A NOVEL EMBEDDED UC-PBG STRUCTURE FOR MICROSTRIP ANTENNAS

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ABSTRACT

Conventional Uniplanar Compact (UC) Photonic BandGap (PBG) structure has the advantage of ease of fabrication. While such configurations are used for microstrip antenna design, the antennas suffer very strong backward radiation and hence reduced antenna efficiency. In this paper, a novel Embedded UC-PBG (EUC-PBG) scheme is presented to overcome the problem. Properties of the proposed EUC-PBG are examined and the characteristics of microstrip antennas on the EUC-PBGs are investigated. Such antennas demonstrate the improved radiation properties over the conventional UC-PBG antennas, and the evidence on surface wave suppression is also demonstrated. Experimental results show very good agreement with theoretical predictions.

INTRODUCTION

Photonic Band-Gap (PBG) structures originating from optics have been extensively applied in the microwave region, they are also referred as Electromagnetic Band-Gap (EBG) by some other researchers [1]. The application of PBG's at microwave frequencies includes the suppression of surface waves, the construction of Perfect Magnetic Conducting (PMC) planes and antenna gain enhancement. More recently, the anisotropic characteristics of PBG structures have been studied [2]-[4] and applied to the design of microstrip diplexer antennas [3], [4] and diplexering filters[8]. The Uniplanar Compact (UC) PBG introduced by T. Itoh [2] *et al* has the advantage of ease of fabrication, and most UC-PBG's have been designed by etching a periodic pattern on the ground plane. While such configurations are used for microstrip antenna design, the antennas suffer very strong backward radiation and hence reduced antenna efficiency. In this paper, a novel Embedded UC-PBG (EUC-PBG) scheme is presented to overcome the problem.

Studies on PBG structures indicate that materials whose dielectric permittivity vary periodically in space may present versatility in controlling the propagation of electromagnetic wave by prohibiting wave propagation over a certain frequency band. The concept of EUC-PBG is to fabricate the UC-PBG structures in layers inserted between the ground plane and the top of substrate layer forming a sandwich construction. In this paper, the Coupled Split Square Ring (SSR) pattern suggested by Pendry and Smith [5], [6] is used as the PBG element. The SSR used by Smith *et al* in constructing left-handed materials can be made resonant at wavelength much larger than the diameter of the rings. And since the Coupled SSR has higher Q than the conventional half-wavelength resonator, the proposed EUC-PBGs consisting of coupled SSRs exhibit extremely sharp cut-off in the forbidden band. Moreover, the concept of EUC-PBGs using SSRs could be extended to the fabrication of novel composite materials for microwave applications.

In the paper, properties of the proposed EUC-PBG are examined. Specifically, the propagation of electromagnetic waves over the proposed EUC-PBG structure is investigated compared with that over the conventional UC-PBGs. Particularly, the characteristics of microstrip antennas on the EUC-PBGs are investigated. Such antennas demonstrate the improved radiation properties over the conventional UC-PBG antennas, and the evidence on surface wave suppression is also demonstrated. For demonstration, all designs are made at around 6GHz and simulation results are presented with experimental verification.

DESIGN OF SSRS

The Coupled Split Square Ring (SSR) pattern suggested by Pendry and Smith [5], [6] is used as the PBG element. The SSR used by Smith *et al* in constructing left-handed materials can be made resonant at wavelength much larger than the diameter of the rings. The structure and dimensions of SSR are shown in Figure 1. The resonant frequency of SSR is usually calculated from the approximation of its effective permeability and the full accurate analysis is not trivial. In

[5], empirical formulations are only given for calculating the resonance of coupled split circular rings. In [7], approximation of resonant frequency is given for an array of square loop-wire structure, but not applied to the proposed SSRs. In this paper, since the square ring is split, the outer ring of SSR can be approximated as a half-wavelength stripline resonator, the resonant frequency can be easily determined from its physical length. The inner split ring is to generate larger capacitance and thus lower the resonant frequency significantly [6]. In general, the smaller is the gap between the outer and inner rings, the lower resonant frequency will be generated. However, the gap used in this paper is comparable to the width of SSRs (Figure 1), and thus the frequency lowering is not considerable. This is demonstrated by two numerical simulations using Agilent Momentum™. The resonant frequency of outer SSR alone is 7.60GHz, and with coupled inner SSR, it becomes 7.25GHz. Therefore, the circumference of outer SSRs can be approximated using

$$l \approx \frac{\lambda_g}{2} = \frac{c}{2\sqrt{\varepsilon_{eff}} f_{res}}$$

where f_{res} is the proposed resonant frequency of SSRs, ε_{eff} is effective permittivity of the medium on which SSRs are fabricated and c is the speed of light in free space.

DESIGN OF EUC-PBG USING SSRS

The proposed EUC-PBG is made from an array of SSRs mentioned above. Figure 2 shows structure of the EUC-PBG, where the SSRs are inserted between the ground plane and the top of substrate layer forming a sandwich construction. The planar circuit elements (microstrip patch antenna in this case) can be fabricated on the top of substrate. The period of the EUC-PBG l_p is given using

$$l_p \approx \frac{c}{4\sqrt{\varepsilon_{eff}} f_c}$$

where f_c is central stopband frequency of the EUC-PBG.

Figure 3 shows a photograph of the EUC-PBG fabricated on RT/Duroid 5880 with substrate thickness 1.524mm, dielectric constant 3. The structure is also simulated using Agilent Momentum™, and its simulated result is shown in Figure 4 together with the measurement result. Both results show reasonable agreement, and the difference is due to the air-gap existed between the two dielectric layers in the EUC-PBG. Since the Coupled SSR has higher Q than the conventional half-wavelength resonator, the proposed EUC-PBGs consisting of coupled SSRs exhibit extremely sharp cut-off in the forbidden band (Figure 4).

DESIGN OF MICROSTRIP ANTENNAS

Microstrip diplexer patch antenna is used to verify the EUC-PBG properties. The detailed design approach can be found from [3] and [4]. For simplicity and comparison, two antennas are designed and their dimensions of the antenna remain unchanged. One of the antennas is fabricated on RT/Duroid with substrate thickness 3mm, dielectric constant 3, and another is fabricated on the proposed EUC-PBG substrate (Figure 2). The dimensions of the rectangular patch are 14.3mm and 12.5mm for resonant operation at 5.5GHz and 6.0GHz respectively. The 50Ω transmission line width is 7.6 mm. The widths of the impedance transformers are 1.26mm. Figure 5 shows a photograph of microstrip diplexer patch antenna on RT/Duroid substrate assembled with SMA connectors. Two antenna characteristics are to be examined to verify the effects of applying EUC-PBGs. They are surface wave suppression and isolation enhancement between two antenna ports. It is known that substrate thickness should be chosen as large as possible to maximise antennas bandwidth and efficiency, however, such antennas also possibly excite surface-wave. For maximum operating frequency, the substrate thickness should satisfy:

$$h \leq \frac{0.3c}{2\pi\sqrt{\varepsilon_r} f_u}$$

where f_u is the maximum operating frequency and ε_r is relative permittivity of the substrate. In our case, ε_r =3.0 and h =3mm, and therefore the maximum operating frequency f_u is about 2.8GHz. So the surface-wave contribution to the antenna design is not negligible.

ANTENNAS MEASUREMENT AND DISCUSSION

Two antennas have been fabricated on a thick dielectric substrate and a EUC-PBG substrate respectively. Figure 6 show that antennas return losses and isolations at different ports. The antenna on conventional dielectric substrate resonates at 5.6GHz and 6.4GHz at different ports, which agree the theoretical predictions. For antenna on the EUC-PBGs, the resonance is at 5.7GHz and 6.8GHz respectively. The shifted resonance is due to change of effective dielectric constant caused by embedded SSRs, and it is surprisingly noted that the variation is not very significant. Figure 7 demonstrates the improvement on antenna radiation patterns. For the antenna without EUC-PBGs, a lot of ripple and distortion are evident on various cuts of radiation patterns at two different ports. They are due to the violation of additional fields from the surface waves originating at the edges of the substrate. In this case, this effect is mainly contributed by the surface mode TM_0 since this mode has no cutoff. On the contrary, radiation patterns of the antenna on EUC-PBGs are smooth and symmetrical, more importantly, compared with conventional UC-PBGs [3], [4], the antenna backward radiation is reduced and hence its efficiency is further improved.

The isolation between two ports of diplexer antenna is also investigated. Figure 6 shows a little improvement on the isolation. This indicates that surface-wave contribution to the dipelxer antenna isolation can be neglected.

CONCLUSIONS

A novel Embedded UC-PBG (EUC-PBG) scheme is presented to overcome the strong backward radiation caused by the conventional UC-PBG antennas with PBG patterns on the ground plane. Compared with the antenna without PBGs, the evidence on surface wave suppression by EUC-PBGs is demonstrated. Experimental results show very good agreement with theoretical predictions. The SSRs used in this paper can be a very good candidate for PBGs size reduction, and hence opens up the possible applications of PBGs at lower microwave frequencies. Moreover, the concept of EUC-PBGs could be extended to the fabrication of novel composite materials for microwave applications.

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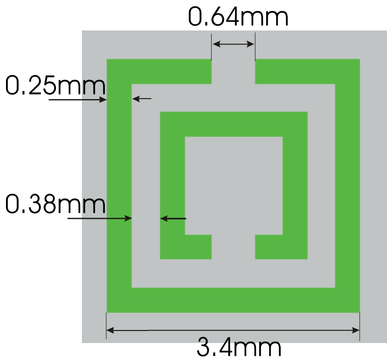

Figure 1. The structure of SSR

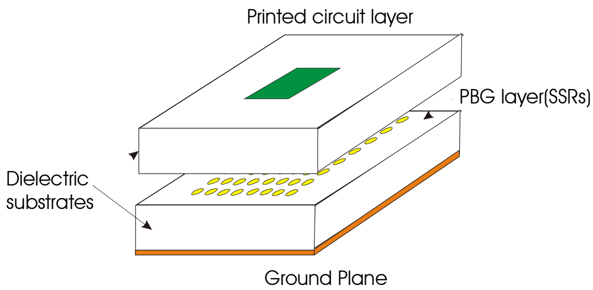

Figure 2. The structure of EUC-PBGs and its application

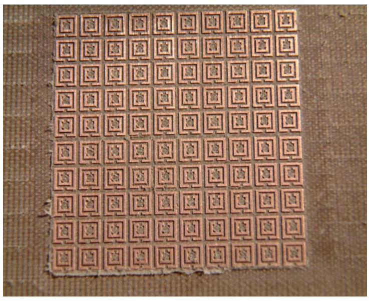

Figure 3. An array of SSRs for EUC-PBGs

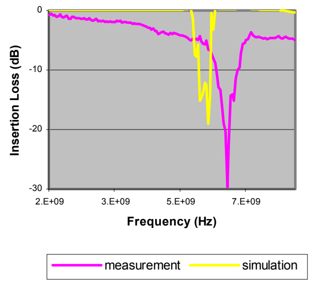

Figure 4. simulated and measured EUC-PBG responses

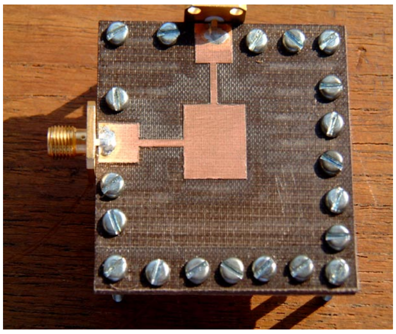

Figure 5. Photograph of a microstrip dipelxer antenna

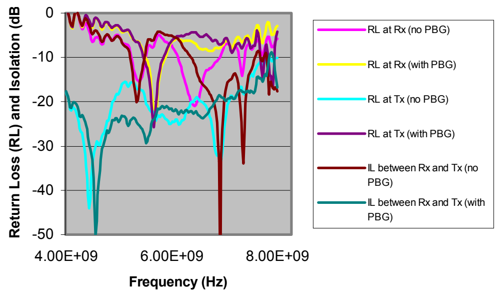

Figure 6. Measured antenna return losses and isolations

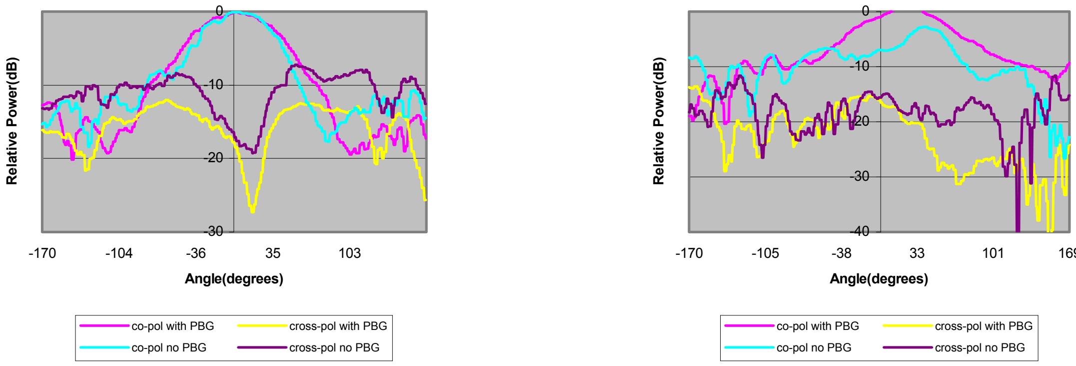

Figure 7 Measured Antenna Radiation patterns at 5.6GHz