Antenna Miniaturization using Magneto-Dielectrics

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Abstract

In this paper, we demonstrate miniaturization of antenna using magneto-dielectric nanocomposite material having permittivity and permeability values higher than one. Zinc ferrite epoxy nanocomposite layer validates the use of such material for antenna miniaturization over patch of the probe fed Microstrip Patch Antenna (MPA). The loaded magneto-dielectric material shifts the resonance frequency of the base antenna to lower frequency thus demonstrating the capability of miniaturization. The fractional frequency change can be used to design antennas with magneto-dielectric cover at specific operating frequency.

Keywords

Magneto-Dielectric, Antenna Miniaturization, Nanocomposite Material, MPA

I. Introduction

Antenna miniaturization using high permittivity materials as substrates has been attempted in the past [1]. The use of high dielectric material with $\varepsilon_r = 1$ are frequently used as a substrate to miniaturize the antenna and is often restricted to antennas operating at a single narrow band (e.g. Bluetooth and GPS). Such high permittivity non magneto-dielectric material increases the Q-factor and decrease the bandwidth [2], and radiation efficiency. To avoid the bandwidth limitation, magneto-dielectrics having not only relative permittivity, but also permeability have also been concerned as an antenna substrate. An experimental study of thick films formed by ferrite-epoxy and Co-Silica-BCB nanocomposite pastes characterized to assess their suitability for inductor and antenna applications carried out in [3]. These experimental results show that nanocomposites with high permittivity and permeability ($\varepsilon_r = \mu_r > 1$) making it a good candidature for miniaturized antennas. Similarly, self-biased bulk Ni-Co-ferrite magnetic films used as a potential mean to miniaturize a patch antenna by loading single layer and multilayer ferrite films [4]. The measurements on these magnetic patch antennas demonstrates that the resonance frequency can be shifted downward over a range of 12-40MHz, which indicates magnetic films do lead to miniaturized antenna by shifting down the resonance frequency. Magneto-Dielectric nanocomposite films provide a unique opportunity for achieving $\mu_r > 1$. With magneto-dielectric loading the resonant wavelength reduced by

$$\lambda_c = \frac{\lambda_0}{\sqrt{\varepsilon_r \mu_r}}$$

(1)

where $\lambda_0$ is free space wavelength. As it can be seen in the denominator, the antenna miniaturization is achieved by controlling both $\varepsilon_r$ and $\mu_r$. This gives antenna miniaturization i.e. lower fractional shifting of resonant frequency [5]. This paper demonstrates the miniaturization capability of magneto-dielectric thin film layer of zinc-ferrite-epoxy nanocomposite material on conductive patch of a probe fed MPA.

II. Background

For a single resonant mode (e.g., fundamental), the resonant frequency $f_r$ of microstrip patch antenna in air is given

$$f_r = \frac{\lambda_0}{2\pi \sqrt{LC}}$$

(2)

where $L$, and $C$ are the effective inductance and capacitance of the resonating patch in the air. The electromagnetic fringing fields on the surface of the patch couples capacitive with the magneto-dielectric layer, where in the real dielectric constant of magneto-dielectric layer primarily affect the capacitance $C$ in equation (2) [6]. The relative high value of the magneto-dielectric material refractive index $n = \sqrt{\varepsilon_r \mu_r}$ contributes to decrease the antenna resonant frequency. Magneto-dielectric material is a mixture of two dielectric materials, the fillers (zinc ferrite) with high permittivity and permeability greater than one and the host polymer matrix (epoxy resin and hardener). The addition of magnetic inclusions in to host polymer matrix increments the fringing field capacitance as the permittivity of inclusions is higher than the host polymer. Consequently the stored energy of the superstrate increases and hence the real part of permittivity. The fringing electric field of the patch antenna is the dominant coupling field to the magneto-dielectric superstrate dielectric layer. This capacitive coupling to the superstrate layer also used to measure the dielectric constant of the unknown test material [7].

III. Design of Circular MPA

Circular Patch antenna designed, fabricated, and tested for 2GHz. The geometry of the probe-fed circular patch antenna is as shown in the fig. 1(a). It is a basic circular probe-fed MSA on a FR-4 substrate ($\varepsilon_r = 4.4$) with a thickness of 1.6 mm and the loss tangent is about 0.0245. The main advantage of a circular MPA configuration compared to its rectangular geometry is that circular patch occupies less physical area. Thus in applications such as arrays, circular geometries are preferred. An SMA connector mounted on the ground plane feeds this antenna.
The inner conductor of the SMA connector attached to the radiating patch of the antenna while the outer conductor is connected to the ground plane. Advantages of probe feeding technique is easy to fabricate, easy to match for 50 Ω impedance, low spurious radiation, and its disadvantages are narrow BW, difficult to model specially for thick substrate. The design procedure involves calculating radius r of the patch and locating probe feed point for 50Ω impedance. The radius ‘r’ of the patch is given as in [8] by

$$r = \frac{F}{\sqrt{1 + \frac{2h}{\pi \mu |ln\left(\frac{\pi}{2h}\right) + 1.7726}}}$$

where

$$F = \frac{8.791 \times 10^8}{f_r^2 \varepsilon_{ef}}$$

$F$ = resonant frequency in Hz; $r$ = radius of the patch in mm; $f_r$ = resonant frequency in Hz; $\mu$ = magnetic permeability of the patch substrate; $\varepsilon_{ef}$ = effective dielectric constant of the substrate

From the above equations, the radius of the circular patch calculated to be 20.9656mm as shown in fig. 3(a). The antenna is simulated using IE3D, version 14.65 from Zeland Software Inc., USA. The feed position for antenna is optimized to get 50Ω matching characteristics at the centre frequency. For 2 GHz it is 11 mm from the centre of patch towards its circumference.

V. Results and Discussion

The antenna without layer and with magneto-dielectric layer condition is then measured for the resonant frequency, return loss, and bandwidth characteristics using vector network analyzer.

VI. Conclusion

In this paper, circular microstrip patch antenna with zinc ferrite-epoxy nanocomposite magneto-dielectric superstrate layer is studied. A magneto-dielectric material based on zinc ferrite nanopowder-epoxy combination is prepared and loaded to a probe fed circular patch microstrip antenna to validate the magneto-dielectric material and its capability to miniaturize the antenna. The primary effect of magneto-dielectric layer on the antenna resonant frequency, and return loss is studied.

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References


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