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Thin Film Enabled Engineered Substrate for Miniaturized Antennas with Improved Bandwidth

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***Abstract*—This paper presents a novel engineered substrate enabled by patterned Permalloy ($Ni_{80}Fe_{20}$, Py) thin films for the development of miniaturized antenna with improved bandwidth. The perspective substrate is implemented with multiple layers of 100 nm thick Py thin film patterns embedded on arbitrary microwave substrate, and each Py layer consists of an array of Py patterns with a dimension of 15μm×40μm and 5 μm gaps among them to suppress the magnetic loss. An equivalent permeability of 2.398 is achieved for engineered substrate embedding with 10 layers of Py thin films. A simple patch antenna has been implemented on the engineered substrate to demonstrate the efficacy of designing miniaturized antenna with improved bandwidth, compared to antenna on regular substrate, results show that the developed antenna on engineered substrate has a size reduction of 47.3% and an improved bandwidth of 49.6%.**

Keywords*—*Py patterns; engineered substrate; miniaturization; bandwidth

I. INTRODUCTION

The development trend of modern wireless communications and radar systems are towards miniature in size and enhanced performance. However, the impedance bandwidth of electrically small antenna is roughly proportional to the volume of the antenna in wavelength. This means that when the antenna is downsized, the impedance bandwidth reduces [1]. Thus, it is still a challenge to design miniaturized antenna with improved bandwidth.

One of the most common miniaturization techniques is implementing an antenna on a high permittivity substrate [2]. However, the strong capacitive coupling between the antenna and the antenna's ground plane severely degrades its efficiency and bandwidth. To overcome this problem, magneto-dielectric substrates with permeability >1 have been developed, which still suffer from the issues of either high magnetic loss or bulk substrate. Magneto-dielectric substrate implemented with a single layer of Permalloy ($Ni_{80}Fe_{20}$, Py) thin film has been studied [3], which has increased permeability, and the magnetic loss of Py could be suppressed and its ferromagnetic resonance (FMR) frequency is increased by patterning it with selectively sizes and aspect ratios. With higher permeability, the same miniaturization factor ($n = \sqrt{\varepsilon_r \mu_r}$) can be achieved with lower permittivity, leading to the reduced coupling between the antenna and the ground plane [4], and will improve both the antenna efficiency and bandwidth.

In this paper, a novel engineered substrate implemented with multiple layers of patterned Py thin film embedded on a Roger RT/Duriod 5880 substrate is proposed for the design of miniaturized antenna with improved bandwidth compared to the antenna on normal dielectric substrate.

II. STRUCTURE DESCRIPTION

Permalloy ($Ni_{80}Fe_{20}$) which has high permeability value ranging from 200 to 9000 is a promising material for the construction of magneto-dielectric substrate. Although ferromagnetic resonance (FMR) frequency of Py limits its RF application, the magnetic loss of Py could be suppressed and its FMR frequency can be increased by patterning it with selectively sizes and aspect ratios. As shown in Fig. 1, the engineered substrate consists of arbitrary RF substrate and multiple layers of patterned Py thin films separated by the same vertical spacing. The thickness of a single Py thin film is 100nm, which is less than the skin depth of Py at working frequency to minimize the loss. Due to its high permeability, the eddy current is introduced on the surface of Py, resulting in resistive losses and lower effective permeability. To overcome this issue, the Py thin film is patterned in a dimension of 15μm×40μm with a 5 μm gap among patterns. In this paper, a simple patch antenna with the length of L and width of W is implemented on engineered substrate to investigate the performance.

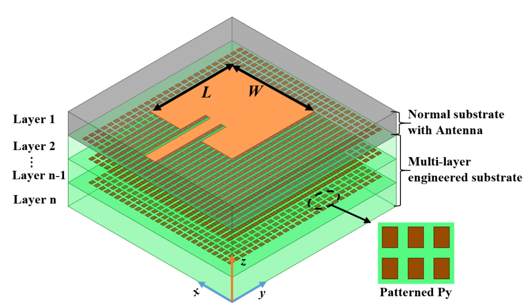

Fig. 1. Configuration of the proposed engineered substrate for antenna design.

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With the implementation of Py thin films, the engineered substrate has a high effective permeability and dielectric permittivity, providing a higher miniaturization factor ($n = \sqrt{\varepsilon_r \mu_r}$) for the development of antennas. In addition, the zero-order bandwidth for an antenna over a magneto-dielectric substrate with thickness of t can be approximated by [4]:

$$BW \approx \frac{96\sqrt{\frac{\mu_r}{\varepsilon_r}\frac{t}{\lambda_0}}}{\sqrt{2}\left[4+17\sqrt{\mu_r \varepsilon_r}\right]} \qquad (1)$$

Therefore, for a given miniaturization factor ($\sqrt{\varepsilon_r \mu_r}$), the antenna bandwidth can be enhanced by increasing μ_r/ε_r with the proposed engineered substrate.

III. Results and Discussions

In order to demonstrate the efficacy of the proposed engineered substrate in the design of miniaturized antenna with improved bandwidth. A 2.45 GHz patch antenna is first designed on a normal FR4 (ε_r=2.2, μ_r=1.0, tanδ= 0.02) substrate with a thickness of 601 μm. Then an antenna with the same operating frequency is implemented on the engineered substrate with the same FR4 dielectric and 10 layers of Py thin films. The implemented engineered substrate has an estimated 2.398 equivalent permeability for the antenna miniaturization [3]. Fig.2 and Table I compare the performance of the antenna on FR4 substrate and engineered substrate. Results show that a 47.3% size reduction is achieved for the antenna implemented on the engineered substrate without deteriorating its performance.

TABLE I. Performance Comparison of Antenna on Different Substrate

Substrate	***Antenna Dimension***	***-10dB BW***	***Max gain***
FR4	28×37mm (0.229λ_0×0.302λ_0)	70MHz (2.86%)	3.5 dBi
Engineeerd substrate	21×26mm (0.171λ_0×0.212λ_0)	73MHz (2.98%)	3.4 dBi

Keeping the same miniaturization factor of 2.09 for antenna on the normal dielectric substrate, a much lower permittivity is needed for the engineered substrate. The performance of the two antennas with the same dimensions but different substrate is compared in Fig. 3 and Table II. With the engineered substrate,

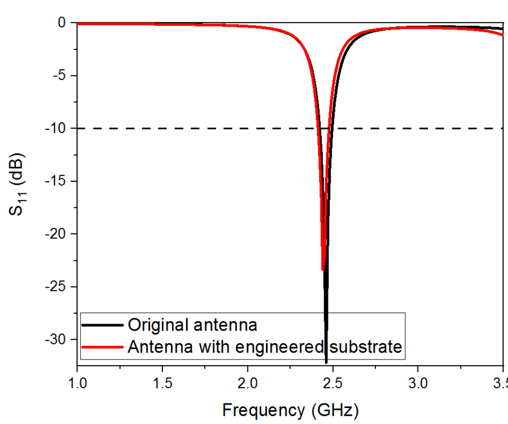

Fig.2. Performance comparison of the antenna on engineered substrate and normal substrate.

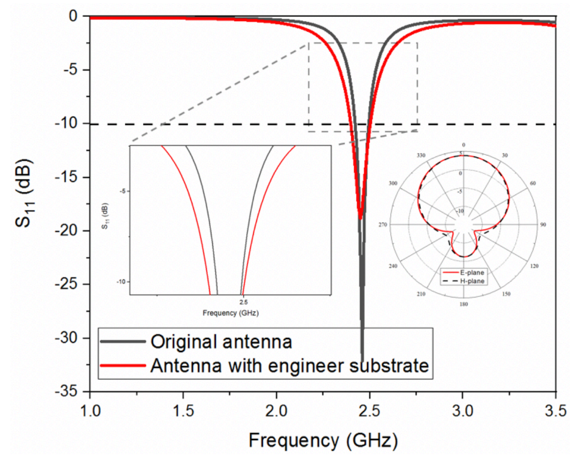

Fig. 3. Bandwidth comparison and radiation patterns of the engineered substrate enabled antenna.

the antenna can have a 49.6% bandwidth increase and higher gain as expected. The radiation pattern of the antenna on the engineered substrate also shows good performance as depicted in the insert in Fig.3.

TABLE II. Performance Comparison

Antenna	$\sqrt{\varepsilon_r \mu_r}$	***-10dB BW***	***Max gain***
Original antenna	2.09 (ε_r =4.4, μ_r=1)	70MHz (2.86%)	3.5 dBi
Antenn with engineeerd substrate	2.09 (ε_r =1.835, μ_r=2.398)	104.8MHz (4.28%)	4.2 dBi

IV. Conlcusion

This paper presents a novel engineered substrate enabled with multilayer Py patterns to provide high equivalent permeability. With such kind of engineered substrate, efficient miniaturization can be achieved without deteriorating the performance of the developed antenna. Compared to the normal dielectric substrate under the same miniaturization factor, antenna implemented on the engineered substrate has improved bandwidth. More size reduction and wider bandwidth can be achieved with more layers of Py film and optimum dimensions.

Acknowledgment

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