ANTENNA AND CIRCUIT APPLICATIONS OF UC-PBG STRUCTURES

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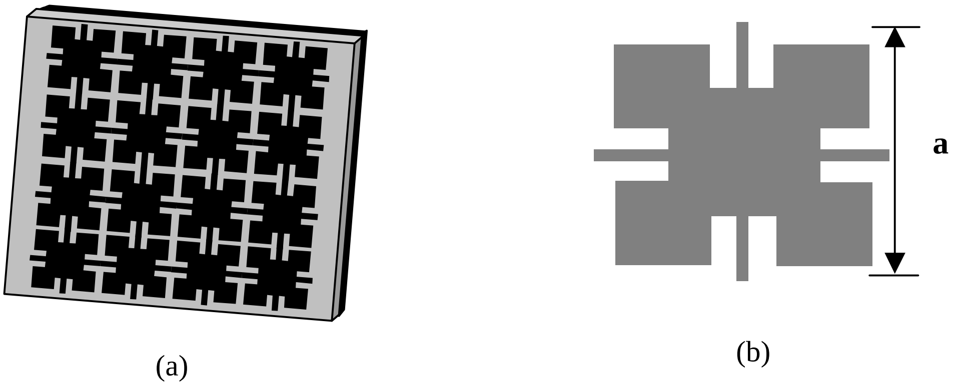
1. Introduction

Photonic band-gap (PBG) materials have been extensively investigated for optical, millimeter-wave and microwave applications [1,2]. Two-dimensional PBG structures are most attractive to high-frequency circuit designers since they provide advantageous features, which cannot be realized by conventional periodic structures. Moreover, 2D PBG structures can be relatively easily integrated with circuits and antennas. However, the common approach using periodic variation of effective dielectric constants by machining air columns into substrates is not cost-effective. Recently developed uniplanar compact PBG (UC-PBG) structure is a periodic metallic pattern loaded on a dielectric slab. The pattern consists of square pads separated by capacitive gaps and narrow lines connecting adjacent cells. The idea is to create strong LC coupling so that the guided wavelength of propagating modes can be reduced, therefore the lattice period of the PBG pattern can be reduced. Fig. 1 shows the schematic of the UC-PBG pattern on a grounded dielectric slab and the configuration of a unit cell.



(a)

(b)

Fig. 1 Schematics of (a) the UC-PBG on a grounded slab and (b) a unit cell of the PBG lattice.

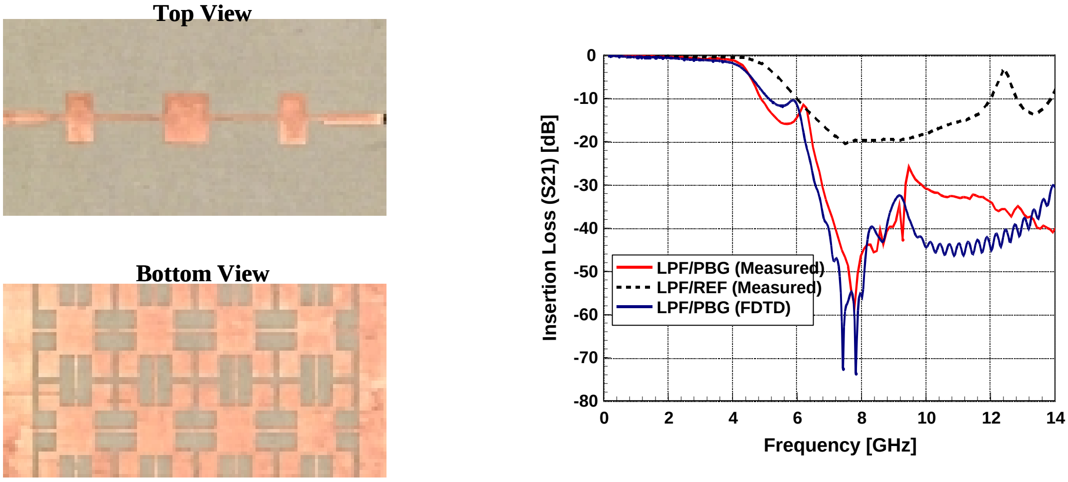
Full-wave analysis (FDTD) has been performed to obtain the dispersion diagram of the grounded slab with UC-PBG loading and results show that there exist complete stopbands (for both TE and TM modes along all directions). This property has been exploited to suppress the parallel-plate mode of a conductor-backed CPW [3] and the surface wave leakage of patch antennas [4]. Another interesting phenomenon is that the UC-PBG loaded substrate behaves like a magnetic surface at the resonant frequency, where the open-circuit boundary is formed at the air-dielectric interface [5]. This feature has been applied to build a TEM waveguide and low-profile antennas.

The UC-PBG pattern provides useful attributes when serving as ground planes of microstrip-based circuits. For example, the inductive and capacitive elements of the UC-PBG lattice generate the slow-wave effect, which reduces dimensions of the circuits built on top. The intrinsic stopbands offered by the periodic pattern can be used to realize spurious-free filters. At frequencies below cutoff of the first stopband, the characteristic impedance remains matched since both L and C increase simultaneously, which is another favorable feature for slow-wave transmission line and filter applications.

Circuit Applications

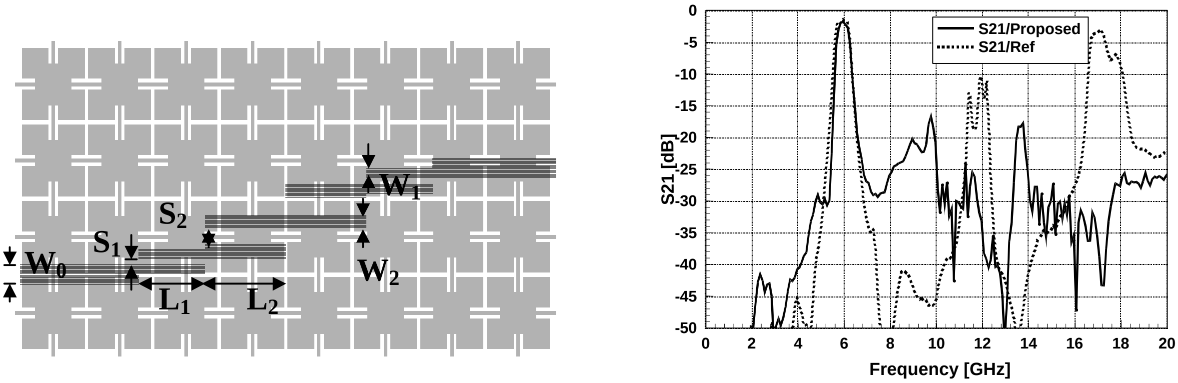
Fig. 2(a) shows the pictures of the UC-PBG ground plane integrated with a lowpass filter. The PBG pattern in this novel LPF has the cutoff frequency at 8GHz, where a deep attenuation and sharp rolloff are observed. The problem of transmission re-entrance for conventional LPFs does not exist in this novel LPF, since spurious passbands have been suppressed by the intrinsic stopband of the UC-PBG structure. Fig. 2(b) shows the S_{21} of this LPF on UC-PBG ground compared with that of a conventional LPF on a solid ground plane.

Fig. 3 (a) shows the schematic of a parallel-coupled bandpass filter built on the UC-PBG ground plane. Analysis of couple-lines on the UC-PBG ground plane has been performed using FDTD and the effects of circuit dimensions (*W* and *S*) on the design parameters, such as characteristic impedance and effective dielectric constant, have been obtained. Fig. 3(b) shows the insertion loss of the UCPBG-based BPF designed according to the coupled-lines analysis, with the S_{21} of a conventional BPF on a solid ground plane plotted as a reference. As can be seen, the second and third passbands of the conventional BPF are suppressed by 15 to 20dB by applying the UC-PBG pattern. The total length of the filter is reduced by 20% due to the slow-wave effect. Furthermore, a good inband response, such as narrow band (9%) and low insertion loss (1.6dB) are achieved. Application of the UC-PBG pattern to power amplifiers for harmonic tuning has also been presented [6].



(a) (b)

Fig. 2 (a) Photographs of the BPF on the UC-PBG ground plane. (b) Simulated and measured insertion loss of the LPF on the UC-PBG ground. (With S_{21} of a conventional LPF as a reference).

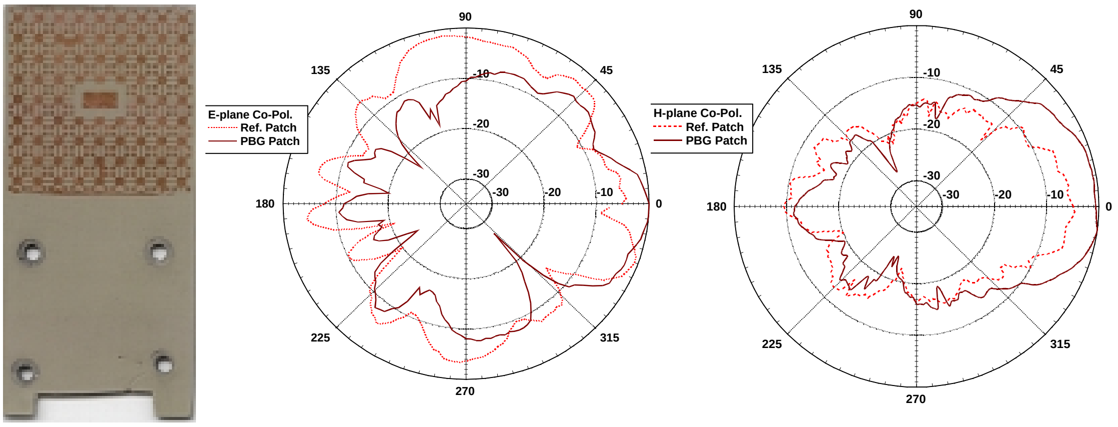


(a) (b)

Fig. 3 (a) Schematic of the BPF on the UC-PBG ground plane. (b) Insertion loss of the proposed filter compared to that of a conventional one.

Antenna Applications

Microstrip patch antennas are extensively used in communication systems for their low profile, low cost and easy fabrication. Patch antennas are usually built on low permittivity substrates for optimum performance, since surface waves are excited on high dielectric constant substrate. On the other hand, it is necessary to built patch antennas on high dielectric constant substrates to reduce dimensions and to achieve a high degree of integration with active devices. The complete stopband provided by the UC-PBG structure can be employed to reduce surface wave losses of patch antennas on high dielectric constant substrate. Fig. 4(a) shows the top view of an aperture coupled patch antenna surrounded by three periods of UC-PBG lattice. The antenna has been designed to resonate at a frequency inside the UC-PBG stopband so that excitation of surface waves is reduced as much as possible. Fig 4(b) and (c) show the measured Co-polar E- and H-plane patterns of the UC-PBG antenna and a reference antenna with same dimensions but without UC-PBG. It is seen that excitation of surface waves is strongly reduced on the E-plane compared to the reference antenna. Measurements have been done at slightly different frequency for the two antennas in order to have the same return loss (S_{11}=–20 dB) for both of them. Cross-polarization level on both planes is below –10 dB.



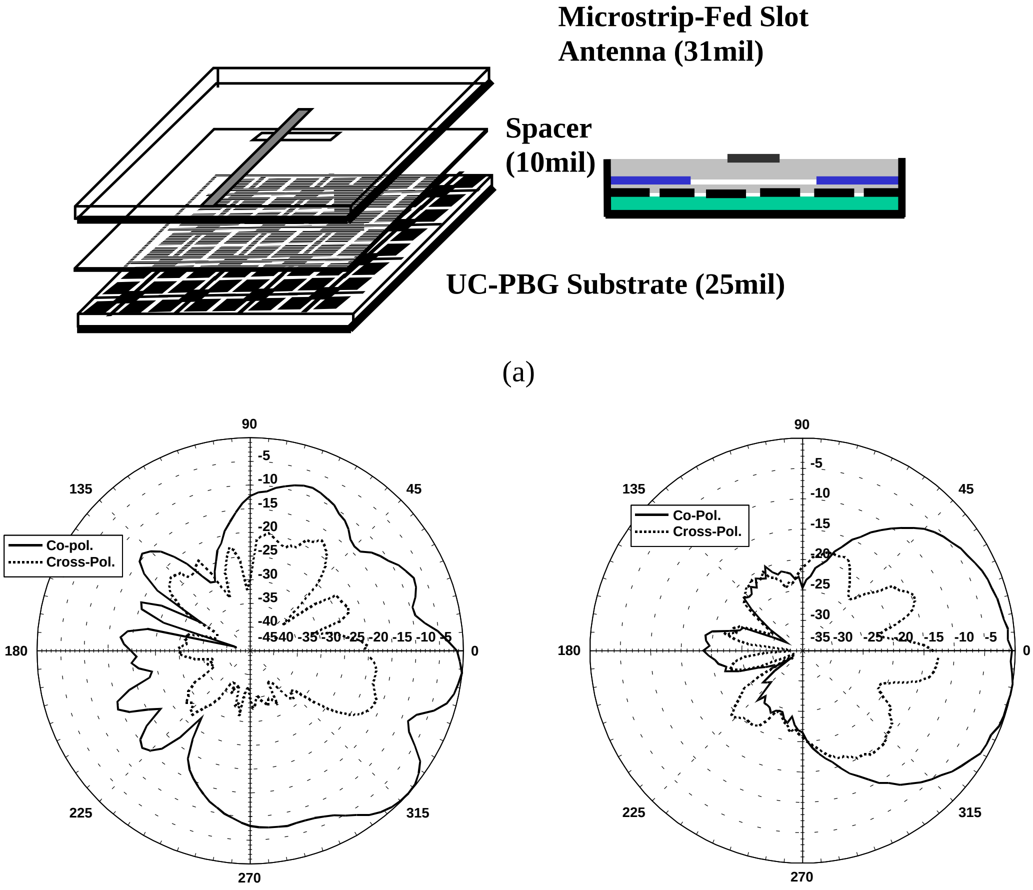
(a) (b) (c)

Fig. 4 (a) Photograph of the patch antenna surrounded by the UC-PBG structure. (b) Measured E-plane and (c) H-plane radiation pattern with those of a reference patch for comparison.

Cavity-backed slot (CBS) antennas have been extensively investigated for applications to airborne and satellite communications because they satisfy the requirements of flush mounting, low cost and light weight. The cavity height is usually designed to be one- or three-quarter wavelengths at the resonant frequency in order not to destroy impedance matching, since the backing conductor is transformed to an open circuit in shunt with the slot. The cavity volume can be reduced through dielectric loading but the bandwidth and efficiency will also be reduced. The unique property of the UC-PBG substrate, which is the realization of an equivalent open-circuit boundary at resonant frequency, can be exploited to realize the CBS with a thin cavity. By loading the UC-PBG pattern, the transformation from shorting plate to an open circuit at the air-dielectric interface is accomplished even for a thin slab. A low-profile CBS can be built using this thin UC-PBG slab as a backing substrate serving as a reflector without degrading the matching condition.

Fig. 5(a) shows the schematic and cross section of the cavity-backed slot antenna using UC-PBG substrate. The slot is fed by an open-ended microstrip at the top layer, which is different from usual CBS antennas with slots at outer surfaces of cavities. This arrangement is to avoid perturbation of microstrip mode by the thin cavity. Fig. 5(b) and (c) show the measured normalized E- and H-plane radiation patterns at 12.05 GHz. The front-to-back ratio is 15 dB for the E-plane and 18 dB for the H-plane patterns. The cross-polarization level is 12 dB to 15 dB below the co-polarization level for both planes. The pattern distortion observed in the E-plane comes from the existence of the microstrip feed line and this problem can be alleviated using other feeding structures such as a coaxial line. The measured gain of this novel CBS antenna is approximately 2.5 dB. A reference CBS antenna has been built using an empty metal cavity with the height equal to a quarter of free-space wavelength (246mil).

The comparison between the proposed antenna and a reference one reveals that a very low profile CBS antenna has been realized and this structure provides good radiation performance at the mean time.



(a)

(b)

(c)

Fig. 5 (a) Schematic and cross section of the proposed CBS antenna. (b) Measured E-plane and (c) H-plane radiation patterns.

Conclusions

Basic properties and applications of the UC-PBG structures have been presented. The distinctive stopbands of the microstrip-based UC-PBG structures have been exploited to build high-performance filters and increase PAE of power amplifiers. Advantageous features of the ground dielectric slab with UC-PBG loading, such as complete stopbands and magnetic surface realization, have been applied to achieve a patch antenna with surface wave suppressed and a very low profile CBS antenna. It is believed that more beneficial properties and applications will be found for the UC-PBG structures.

References

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