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REVIEW

A novel design of Fabry-Perot antenna using metamaterial superstrate for gain and bandwidth enhancement

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ABSTRACT

The procedure of gain enhancement for a microstrip patch antenna by employment of metamaterial superstrates and forming Fabry-Perot (FP) antennas is presented and discussed in this paper. In order to improve the gain characteristic of the microstrip patch antenna, a novel metamaterial superstrate with S-shaped elements is implemented. The main advantage of the presented S-shaped elements structure is that, it leads to achieve simultaneous enhancement on antenna gain and bandwidth. The microstrip patch antenna and its reflective surface are designed and modified for ISM-band, which operates at 5.725–5.875 GHz. A prototype of the designed antenna structure is manufactured and measured. The designed and fabricated antenna has a simple structure and does not include undesirable complexity of the recently reported FP antennas. The antenna has a good radiation behavior in the improved desired bandwidth of 5.65–5.935 GHz with more than 0.92% impedance bandwidth and 8 dBi gain improvement at maximum radiation direction.

1. Introduction

The small size, light weight, low cost, and ease of fabrication and integration of microstrip antennas are the advantages which make this type of antenna a good candidate for many applications in industry and mobile wireless communications. However, these antennas suffer from some weak points such as low impedance bandwidth and gain level, which lead to their poor performance in some specific applications [1]. Consequently, in recent years different planar and non-planar strategies and methods have been investigated and developed to overcome these drawbacks [2–7].

The array technique is a common method which is often used to achieve high directivity, broadband and circularly-polarized antennas. However, implementation of power dividers in array antenna structures introduces inevitable losses into the design [2]. So achieving higher gain levels with a low-profile antenna that utilizes a single radiating antenna element opposed to an array antenna structure is a desired design goal and the Fabry-Perot (FP) optical concept is a well-known solution to this demand. In recent years a vast research effort has been focused on FP structures and different FP antennas with various geometries have been proposed for different applications [8–12].

The original model of FP antenna consists of a printed microstrip radiator (any kind of cavity can be used as the radiating element), a conductive ground plane (under the radiating element), and a dielectric cover with thickness of a quarter of wavelength in dielectric ($\lambda_g/4$) that is located with the distance of half a wavelength in air ($\lambda_0/2$) from the plate on which the radiating element is placed. However, not only all its technical characteristics of directivity, or aperture efficiency, bandwidth for impedance matching, and sidelobe level (SLL) are not satisfactory; but also the thickness and weight of cover are not acceptable, especially at lower frequencies and that is why the majority of the proposed designs are presented for applications above 10 GHz [13,14].

However, main disadvantage of these antennas is their narrow bandwidth [15–17]. This is the fundamental limitation of antenna gain enhancement with FP structures. To overcome this shortcoming, multilayer structures based on EBG reflectors or feed patch array have been designed and presented [13,14,16]. In Ref. [13] a four-layer antenna structure is presented while in [18] through placing the EBG plane on the same plate of the radiating patch, with respect to the FP plate above them a two-layer structure is formed. Increasing superstrate layers as [13], leads to an inevitable enlargement of overall size and structural complexity of the antenna and surrounding the radiating element by EBG structure on a same plate as [18,19] which causes problems in integrating the radiating element with other components of the goal system.

There are several recently published works which have used superstrates consist of metamaterial elements, in order to improve

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the gain [20,21]. In the design of patch section of the microstrip antennas, the metamaterial elements can be used in order to increase the bandwidth of the antenna or create multi-band antennas [22,23] and also for reaching directivity increase it can be used in the superstrate of the microstrip and horn antennas [24,25]. Using the metamaterial unit-cell in the superstrate of the microstrip antenna [20,21] leads to a significant increase in the antenna gain which can be achieved by implementing multiple superstrates. The proposed antennas in these papers are wideband and the use of superstrate has led to a decrement in bandwidth of the antenna. The proposed antenna in this paper has a lower gain improvement level but it has other advantages such as using just a single layer of superstrate which improves gain and bandwidth of the antenna simultaneously and has a compact size and lower height in comparison with the mentioned antennas.

In this Letter, design of a single element microstrip patch antenna with a single superstrate for gain enhancement is presented and discussed. In order to maintain the low profile advantage of the microstrip antennas, the main purpose of this study is to increase gain of the antenna by means of just a single layer reflective surface without any other additional structures or layers while the bandwidth is enhanced. Searching and studying different characteristics of metamaterial elements for being used on the reflective surface resulted in an S-shaped element. The microstrip patch antenna and its FP reflective surface were designed for ISM-band applications at 5.725–5.875 GHz. A suitable improved impedance matching bandwidth, gain and radiation characteristics were obtained in the frequency band of operation. The following sections deal with the antenna geometry, design theory, simulation and experimental results.

2. Antenna design and configuration

The proposed FP microstrip patch antenna configuration with its design parameters is shown in Fig. 1, which is printed on an FR4 substrate with thickness of 1.6 mm, permittivity of 4.4, and loss tangent of 0.018. As it is observed in Fig. 1, the antenna structure consists of a simple coaxial-fed patch antenna and a reflective surface above it which is $\lambda_0/2$ far from the patch in space, at operating frequency. The patch antenna is designed for operation at 5.725–5.875 GHz and the reflective surface above the patch antenna is printed on a dielectric substrate with same qualities of the patch antenna substrate and consists of S-shaped elements. The final modified design parameters of the proposed antenna are listed in Table 1.

In the design of reflective structure the attention was focused on the gain improvement and bandwidth enhancement simultaneously and after considering many metamaterial elements such as

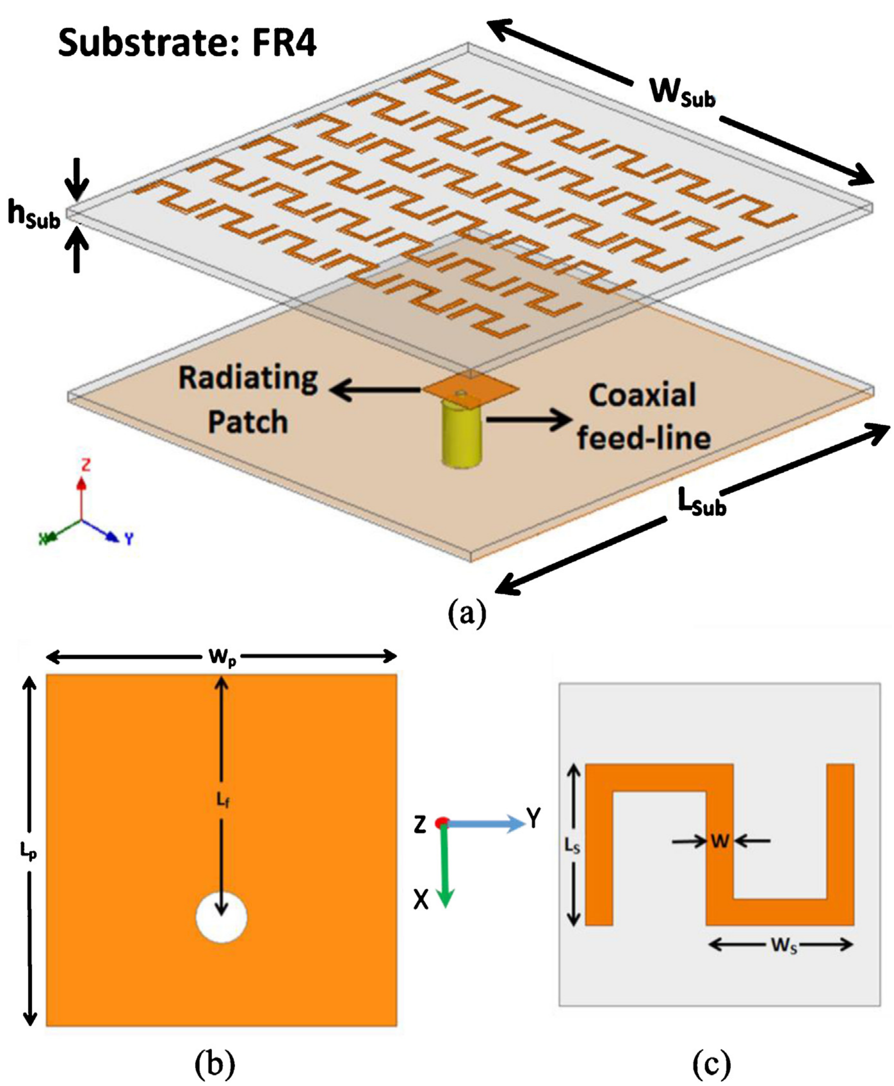

Fig. 1. The geometry of the proposed antenna: (a) side view, (b) radiating patch, (c) an S-element of the superstrate.