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Wearable cavity-backed slot antenna using a conducting textile fabric

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1. Introduction

As wireless communication networks are growing larger and larger, mobile terminals would take more important part, and they have to be more compact and their functions should be further developed. An antenna is one of key elements in such mobile terminals in wireless systems. Thin, light weight, compact and flexible antenna would be of great use. Examples are; a flexible antenna integrated within clothing (so called a wearable antenna), and flexible RFIDs attached on objects in various configurations.

As for a wearable antenna, a microstrip antenna was proposed and the characteristics were reported in the case of being bent [1][2]. Microstrip antennas are, in general, considered to need a large area of the ground plane so as to be less affected by an object behind, for example a human body.

A cavity backed slot antenna (CBSA) [3][4] is also able to have a thin structure of a few mm thickness. A flexible CBSA consisting of aluminium foils and a polystyrene foam was reported and the radiation characteristics from the bent antenna are shown [5]. CBSAs are considered to be less sensitive to objects in the backside because of their backed cavity.

In this paper, a CBSA is fabricated with a conducting fabric and verified as a wearable antenna.

2. Operation frequency and slot size

The configuration of the fabricated cavity-backed slot antenna (CBSA) is shown in Fig.1. This structure is based on a cavity of a thin rectangular conducting box with a slot on its wall. A slot having length of $L/2$ and width of w is centered on the top surface of the cavity. The distance from each edge of the slot to the sidewall of the cavity is $L/4$ as shown in Fig.1. This distance corresponds to a quarter wavelength when the slot length is a half wavelength. The height of the thin cavity is h, and the offset of the feeding point from the slot center is d. Analysis is done using an electromagnetic field simulator based on the finite element method, Ansoft HFSS.

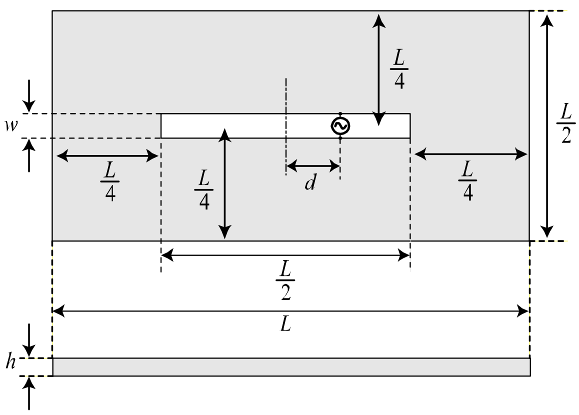

Fig.1 Configuration of the cavity-backed slot antenna.

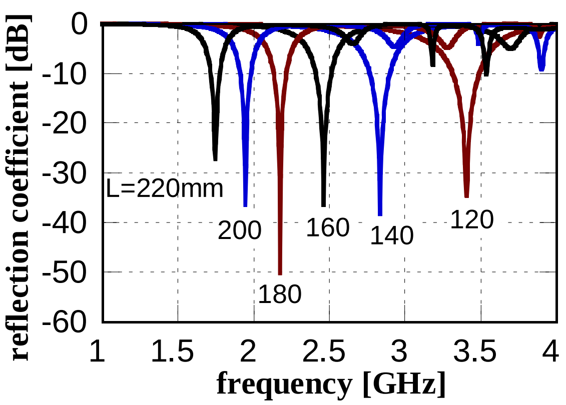

Fig. 2 Return loss characteristics.

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First of all, the resonant frequency is investigated in relation to the cavity and slot size, *L*. The return loss characteristics are shown in Fig.2 as a function of *L*. The offset, *d*, is chosen so that the minimum peak of the loss be less than -20dB. The cavity height, *h*, and the slot width, *w*, are fixed to *h*=2.5mm and *w*=4.0mm. The cavity is modelled as a perfect conductor and all other regions are air in the simulation.

Table 1 Resonant frequency and bandwidth.

L [mm]	*d* [mm]	frequency [GHz]	L/λ	bandwidth [MHz]
120	13.0	3.408	1.36	180 (5.3%)
130	16.3	3.096	1.34	154 (5.0%)
140	21.5	2.834	1.32	131 (4.6%)
150	22.8	2.628	1.32	116 (4.4%)
160	24.0	2.455	1.31	101 (4.1%)
170	27.3	2.324	1.31	90 (3.9%)
180	30.5	2.174	1.30	83 (3.8%)
190	31.8	2.043	1.29	83 (4.1%)
200	33.0	1.945	1.30	68 (3.5%)
210	36.3	1.844	1.29	64 (3.5%)
220	40.5	1.746	1.28	60 (3.4%)

The resonant frequency decreases with longer *L*, and it is 2.455GHz when *L*=160mm. The second resonances appear at lower frequencies than the twice of the dominant one. It is because of the higher modes in the cavity. Table 1 shows the offset, *d*, the first resonant frequency, the ratio of L/λ, and the bandwidth of -10dB as a function of the cavity's longer side, *L*. It is read from this table that *L* should be chosen as about 1.3λ for the target operation frequency (i.e. the slot length is $L/2=0.65\lambda$).

3. Prototype fabric antenna

Next, a prototype antenna is fabricated using a conducting cloth. The fabric cloth used here has conducting yarn of silk fibres wound up with thin aluminium fibres. The densities of the conducting yarn are 4 lines/mm for the woof and 0.65 lines/mm for the warp. A thin polystyrene foam sheet is wrapped with the conducting fabric in an envelope shape to make a flexible cavity. The configuration is chosen as *L*=160mm, *w*=4mm, and *h*=2.5mm so that the operation frequency be near 2.45GHz. The slot is made by getting rid of the conducting yarn in the designed shape. The feeding point is found so the reflection be minimum and set as *d*=25mm. The feeder is a microstrip line of 50Ω characteristic impedance, and it is connected to a coaxial cable of a network analyzer though an SMA connector. Figure 3 shows a picture of the prototype antenna with the feeder.

The measured reflection characteristic of the prototype CBSA is shown in Fig.4 together with the simulated result. The dominant resonant frequency is 2.460GHz in the measurement and 2.455GHz in the simulation, and the bandwidths on -10dB are 210MHz and 101MHz, respectively.

Fig.3 A slot antenna backed by a fabric cavity.

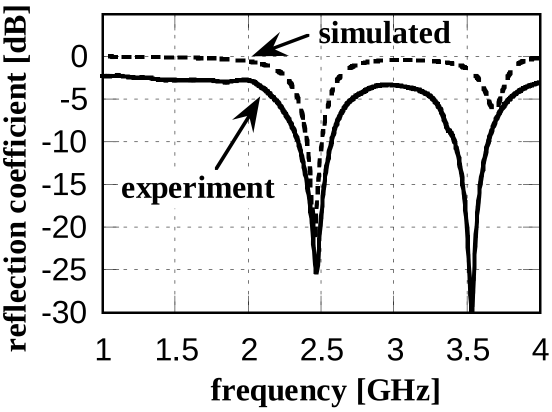


Fig.4 Return loss characteristics.

The resonant frequency is close to the designed one. The bandwidth is twice of the expected value. It is because *Q* of the fabricated antenna is low due to the low conductivity of the metallic yarn while a perfect conductor is used in the simulation model.

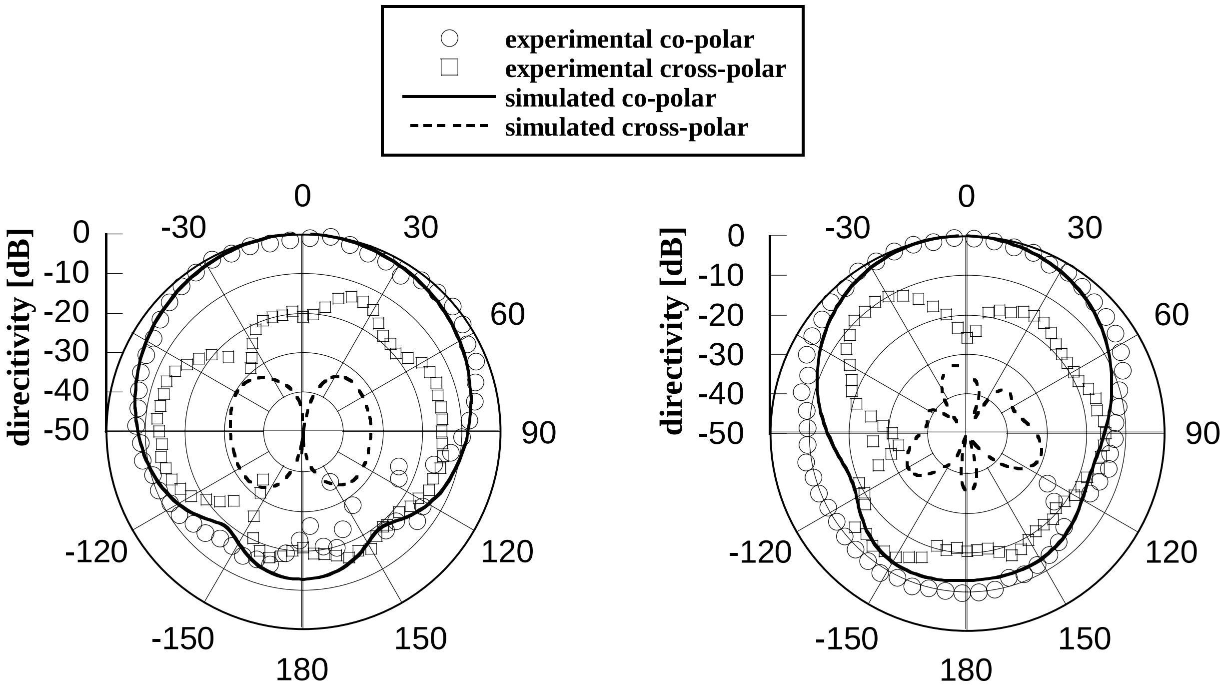
The measured and simulated radiation directivities are shown in Fig.5. Each graph shows both co- and cross-polarization characteristics. 0 degree means the front direction of the slot and 180 degree is the backside. It is seen in the E-plane pattern that the measured result agrees to the simulation for the co-polarization. The radiation level to the backside is about -10dB smaller than that to the front side. In the H-plane, the measured pattern is more isotropic than the simulated one. The cross-polarization power is larger than the simulated result in both E- and H-patterns.

The antenna gain is 3.18dBi. As a comparison, another flexible CBSA in the same structure made of an aluminium foil instead of a fabric showed the gain of 7.72dBi.

4. In cases of bending and being backed by water

Next, the resonant frequency shift and the change in the bandwidth by bending the antenna are measured. Two types of bending are studied; one is that the axis of the bend is parallel to the slot, and the other is that the axis is perpendicular to the slot in the top surface of the cavity. Bending angle is varied as 30, 60, 90 degrees, and unbent. Figure 6 is in the parallel case, and Fig.7 in the perpendicular case. In both cases, the resonant frequency decreases by bending, but broadening effect in the bandwidth seems slightly larger in the perpendicular case.

Finally, the effect of an object behind the antenna is studied. The prototype antenna is set on the sidewall of PET bottles filled with water and the gain is measured. Tow bottles are used and their size is about 100 x 80 x 280mm^3. The gain degrades into 2.11dBi, and this degradation by about 1dB is not significant in the antenna performance.



(a) E-plane.

(b) H-plane.

Fig. 5 Radiation patterns.

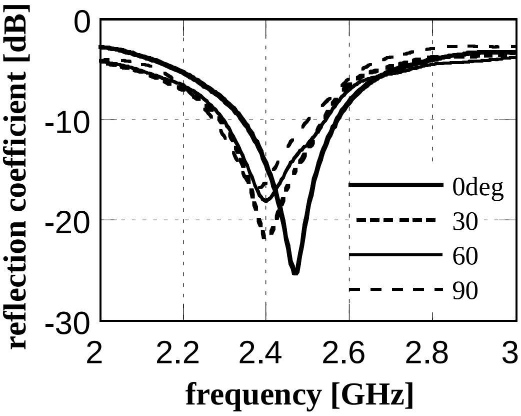


Fig.6 Return loss characteristics in case of parallel bending.

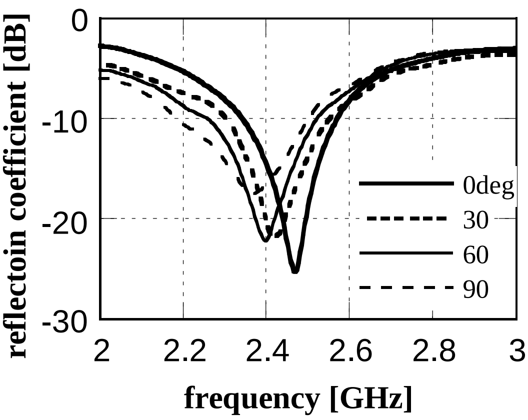


Fig.7 Return loss characteristics in case of perpendicular bending.

5. Conclusion

A slot antenna backed by a thin cavity is developed to a fabric antenna and its return loss and radiation characteristics are investigated by simulations and measurements. The effects of bending the antenna and being backed by water on the antenna characteristics are also studied.

While a flexible slot antenna using an aluminium foil has been reported already, the antenna proposed here has a cavity which is made of a conducting fabric. Due to that, the antenna is easer to integrate into clothes and the realization of wearable antennas with a human body is expected.

As future problems, the relationship among the yarn format, the conductivity of the fabric and the antenna *Q* should be studied, and the miniaturization of the cavity is to be devised. Polarization free or circularly polarized antennas may be required in some applications like the GPS system and RFIDs. It is reported that bending a circularly polarized antenna significantly degrades the axial ratio [6], so a design considering that fact is necessary.

Acknowledgments

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