Studies on a Cavity-Backed Slot Antenna Made of a Conductive Textile Bent along a Spherical Surface

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***Abstract*—The reflection and radiation characteristics of a cavity-backed slot antenna fabricated of a conductive textile have been studied. The operation frequency is about 2.3GHz, and the variation in the characteristics is evaluated when the antenna is bent. The bending shape is spherical while the cylindrical bending case was reported previously. The excitation of the antenna is performed by an electromagnetic coupling. The conductive threads in the used textile are made by means of a traditional technology. The whole radiation pattern does not change much by bending on the radius of curvature of 200mm.**

I. Introduction

Wearable electrical systems are expected to have a new class of applications such as a personal health monitoring system, a sensor network for obtaining wearer's environment, intelligent personal assistants, and so on. Among them, body-centric wireless communication systems are introduced and paid much attention [1]. One example of the applications of flexible antennas under bending condition [2-5] is a wearble antenna. It is on body and should be able to be deformed along the body line. Tranceivers for wireless communications can be fabricated in a small size like a button-size while antennas cannot be miniaturized too much in order to keep better efficiency. Another application example is antennas for RFID tags on curved items.

Planar antennas, such as microstrip antennas, slot antennas and so on, have been widely used due to their low profile and easy fabrication. Curved structures of them, not in planar, have also been studied for tens of years. They, however, are designed as in a fixed structure of a curved shape, and they are not assumed to be modified into the planar or curved antenna. We have already reported on a soft antenna using a conductive textile and its characteristics of the flat case and the case of being bent roundly along a cylindrical surface [6].

Though other antennas such as a printed antenna on a soft film may be bent in a cylindrical shape, it is difficult for such planar antennas to be bent along a spherical shape. It is because the spherical bend needs partial deformation in the antenna size. On the other hand, a conductive textile can be bent along a spherical shape because it can stretch and be crinkled (i.e. flexibility or sometimes called as drapability). Different from the previous study [6], this paper reports spherical bending characteristics of a cavity-backed slot antenna using a conductive textile. The antenna itself is the same as reported previously. The measured and simulated results are shown for the variation of the reflection and radiation characteristics when the antenna is bent spherically and in a flat shape.

II. Cavity-Backed Slot Antenna

The fabricated antenna is a cavity-backed slot antenna (CBSA)[6][7] as shown in Fig.1. A rectangular cavity is made of a conductive textile sheet. The conductive textiles are created by incorporating silk and conductive threads into fabrics by means of weaving. The density of the conductive threads is 0.78 threads/mm in the warp and 3.7 threads/mm in the woof. The textile used here is the same as in previous works [6][8]. In those papers the details on the conductive thread and the weave style of the textile have been described. The conductive threads used in this study are not woven with fine metallic wires or filaments, but made by means of a traditional technology and have been used as ornamental yarn for clothes for hundreds years.

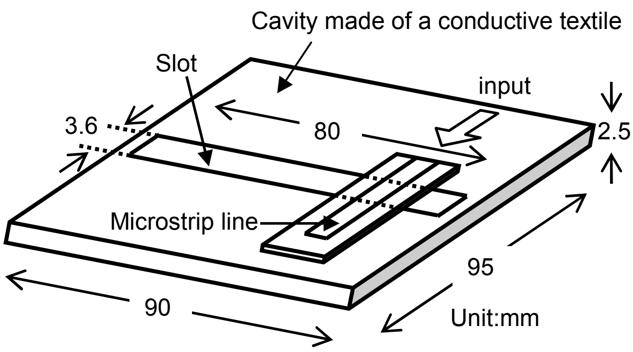


Fig. 1. Cavity-backed slot antenna.

Polyethylene foam sheets are wrapped with the textile in an envelope shape to make a flexible cavity. The slot is made by getting rid of the conductive threads in the designed shape. Since the antenna is made of a textile, the cavity does not have strict right corners but has round ones. The size of the cavity is about 95 x 90 x 2.5mm. In addition the thickness of the cavity is not always constant but deformed partially. The operation frequency is about 2GHz.

One of the big problems in electrical circuits consisting of conductive textiles is that soldering cannot be formed on them. To solve this problem, the excitation of the antenna is conducted by an electromagnetic coupling like the previous antenna. In applications of CBSAs as wearable antennas, the excitation of the slot from the front side is considered easier than setting the exciting point in the cavity. A feeder line crosses just in front of the slot and then connected to an open-ended microstrip stub line instead of touching the antenna conductor. The excitation is performed mainly by the magnetic field around the slot line coupling to that from the feeder line.

The position of the microstrip line for feeding shifts from the center of the slot line. The offset and the length of the open stub line are tuned to match the impedances of the feeder and the antenna. The microstrip line is made on a soft substrate in order to be bent along the curved antenna surface when it is bent. The substrate is a PTFE sheet of 0.5mm thickness, and the strip width is 1.8mm. The offset position and the stub length are roughly calculated by a simulation and tuned experimentally on the fabricated antenna. Finally the offset is 28.6mm and the stub length is 25.0mm.

III. Experimental Results

The reflection and radiation characteristics were measured for the flat and bending cases. The roundly bending case was carried out by setting the antenna cavity on the surface of a polystyrene foam in a spherical shape. The radius of curvature is rc = 200mm. The bandwidth, in the following descriptions, means the width of the frequency band at which the reflection is less than -10dB.

Figure 2 shows the reflection characteristics. The bandwidth is 230MHz for the flat antenna and becomes narrower to 162MHz for the bending case. The center frequency shifts lower by about 84MHz. The tendencies are similar to the case of the cylindrical bend that was previously reported. The frequency shift in this case is larger than that in the cylindrical bend on shorter radius of curvature.

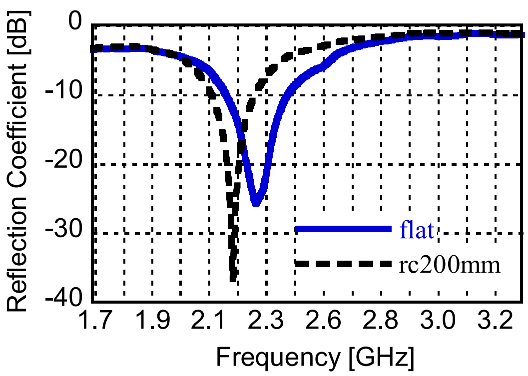
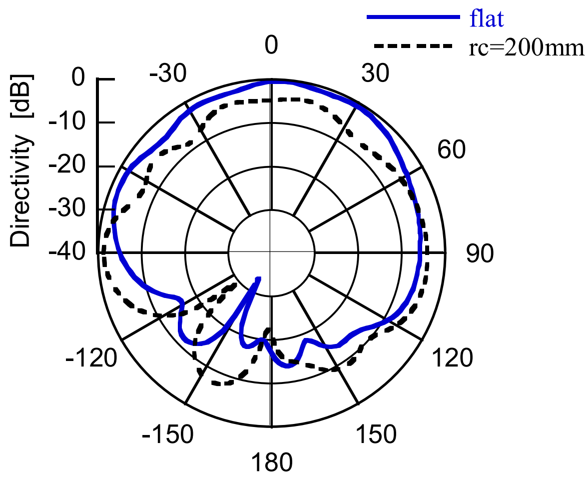


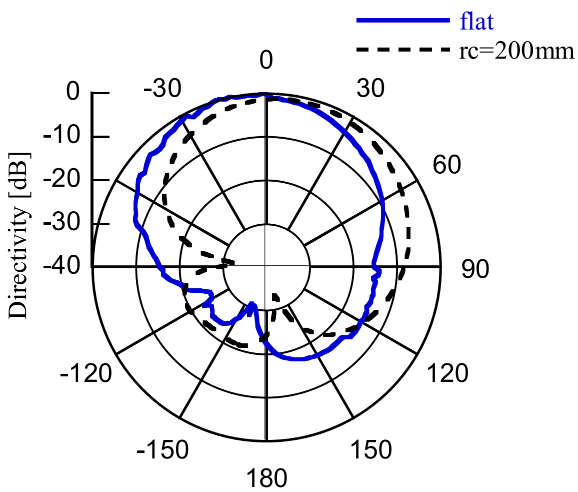
Fig.2 Reflection characteristics (measurement).

Next, the radiation pattern will be shown. The fabricated CBSA is used as a receiving antenna, and the transmitting antenna is a double-ridged waveguide antenna (Lindgren, model 3115). The distance of the two antennas is 2.5m, and the frequency is chosen as 2.33GHz.

The variation in the radiation patterns by being bent are shown in Fig.3 (a) and (b) for E- and H-plane characteristics, respectively. The microstrip feeder may affect the resonance of the slot, so the symmetry of the radiation from the slot is considered to be broken.



(a) E-plane pattern



(b) H-plane pattern.

Fig. 3 Radiation patterns (measurement).

In the E-plane radiation, big modification in the whole pattern is not seen. Several dB changes appear in the front side of -90 to 90deg. In H-plane pattern, the whole beam seems to rotate, which is similar to the cylindrical bending case. Since the slot itself is bent on the sphere, the plane including the slot (H-plane) is more affected than the plane normal to the slot (E-plane).

As described before, since the inner material of the cavity is very soft polyethyrene foam sheets, the cavity is not a strict rectangular solid but has irregular surfaces. The thickness of the cavity was made 2.5mm, but it may be uneven after repeatedly bending and flattening. The measured results have fluctuation for each experiment. The results for the flat case were not the same as those for the previously reported antenna though the size is the same as previous one. This is because the roughness of the soft cavity thickness.

IV. Simulation

In this section, the simulation is described. The simulation was carried out by HFSS of ANSYS based on the finite element method. The size of the antenna is the same as the fabricated one. The conductive textile of the cavity is modelled as an aluminum sheet.

When being bent, the cavity dose not keep the size of the rectangular solid. In the calculation model, the slot length keeps constant while the lengths between the corners of the cavity are a bit shortened to make the cavity along the sphere.

The reflection characteristics are shown in Fig.4. Little change is seen by the bend in the reflection for rc=200mm. For rc=150mm, the bandwidth becomes narrower and the center frequency shifts significantly higher. This shift is the opposite move comparing to the experimental result. The simulated structure may not be a good model for the deformation of the fabric cavity, especially for the deformation of the thickness. A better model and more study are necessary.

Figure 5 shows the calculated results of the radiation pattern. The frequency is chosen 2.33GHz. When being bent, little change in the pattern is seen in the E-plane pattern and in the direction from -60 to +60 degree of the H-plane pattern. It seems that the real deformation in the experiment is not taken well in the simulation model, for example the thickness change and the little movement of the excitation port, etc. Electric circuits using textiles always have such a problem as the deformation accompanying expansion and contraction, so their design in a wearable electrical system should be much attention in that point.

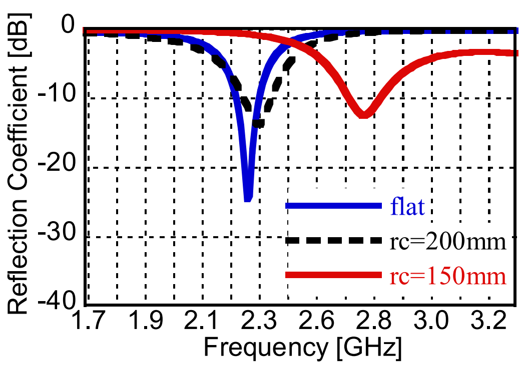
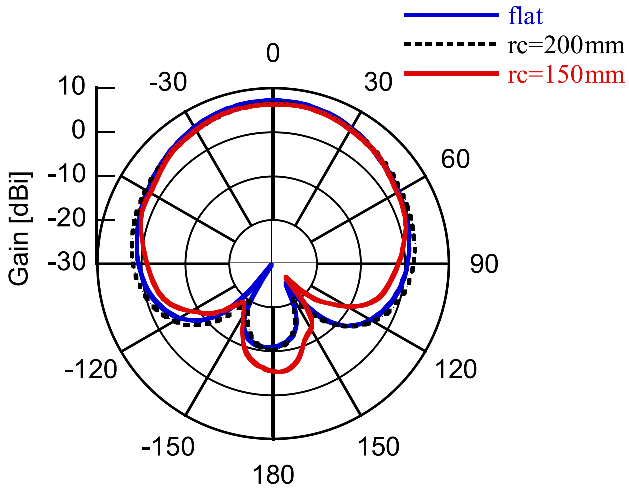
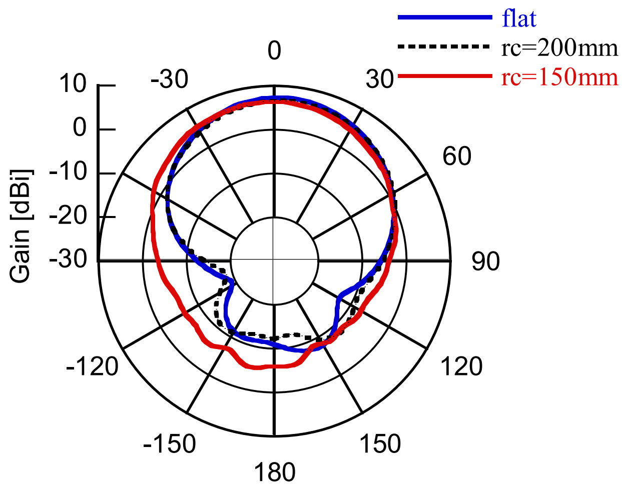


Fig.4 Reflection characteristics (simulation).

If the electromagnetic coupling between the antenna and the feeder is able to be presented as a distributed circuit model, the impedance tuning by the offset positioning and the stub line would be easier. The authors are now trying to make a circuit model of the coupling between the cavity-backed slot line and the microstrip line.



(a) E-plane pattern,



(b) H-plane pattern.

Fig. 5 Radiation patterns (simulation).

V. Conclusion

A flexible planar antenna has been measured and calculated for the use both in a flat shape and in a spherical bend, in considering applications on a human body or on a curved item. The operation frequency is about 2.3GHz. The excitation of the antenna is performed by an electromagnetic coupling to avoid soldering.

The antenna that is designed in a flat shape and then bent on a spherical surface is different from the one that is originally designed to use in a spherical shape (for example, the simulated model in this study). It is because such antenna follows expansion and contraction of the antenna material.

The stretch, crinkles and other deformations should be well modelled in the simulation and the design.

The measurement results show that such an antenna can be used as a microwave antenna without noticeable deterioration in the quality. This conductive textile employing a traditional technology is hopeful to use in wearable electrical systems and this antenna is verified as one of the applications.

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REFERENCES

[1] P. Hall, Y. Hao, K. Ito (edit), “Special issue on antennas and propagation on body-centric wireless communications,” *IEEE Trans. Antennas Propag.*, vol.57, no.4, Apr.2009.

[2] P. Salonen, Y. Rahmat-Samii, H. Hurme, M. Kivikoski, "Effect of textile materials on wearable antenna performance," *Proc. IEEE Antennas and Propagations International Symposium*, vol.1, pp.459-462, June 2004.

[3] Y.Ouyang, E. Karayianni, W. J. Chappell, "Effect of fabric patterns on electrotextile patch antennas," *Proc. IEEE Antennas and Propagations International Symposium*, vol.2B, pp.246-249, 2005.

[4] M. Tanaka, J. H. Jang, "Wearable microstrip antenna for satellite communications," *IEICE Trans. Communications*, vol.E87-B, no.8, pp.2066-2071, Aug. 2006.

[5] T. Yoshida, H. Shimasaki, M. Akiyama, "Wearable cavity-backed slot antenna using a conducting textile fabric," *Proc. 2007 International Symposium on Antennas and Propagation*, POS1-2, Aug.2007.

[6] H. Shimasaki, M. Tanaka, “Measurement of the roundly bending characteristics of a cavity-backed slot antenna made of a conductive textile,” *Proc. 2011 Asia-Pacific Microwave Conference*, Dec.2011.

[7] T. Hikage, M. Imada, M. Omiya, K. Itoh, "Development of low-profile cavity-backed slot antenna for microwave energy transmission," *IEICE Trans. Communications*, vol.J82-B, no.10, pp.1905-1914, Oct. 1999.

[8] H. Shimasaki, M. Tanaka, M. Akiyama, "Effects of woof style and weave on the surface resistivity of conductive textiles," *Proc. 2010 Asia-Pacific Microwave Conference*,Dec.2010.