Flexible Substrate Materials for Wearable Antennas

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***Abstract*—Several flexible substrate materials potentially usable for wearable antennas are presented in this paper, including rubber, leather and foam. The measured electrical characteristics are compared to show their pros and cons in view of wearable antenna design. Two planar inverted-F antennas based on two promising materials are designed, fabricated and measured. Material characteristics and experimental results suggest that natural rubber, which has a relative permittivity of around 6.4 is an appropriate flexible material for wearable antennas.**

***Index Terms*—Flexible materials; PIFA; wearable antennas.**

I. Introduction

Demands of flexible antennas in various wearable electronic systems have been increasing dramatically in recent years [1]. Beside the requirement of garment integration at a low cost [2], wearable antennas are expected to be flexible and lightweight in order to cope with the on-body operating conditions. Those characteristics are significantly affected by the choice of the antenna substrate.

Currently, most of the wearable antenna designs are using substrates composed of textile materials such as fleece or felt, or specialized foams. One of these specialised foams is Cumming Microwave PF4-foam, which has been utilized e.g. in [3], [4]. This material is flexible, lightweight and low loss (tanδ = 0.0001), however its low relative permittivity ε_r = 1.06 makes the wearable antennas larger than counterparts made using circuit board technology. Additionally, PF4-foam may have a prohibitive cost for mass production. Some other investigations on flexible antennas suggested the use of low-cost felt substrates [5], [6]. However, due to the high loss tangent tanδ = 0.02, the efficiency of the resulting antennas only reached about 70% [5].

In this study, promising flexible materials are introduced and assessed as substrate for wearable antennas. Two antennas using two selected promising materials are designed, fabricated and measured. Experimental results suggest that these materials are appropriate for flexible wearable antennas.

II. Material Consideration

In this study, three categories of low-cost flexible materials have been selected for assessment, including natural rubber, buffalo leather and foam. Relative permittivity and loss tangent of these materials have been measured using a Dielectric Assessment Kit by SPEAG and the results are displayed in Table I. The materials' flexibility is qualitatively demonstrated in Fig. 1.

Among these considered materials, natural rubber is expected to be the most appropriate material for wearable antenna applications due to its high relative permittivity and low loss, as measured in two different samples. Furthermore, important characteristics of natural rubber include perfect waster resistance and very high resilience which are highly desirable for wearable applications.

TABLE I
Flexible material characteristics (at 5.8 GHz).

Material		Relative permittivity	Loss tangent	Thickness (mm)
Natural rubber	Sample 1	6.31	0.002	5.1
	Sample 2	6.46	0.001	4.1
Buffalo leather	Side sample 1	2.68	0.063	1.5
	Side sample 2	2.30	0.033	1.6
	Shoulder sample 1	2.76	0.049	1.6
	Shoulder sample 2	2.33	0.057	2.5
	Shoulder sample 3	2.80	0.058	3.0
Foam	Blue	1.02	0.013	3.4
	Black	1.22	0.013	3.1
Felt		1.20	0.025	1.8

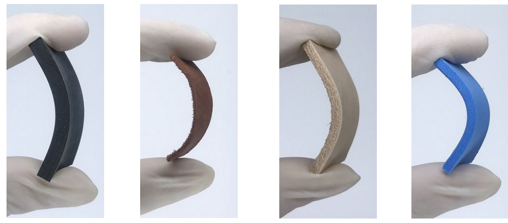

Fig. 1. Different flexible materials.

For buffalo leather, five different samples were tested, yielding almost similar relative permittivity at the average of 2.57. The second sample of side leather has the lowest loss tangent tanδ = 0.033, however this value is still high in term of suitability for antenna design. The two different samples of foam tested exhibited low relative permittivity and mid-range loss tangent with averages of 1.12 and 0.013 respectively. Those characteristics will lead to a large antenna size and modest efficiency. Considering that similar foams have been investigated in the past, these samples are not further considered.

In this study, the two most promising materials are selected for further assessment, namely the second sample of natural rubber and the second sample of buffalo side leather.

III. Antenna Structure

To investigate the potential of the two selected materials, two Planar Inverterd-F Antennas (PIFA) are designed using CST Studio Suite 2019 and fabricated. The antenna configuration with 50 Ω SMA probe feed is shown in Fig. 2, with the dimensions given in the caption. The quarter-wave patch and ground plane are realized using a silver-coated nylon

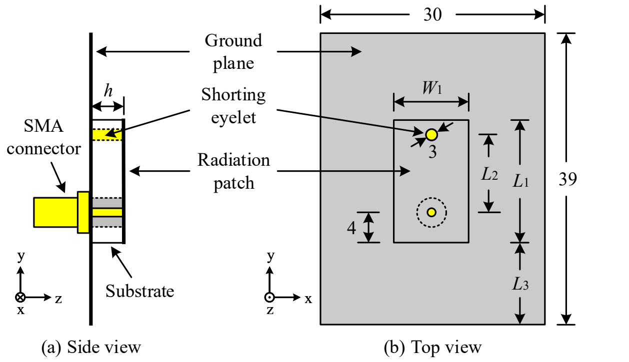

Fig. 2. Antenna configuration and dimensions (mm). Antenna using leather substrate: L_1 = 22, L_2 = 15.5, L_3 = 13, W_1 = 16, h = 3.2; Antenna using rubber substrate: L_1 = 16.4, L_2 = 10.4, L_3 = 15, W_1 = 10, h = 4.1.

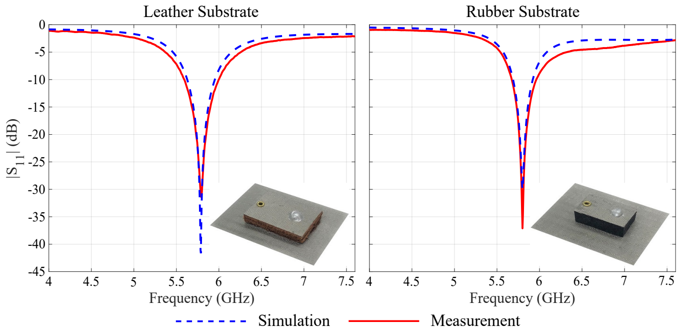

Fig. 3. Simulated and measured reflection coefficients of antennas using leather and rubber substrates. Fabricated antennas are displayed in the insets.

RIPSTOP fabric with a sheet resistance of 0.01 Ω/square. An eyelet with 3.0 mm outer diameter is implemented as a shorting post. Because of the high loss tangent of buffalo leather, a substantial substrate thickness is required to achieve appreciable efficiency [7]. Specifically, two layers of leather are stacked (yielding a total thickness of 3.2 mm) to realize the antenna substrate in this case. It is furthermore worth noting that due to the higher relative permittivity, the antenna using the rubber substrate is approximately half the size of the antenna made using the leather substrate.

IV. Experiment Results

The good agreement between simulated and measured reflection coefficients for the two antennas is illustrated in Fig. 3. The minor discrepancies occur mainly due to unavoidable fabrication tolerances. Due to its higher permittivity and smaller size, the antenna using the rubber substrate has a slightly narrower bandwidth extending from 5.68 to 5.96 GHz, compared to the antenna using the leather substrate which has a bandwidth spanning from 5.60 to 6.00 GHz.

Figure 4 shows the simulated and measured radiation patterns of the two antennas. Since the ground plane dimensions are identical for both antennas, the smaller resonant patch of the antenna using rubber leads to a lower back radiation than the antenna using the leather substrate. As expected, the antenna using the lower loss rubber substrate has a better realized gain and radiation efficiency of 7.39 dBi and 95.3% respectively, compared to 6.70 dBi and 70.3% for the antenna using the leather substrate.

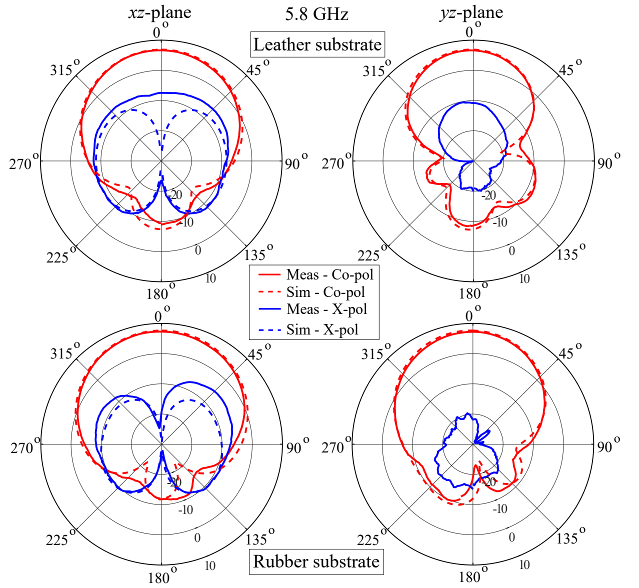

Fig. 4. Simulated and measured radiation patterns of the proposed antennas at 5.8 GHz.

V. Conclusion

Several potentially usable flexible substrate materials for wearable antennas have been assessed. Among the tested materials, two substrates - natural rubber and buffalo leather - were selected for design and fabrication of antenna prototypes. Natural rubber has been found to be an appropriate flexible material for wearable antennas due to its high permittivity (small antenna size), low loss (high antenna efficiency), low cost, high resiliency and water resistance characteristics.

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