saghlatoon, M. Mahdi Honari, R. Mirzavand, P. Mousavi, A. Kumar, T. G. La, H. J. Chung, "A novel investigation on printed stretchable WLAN antennas," IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, 2012.

6. R. Hasan and R. Baktur, "Feasibility Study of Stretchable Antenna," submitted to 2020 IEEE Antennas and Propagation Symposium, Montreal Canada.