Effect of a Flexible Polymer Dielectric and Magneto-Dielectric Composite Substrates in Antenna Array

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Abstract*—This paper presents a comparative study on the effect of the polymer dielectric and magneto-dielectric substrates in antenna array. A 1×2 multilayer antenna array based on polymer magneto-dielectric (PDMS-Fe_3O_4) composite substrate have been designed and fabricated to evaluate the contribution of such substrate materials in antenna array performance and characteristics. The proposed antenna was compared with another antenna fabricated on multilayer dielectric polydimethylsiloxane (PDMS) substrates which used as a reference antenna. Both antennas are operating at 5.8 GHz. The simulated and measured results of the proposed magneto-dielectric (PDMS-Fe_3O_4) antenna have shown an excellent enhancement in impedance bandwidth up to 1554 MHz (26.7%) compared to 470 MHz (8.1%) for a pure dielectric PDMS antenna that has the same substrate thickness. The gain and radiation efficiency of the magneto-dielectric based antenna is 7 dB and 60%, respectively, which indicate a good and satisfactory of antenna's performance.

Keywords*—*polymer substrate; magneto-dielectric; PDMS;* PDMS-Fe_3O_4, *multilayered antenna, array antenna.

I. Introduction

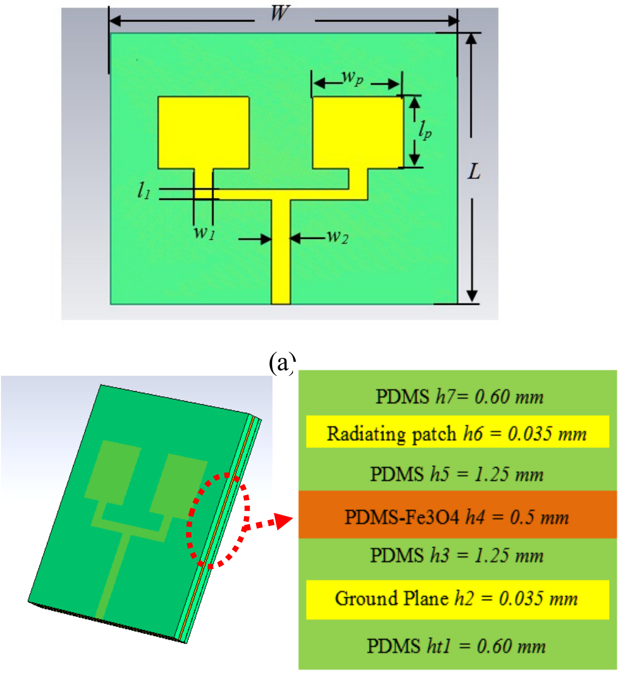
The modern wireless communication systems demand a new class of antennas and RF/microwave devices that are compact, conformal, flexible, robust and retain an excellent performance. However, substrate materials have the main effects on the antenna performance and characteristics above-mentioned [1]-[3]. The flexibility, conformality, size miniaturization and enhancement of the bandwidth, efficiency, and gain of the antenna are part of the challenges and difficulties that could not be overcome by using conventional dielectric substrates such as FR-4, Rogers, Duroid, Taconic board, and others. Moreover, these substrate materials tend to be heavy, rigid and inflexible and hence not suitable for light-weight and conformal antennas. In the last few years, the researchers in antennas and microwave field mainly focus on the electromagnetic properties of the materials such as permittivity, permeability and their dielectric and magnetic losses to improve antenna performance and features. Therefore, the utilization of magneto-dielectric substrate materials have existed and applied in RF microwave devices [4], especially in antenna designs for miniaturization dimensions [5], and enhancement bandwidth and efficiency [6]. There are many benefits for use of magneto-dielectric substrate with permeability and permittivity more than unity (ε_r and $\mu_r>1$) which have achieved an excellent enhancement in antenna bandwidth, and enables to miniaturize the size of the microstrip antenna with maintaining good efficiency and gain [7]-[8]. Recently, the advanced in modern technologies have made it possible to design a polymer-based composite substrate with favorable mechanical and electrical properties such as flexibility, thermal stability, low permittivity, modifiable electromagnetic properties such as permittivity and permeability. A few types of polymer-based and magnetic materials have been integrated with other materials such as ceramic, titanium, nickel, ferrite, and many other to introduce a new class of substrate with desirable RF features. There are few antennas based on polymer substrates presented in [9]-[13].

This paper presents numerical and experimental studies on the effect of a flexible polymer dielectric (PDMS) and magneto-dielectric (PDMS-Fe_3O_4) composite substrates in antenna array. The first antenna is designed and fabricated using a 30% of magnetite nanoparticles (10 nm) of iron oxide (Fe_3O_4) and 70% of polydimethylsiloxane (PDMS) which both composites to form the magneto-dielectric (PDMS-Fe_3O_4) substrate layer. Meanwhile, the second antenna is fabricated on a pure dielectric PDMS substrate which used as a reference antenna to evaluate the effect of such proposed substrate materials. The proposed antennas consist of a 1×2 patch array structure with 50 Ω microstrip line. Both antennas designed using CST MWS software and measured using an Agilent Technologies E8051C ENA Network Analyzer and 2D Anechoic Chamber.

The paper is structured as follows: Section II discussed the design geometry, layer structures, and substrate material properties. Section III shows the simulated and measured results of the two proposed antennas. Section IV includes the conclusion of this work.

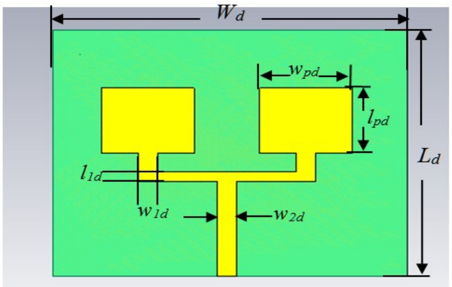
II. ANTENNA DESIGN GEOMETRY

Fig.1 illustrates the simulated geometry of a 1×2 multilayer polymer magneto-dielectric PDMS-Fe_3O_4 antenna array operating at 5.8 GHz. It consists of 2-element array patch with full ground plane, and the microstrip feed line has connected to the patch from the edge of the substrate using the 50 Ω microstrip line. The radiating patch and ground plane of the proposed antenna embedded inside the substrate. Fig.1(c) demonstrates the layer structures of the proposed antenna and its thickness. The magneto-dielectric (PDMS-Fe_3O_4) layer (*h4=0.5mm*) uses a composition of 70% PDMS and 30% magnetic (Fe_3O_4) nanoparticles (10 nm) of iron oxide. Fig. 2 demonstrates the reference antenna which designed using pure PDMS substrate and it has the same array structure and thickness as PDMS-Fe_3O_4 antenna. Both antennas' dimensions and parameters are tabulated in Table I.

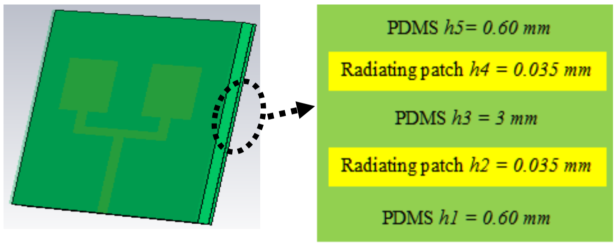


(b) (c)

Fig.1.The simulated geometry of a 1×2 PDMS-Fe_3O_4 antenna array, (a) radiating elements view, (b) side view, (c) layers structure.



(a)



(b) (c)

Fig.2.The simulated geometry of a 1×2 pure PDMS antenna array, (a) radiating elements view, (b) side view, (c) layers structure.

TABLE I
DIMENSIONS OF THE PROPOSED POLYMER MAGNETO-DIELECTRIC AND PURE DIELECTRIC ANTENNA ARRAY

Parameters	Dimension (mm)	Parameters	Dimension (mm)
W	65	W_d	71
L	50	L_d	55
w_p	17	w_{pd}	19
l_p	13	l_{pd}	13.6
l_1	2	l_{1d}	2.5
w_1	3	w_{1d}	3.5
w_2	3	w_{2d}	3.5

The permittivity and loss tangent of the proposed magneto-dielectric (PDMS-Fe_3O_4) composite substrate were measured using Agilent Dielectric Probe Kits and ENA Network Analyzer. Fig. 3 shows the measured permittivity and loss tangent of PDMS-Fe_3O_4 (70% PDMS, and 30% Fe_3O_4) which are 2.8 and 0.023, respectively. However, permittivity and loss tangent of PDMS-Fe_3O_4 are varied with the changing ratio of Fe_3O_4 to PDMS.

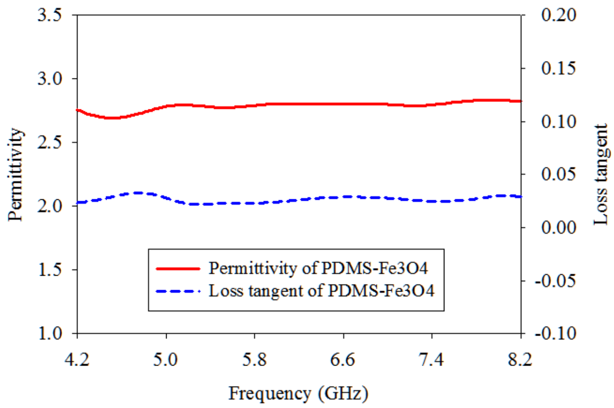
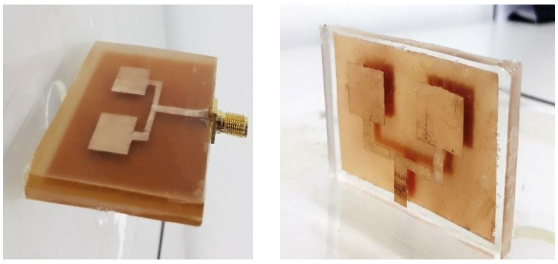


Fig.3. Measured permittivity and loss tangent of PDMS-Fe_3O_4

Fig.4 demonstrates the fabricated prototype of the multilayer 1×2 magneto-dielectric PDMS-Fe_3O_4 and pure dielectric PDMS antennas array. The prototype antennas are transparent, flexible, lightweight, and conformal.



(a) (b)

Fig.4. Fabricated prototype of 1×2 PDMS-Fe_3O_4 and PDMS antennas array, (a) prototype of PDMS-Fe_3O_4 antenna. (b) prototype of PDMS antenna.

III. Results and Discussion

Fig.5 shows the simulated return loss (S11) of the 1×2 multilayer polymeric magneto-dielectric PDMS-Fe_3O_4 and the pure dielectric PDMS antennas array. The multilayer PDMS-Fe_3O_4 antenna gives a return loss of -29 dB at the desired frequency of 5.8 (GHz). Meanwhile, a return loss of -24.32 dB is obtained by the pure dielectric PDMS antenna. Moreover, the bandwidth of the PDMS-Fe_3O_4 antenna improved up to 28.87% (1675 MHz) compared to 7.36% (427.2 MHz) presented by the pure PDMS antenna, see Fig. 5. Therefore, the magneto-dielectric substrate PDMS-Fe_3O_4 is pointedly enhanced the bandwidth of microstrip antennas.

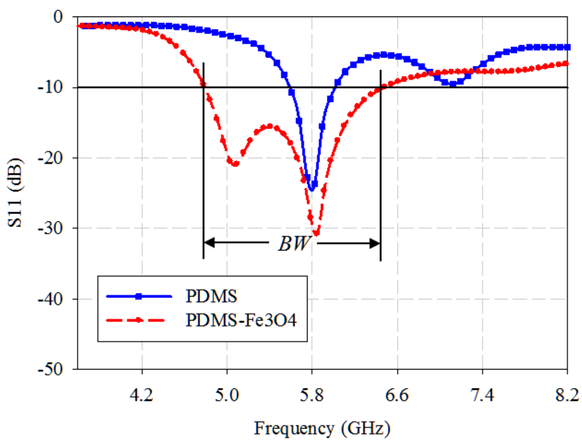


Fig.5. Simulated return loss (S11) of the proposed 1×2 magneto-dielectric PDMS-Fe_3O_4 and pure dielectric PDMS antennas array.

Fig.6 depicts the measured return loss (S11) of proposed antennas. The measured return loss (S11) for magneto-dielectric PDMS-Fe_3O_4 and the pure PDMS antennas at 5.8 GHz are -28.5 dB and -23.1 dB respectively as can be seen in Fig.6. The magneto-dielectric PDMS-Fe_3O_4 prototype achieved a bandwidth of up 1554 MHz (26.7%) in comparison to 470 MHz (8.1%) for the pure PDMS antenna array. Thus, the integration of magnetic (Fe_3O_4) nanoparticles with PDMS has a significant effect in improving the bandwidth of microstrip antennas.

Fig.7 illustrates the 3D and polar plot radiation patterns of the PDMS-Fe_3O_4 and PDMS antennas at 5.8 GHz. It is observed that the angle of radiation pattern of the pure PDMS antenna is radiating at 0°, while it shifted to 25° for PDMS-Fe_3O_4 antenna. A wide half power beamwidth (HPBW) coverage of about 63.50^0 and 83^0 for PDMS-Fe_3O_4 and pure PDMS antennas is featured in the *H-planes* respectively, see Fig.7(c) and 7(d). The pure PDMS antenna gives a 8 dB of gain and 70% of radiation efficiency. While the gain and radiation efficiency of PDMS-Fe_3O_4 antenna is 7 dB and 60% respectively. This is due to the presence of the magnetic materials that normally exhibit high losses. However, it still maintains good and satisfactory of antenna's performance beside an excellent enhancement in the antenna bandwidth.

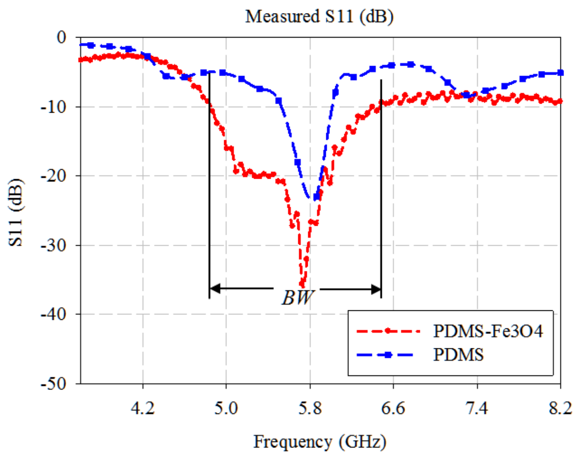
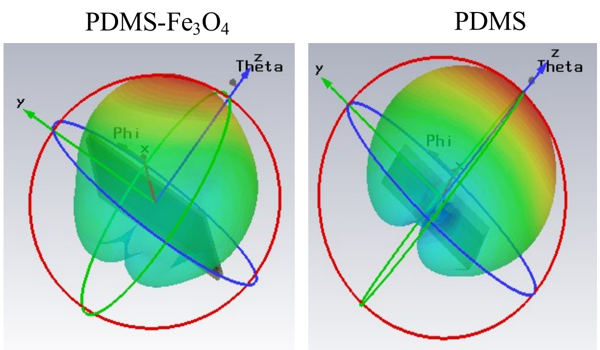
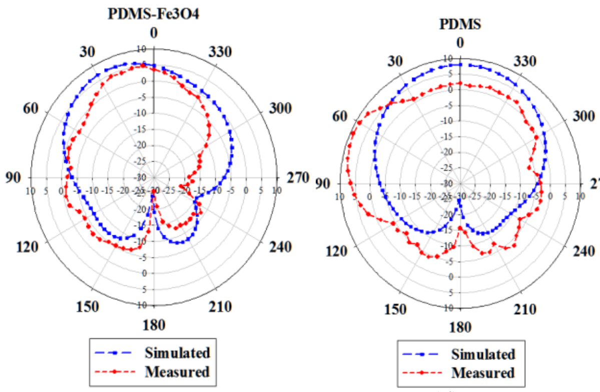


Fig.6. Measured return loss (S11) of the proposed 1×2 the magneto-dielectric PDMS-Fe_3O_4 and pure dielectric PDMS antennas array.



(a) (b)



(c) (d)

Fig.7. The simulated and measured radiation patterns of the multilayer 1×2 PDMS-Fe_3O_4 and pure PDMS antennas array, (a) 3D of PDMS-Fe_3O_4, (b) 3D of PDMS, (c) polar plot of PDMS-Fe_3O_4 (*H-plane*), (d) polar plot of PDMS (*H-plane*).

IV. CONCLUSION

An experimental and numerical study on the effect of the polymer dielectric and magneto-dielectric substrates in antenna array is presented. A 1×2 antenna array structure operating at 5.8 GHz using polymer magneto-dielectric composite substrate is designed and fabricated. A 30% of iron oxide (Fe_3O_4), magnetic nanoparticles solution are composited with 70% of polydimethylsiloxane (PDMS) to build up the polymer magneto-dielectric layer (PDMS-Fe_3O_4). The proposed polymer magneto-dielectric based antenna was compared with pure dielectric PDMS substrate for the same design array structure at the same resonance frequency 5.8 GHz. The measured results of the proposed magneto-dielectric (PDMS-Fe3O_4) antenna have shown a significant enhancement in the bandwidth up to 1554 MHz (26.7%) compared to 470 MHz (8.1%) for pure dielectric PDMS antenna. Furthermore, the measured return loss (S11) for magneto-dielectric PDMS-Fe_3O_4 and the pure PDMS antennas at 5.8 GHz are -28.5 dB and -23.1 dB, respectively. The gain and radiation efficiency of the magneto-dielectric based antenna is 7 dB and 60%, which is slightly lower than the pure dielectric PDMS antenna that has a gain of 8 dB and 70% of radiation efficiency because the presence of the magnetic materials that commonly have higher losses. However, the performance of the magneto-dielectric (PDMS-Fe_3O_4) antenna still retains good and satisfactory of performance.

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