Applications of Magneto-Dielectric Materials in Wearable Antenna Design

Ala Alemaryeen, and Sima Noghanian
Department of Electrical Engineering, University of North Dakota
Grand Forks, ND, USA
ala.alemaryeen@und.edu, sima.noghanian@und.edu

***Abstract*— This paper is focusing on suggesting realizing antennas using flexible Magneto-Dielectric (MD) materials for wearable applications. For proof of concept, different monopole antenna configurations are studied and their performances evaluated at 2.45 GHz. Monopole based MD antenna integrated a ground plane at a distance of 4 mm away from the antenna has showed a comparable performance to the monopole integrated flexible Artificial Magnetic Conductor (AMC) structure and a superior performance compared to the monopole based dielectric antenna. In addition, a study on the structural deformation of the proposed monopole configurations in terms of antenna bending in two perpendicular planes is presented. Results demonstrated the effectiveness of using flexible MD materials to stabilize antenna performance within the industrial, scientific, and medical ISM-2.45 GHz band.**

Keywords—magneto-dielectric material; monopole antennas; wearable antennas

I. Introduction

Wearable antennas design and fabrication are fast growing fields of research due to their potential use in healthcare, military, and public safety applications [1]. New materials always raise the hope that the fundamental limitations, e.g. human body loading and structural deformation effects on wearable antennas might be abrogated. Considerable efforts have been devoted toward development of Magneto-Dielectric (MD) materials in antenna design [2-3]. However, the current state of the art in wearable antenna design leaves much to be desired. In this paper, the design of a wearable monopole antenna using MD material is presented. Results of the study demonstrated that an ability to use flexible MD material in antenna design could greatly improve antenna performance stabilization in wearable applications context when the antenna experience structural deformation, e.g. antenna bending. However, this is challenging to realize using standard manufacturing methods and traditional solid MD materials. The development of MD materials itself is a study in mechanical and chemical engineering fields, as one must attempt to satisfy multiple of antenna goals that focus on minimizing material losses and designing materials for low cost production. In addition, MD materials generally have permittivity (ε_r) and permeability (μ_r) that are greater than 1 individually, by realizing MD material of $\mu_r/\varepsilon_r \approx 1$ the intrinsic impedance of MD material is approximately equal to intrinsic impedance of free space. Therefore, this is resulting in improved impedance bandwidth [2].

This work was supported by University of North Dakota.

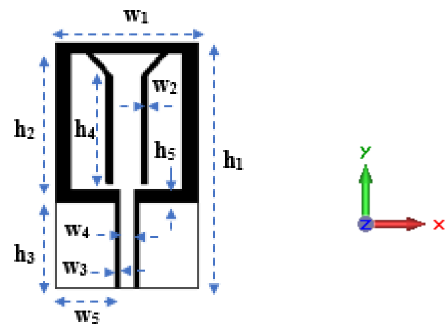


Fig.1. Configuration of monopole antenna. The optimized dimensions in *mm* are $h_1 = 57$, $h_2 = 32$, $h_3 = 20$, $h_4 = 25$, $h_5 = 3$, $w_1 = 32.1$, $w_2 = 1$, $w_3 = 0.3$, $w_4 = 3$, and $w_5 = 14$.

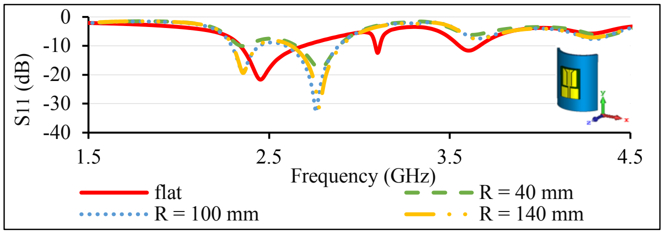
II. Antenna Design And Results

Different monopole antenna configurations are studied and their performances evaluated at 2.45 GHz using CST Microwave Studio [4] as summarized in Table I. Initially, the monopole antenna shown in Fig. 1 is designed using dielectric substrate made of Pellon fabric with a thickness of 3.6 mm, $\varepsilon_r = 1.08$, and dielectric loss tangent $\tan\delta_e = 0.008$. The antenna is backed with Artificial Magnetic Conductor (AMC) acting as a ground plane printed on 1.52 mm thick RO3003 flexible material with $\varepsilon_r = 3$ and $\tan\delta_e = 0.0013$. Configuration and dimensional details of the AMC structure can be found in [5]. Dielectric material is replaced by MD material with a thickness of 3.6 mm, $\varepsilon_r = \mu_r = 4$, and $\tan\delta_e = \tan\delta_m = 0.008$. As seen in Table I, using MD material in the antenna design did not improve the antenna gain that much. In addition, it resulted in a reduction in the antenna bandwidth compared to the antenna on a dielectric layer. However, the integration of a Ground Plane (GP) of copper material at a distance of 4 mm away from antenna, which is designed using MD substrate, shows an improvement in the antenna gain comparable to that obtained using AMC structure.

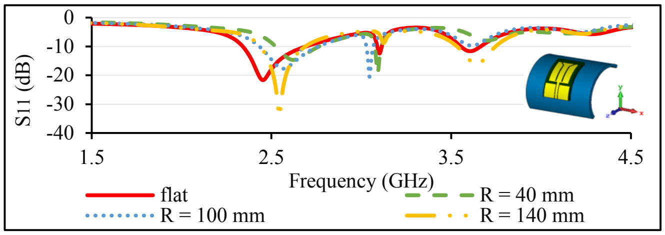
TABLE I. Performance Comparison of Stuided Antennas at 2.45 GHz

	Size (mm²)	*Gain (dB)*	*B.W.* [a]
Monopole, Dielectric	32×57	2.447	2.59 GHz
AMC Antenna	124×124	8.410	40 MHz
Monopole, MD [b]	32×57	2.487	1.05 GHz
Monopole, MD, GP [c]	84×107	8.120	350 MHz
Monopole, Dielectric, GP	84×107	3.671	-

[a] Bandwidth (B.W), [b] Magneto-Dielectric (MD), and [c] Ground Plane (GP)



(a)



(b)

Fig. 2. S_{11} of monopole based MD antenna bent in (a) E-plane, and (b) H-plane directions in free space.

Moreover, a higher bandwidth value is achieved compared to the antenna integrated AMC structure. In order to verify that the addition of the ground plane has in fact superior effects when the antenna design is based on MD material, another scenario is studied while integrating the GP with the antenna on a dielectric layer. Results demonstrated that the antenna gain did not improve as much as antenna on MD layer. In addition, the -10 dB bandwidth is shifted out of band of interest.

III. Potential of Magneto-Dielectric Material in Wearbale Antenna Design

In wearable antenna systems, it is difficult to keep the antenna flat all the time as the antenna will be subject to several shape distortion forms due to the human body movements. Therefore, investigation of the antenna performance on the dynamic body environment such as under bending conditions is one of the important factors to be considered. Bending radii (R) chosen in our investigation are: 40 *mm*, 100 *mm* and 140 *mm* to approximate a human adult's arm, leg and thigh. Moreover, investigations of antenna performance were executed for two bending directions: E- and H-plane. Fig. 2 presents simulated reflection coefficient (S_{11}) of the monopole based MD antenna in flat form and under aforementioned bending conditions. Radiation performance summary within industrial, scientific, and medical ISM-2.45 band of studied monopole antenna configurations are summarized in Table II and Table III for E- and H-plane bending conditions, respectively. The advantage of using MD materials in realizing wearable antennas can be seen through the performance stabilization when the antenna subject to different bending conditions to achieve the desired antenna functionality over the frequency range of interest.

IV. Conclusion

In this paper, the potential of using flexible MD material of $\mu_r/\varepsilon_r = 1$ in wearable antennas design in having stable performance under realistic conditions e.g. bending conditions is investigated. However, this is challenging to realize using standard manufacturing methods and traditional solid MD materials. Future research will continue investigating the possibility of fabricating flexible MD materials.

TABLE II. Performance Summary of Antennas (E-plane Bending)

Scenario	2.4 GHz		2.45 GHz		2.5 GHz	
	Gain (dBi)	*FBR*[a]	*Gain (dBi)*	*FBR*	*Gain (dBi)*	*FBR*
Monopole Antenna, Dielectric Material						
Flat	2.413	0.0089	2.447	0.0096	2.482	0.0108
R= 40 mm	2.547	0.7162	2.580	0.7401	2.603	0.7680
R= 100 mm	2.414	0.5940	2.403	0.6304	2.370	0.7836
R= 140 mm	2.546	0.5598	2.539	0.6330	2.519	0.6960
Monopole Antenna, Magneto-Dielectric Material						
Flat	7.610	9.4041	8.115	9.7870	8.152	10.265
R= 40 mm	6.975	9.7563	6.930	9.7342	6.786	9.7723
R= 100 mm	7.578	9.6801	7.640	9.8234	7.565	10.052
R= 140 mm	7.544	9.6354	7.606	9.8247	7.524	10.102
AMC Antenna						
Flat	1.937	10.882	8.410	22.4247	0.7752	8.4247
R= 40 mm	6.475	12.086	-0.1179	8.05620	0.1721	7.5251
R= 100 mm	8.802	17.224	2.6300	8.6005	1.2300	18.616
R= 140 mm	9.470	19.264	0.4224	8.2606	2.2060	21.753

a. Front to Back Ratio (FBR)

TABLE III. Performance Summary of Antennas (H-plane Bending)

Scenario	2.4 GHz		2.45 GHz		2.5 GHz	
	Gain (dBi)	*FBR*	*Gain (dBi)*	*FBR*	*Gain (dBi)*	*FBR*
Monopole Antenna, Dielectric Material						
Flat	2.413	0.0089	2.447	0.0096	2.482	0.0108
R= 40 mm	2.459	0.6097	2.526	0.6507	2.589	0.6987
R= 100 mm	2.640	0.6152	2.706	0.6570	2.768	0.6945
R= 140 mm	2.646	0.4014	2.697	0.4542	2.747	0.5162
Monopole Antenna, Magneto-Dielectric Material						
Flat	7.610	9.4041	8.115	9.7870	8.152	10.265
R= 40 mm	4.622	9.4182	5.002	8.0643	5.137	6.9332
R= 100 mm	6.554	10.292	7.137	9.9807	7.318	9.9007
R= 140 mm	6.580	10.192	7.349	10.044	7.664	10.088
AMC Antenna						
Flat	1.937	10.882	8.410	22.424	0.7752	8.4247
R= 40 mm	1.266	5.4520	0.500	2.6120	2.7130	20.890
R= 100 mm	2.189	11.116	2.664	22.505	-0.8567	18.928
R= 140 mm	4.352	24.404	2.791	17.242	0.3762	9.4850

References

[1] Z. Jiang, D. E. Brocker, P. E. Sieber, D. H. Werner, "A compact, low-profile metasurface-enabled antenna for wearable medical body-area network devices," *IEEE Trans. Antennas Propag.*, vol. 62, no. 8, pp. 4021-4030, Aug. 2014.

[2] J. Lee, J. Heo, J. Lee and Y. Han, "Design of small antennas for mobile handsets using magneto-dielectric material," *IEEE Trans. Antennas Propag.*, vol. 60, no. 4, pp. 2080-2084, April 2012.

[3] H. Mosallaei and K. Sarabandi, "Magneto-dielectrics in electromagnetics: Concept and applications," *IEEE Trans. Antennas Propag.*, vol. 52, no. 6, pp. 1558–1567, Jun. 2004.

[4] CST Microwave Studio, www.cst.com, visited August 2014.

[5] A. Alemaryeen and S. Noghanian, "AMC integrated textile monopole antenna for wearable applications," *ACES Journal*, vol. 31, no. 6, pp. 612–618, June. 2016.