Abstract

This paper presents design for miniaturization and broadband antenna using the magneto dielectric material (MDM). Two antenna examples are presented to prove the ability of miniaturization and broad bandwidth by use of the MDM and the cylindrical magneto material (CMM). The first meander line antenna is very small with overall dimension of $0.078\lambda_0 \times 0.016\lambda_0 \times 0.0023\lambda_0$ at 433.92 MHz. The second example antenna with probe feeding structure sealed by the dual CMM shows high gain pattern and broad bandwidth. It confirms that antenna size can be minimized by control of relative permeability and permittivity and antenna bandwidth is also controlled by material structure.

1. Introduction

Recently, needs of the broadband antenna with small size is rapidly increased [1]. Customers also expect small and simple electronic devices such as handy phone terminal, PMP(Portable Multimedia Player) and PDA(Personal Digital Assistants) with impressive improvement in size reduction. So, the small size is often paid attention in antenna design. For example, Handy terminal size will become small progressively; on the other hand, the electrical antenna size will go to large because of many kinds of service by low frequency use. The fundamental limitations on antenna size have been studied and proposed by Wheeler [2] and Chu [3]. They had approached on a mathematical relationship between antenna size and $Q$. Because this limitation cannot be changed, the solutions for this problem can be sharing the resource with radiated part such as use PCB for ground plane in embedded antenna, using new material, or system solutions such as smart antenna.

As the basic research for antenna miniaturization by material use, R. C. Hansen and M. Burke [4][5] had proposed the basic concept of antenna used the magneto dielectric material (MDM) as substrate and it was operated at low frequency band. For antenna miniaturization, the research on artificial magneto-dielectric loading for improving the impedance bandwidth properties of microstrip antennas has been proposed by Sergei A. Tretyakov team [6]. However, it was appeared the decrease of bandwidth, gain and efficiency of antenna above research even though it had been used for the ideal MDM without tangential loss.

Most microstrip patch antenna designs until now have been based on the dielectric which is just changed the permittivity. This makes the antenna design procedure simpler because only one parameter of dielectric coefficients affects to antenna performance. On the other hand, this limits the ability of easily improving the antenna performance. Thus, the MDM can offer more number of parameters in order to improve the performance, so that some characteristics of antenna can be improved to satisfy the requirement of application. In this paper, second examples of patch antenna are presented to prove the ability of miniaturization by use of the MDM and the cylindrical magneto material (CMM). The first example antenna type with omni-directional radiation pattern is meander line on the MDM substrate and its resonance frequency is 433.92 MHz. The second type with directional radiation pattern is patch antenna that feeding pin is surrounded by the CMM. Unfortunately, the manufacturing process for this kind material requires a long time and a high cost, it is suggested only the theoretical design approach for two antenna types in this paper.

2. Antenna design

2-1. Meander line MDM tag antenna

The MDM can miniaturize the antenna size by the same factor with ordinary dielectric material, but values of permittivity and permeability are more reasonable [7]. Thus, the field confinement is
minimized and the medium is far less capacitive. Furthermore, since the characteristic impedance of MDM medium is close to that of the surrounding medium, it allows for ease of impedance matching over a wider bandwidth and suppression of the surface wave [8].

Fig. 1 shows the structure of meander line MDM tag antenna operated at 433.92 MHz, using probe feeding method [9]. The upper metal plate contains a conventional meander line structure and the length of one meandered section is 11 mm. The line width is chosen at 1 mm and the gap between two adjacent meandered sections is chosen at 0.5 mm in order to reduce the antenna size. Firstly, thinking as using the popular FR4 dielectric, the permittivity is 4.4. The total length of the meander line is required about one wavelength [10], and the calculated number of turns is 15.1.

However, actually the total length of meander line is required a little greater than one wavelength because of the mutual coupling between adjacent segments. Hence, the number of turns for this antenna is chosen at 16. In order to analyze the effect of parameters of MDM, the permittivity and permeability is intentionally chosen at different values as using for estimated above, 5.21—$j0.012$ and 2.39—$j2.58$, respectively.

These values are based on properties of one commercial Ni-Zn material. In the bottom metal plate, the ground size is also kept reduce to expect an omni-directional pattern. From simulation, the feeding point is found so that the input impedance is nearest to $50 \, \Omega$. The return loss of this initial model is shown in Fig. 2 (circular-marked line). The resonant frequency is lower than target frequency due to the higher values of permittivity and permeability compare with values using for calculation. The properties of MDM are changed to find the optimized values of $\varepsilon_r$ and $\mu_r$ so that the antenna resonates at 433.92 MHz with best performance. The results of return loss with respect to the varying the permittivity are shown in Fig. 2. It can be seen that when dielectric constant increases, the resonant frequency shifted to low frequency area. At $\varepsilon_r=1.71$ (rectangular marked line), good resonant characteristic is calculated with return loss of meander line antenna of $-30 \, \text{dB}$ at 433.92 MHz.

Next, in the complex permittivity component, only $\varepsilon''$ parameters as shown in Fig. 3 are changed. Value of $\varepsilon'$ is fixed at 1.71 and permeability is not changed. The effect of $\varepsilon''$ applies only to return loss level without frequency shifting even very small loss values of $\varepsilon''$ are chosen. The resonant frequency is almost same. It means that this loss property just affects to the efficiency of the antenna. The calculated best return loss of $\varepsilon''$ value is 0.004.

Fig. 4 shows the return loss results of the real part of relative permeability components of magneto-dielectric, when $\varepsilon_r =1.71—j0.004$. When the real part of permeability increases, the resonant frequency of antenna is lowered. This effect is well-known, similar with the change of permittivity. A good performance at 433.92 MHz is observed in the case of rectangular line. The calculated maximum gain is $-4.3 \, \text{dBi}$ at 433.92 MHz. The gain reduction does not appear so much as miniaturization of antenna size. This antenna design has omni-directional pattern characteristics.

2-2. CMM probe feeding structure

Fig. 5 shows the reference antenna structure to compare with design for feeder closed by the single and dual CMM. Block part in Fig. 5 is basically filled by air ($\varepsilon_r =\mu_r = 1$) [11]. The optimized antenna size, the resonant frequency, the maximum directivity gain and the bandwidth of the reference antenna as shown in Fig. 5 are $205 \times 90 \times 26.6 \, \text{mm}$, 0.92 GHz, about -6.69 dB and 0.32 GHz (0.72 ~ 1.04 GHz) at -10 dB below, respectively. The return loss results with respect to the various values of relative permeability and permittivity shows similar results of Fig. 2 and Fig. 4, when block part of Fig. 5 is filled with dielectric material and magnetic material substrate.

Tangential loss is assumed the zero in second antenna design, because tangential loss value variations of permittivity and permeability are very small as shown in Fig. 3. The parameters of $t_1$ and $r_1$ are thickness of magnetic material and distance between the surface of feeding line and inner surface of the single CMM, respectively. The parameters of $t_2$ and $r_2$ are thickness of the second CMM and distance between the surface of feeding pin and inner surface of the second CMM, respectively. The calculated return loss of antenna with the single CMM feeding line structure shows the results shifted to low frequency in comparison with one of antenna without the CMM, when $\mu_r$ equals to 10 and tangential loss is assumed zero. Even the values of $t_1$ and $r_1$ change; the resonant frequency shifted to low frequency is not almost changed. Therefore, it means that the resonant frequency depends on the relative permeability of magnetic material. In comparison with
the calculated return loss result between with single CMM and without CMM, when \( \mu_r \) equals to 10, the resonant frequency of antenna with a single CMM feeding structure of Fig. 5 is more shifted to low frequency direction. This means that the CMM feeding structure is more suitable than antenna with magnetic material structure used as substrate of block part as mentioned in Fig. 5 for antenna miniaturization.

Fig. 6 shows the calculated return loss of antenna with dual CMM feeding structure. The parameter values of t1, r1 and t2 are given. Triple resonant frequencies are appeared by the dual CMM structure. Broad bandwidth is calculated as shown in Fig. 6. Especially, the resonant frequency is shifted to low frequency and the bandwidth appears 0.04 GHz ~ 0.75 GHz at -10 dB below. The calculated gain is about 16 dB. This high gain is realized by antenna radiator with strong current of feeding line. It is considered that the electric current excited by feeding pin generates the magnetic field by Ampere’s law. This magnetic field reacts to the first CMM and the strong magnetic spin effects occur. In turn, the magnetic current generated at the first CMM by Faraday's law produces the electric field rotation in the sealed second CMM. Therefore, the strong current of feeder will be transmitted and the antenna gain will increase progressively.

3. Conclusion

This paper presents antenna design for the usage of MDM and CMM with probe feeding structure to miniaturize. The first proposed meander line antenna, whose size is very small with overall dimension of \( 0.078\lambda_0 \times 0.016\lambda_0 \times 0.0023\lambda_0 \), has return loss, and bandwidth of —38 dB, and 58 MHz at 433.92 MHz, respectively. The second patch antenna with probe feeding structure sealed by the CMM shows high gain pattern and broad bandwidth with comparison of antenna with single magnetic material substrate. Dual CMM feeding structure has dual resonant frequency and frequency is moved to low frequency direction. It means that antenna can be minimized by control of relative permeability and permittivity as well as magnetic material structure.

Acknowledgments

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References


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![Fig. 1. Structure of meander line MDM antenna designed at 433.92 MHz.](image1)

![Fig. 2. Return loss with respect to the real part of permittivity.](image2)

![Fig. 3. Return loss with respect to the imaginary part of permittivity.](image3)

![Fig. 4. Return loss with respect to the real part of permeability.](image4)

![Fig. 5. Feeder structure sealed by dual CMM](image5)

![Fig. 6. The return loss of dual CMM](image6)