A Novel Approach for Gain and Bandwidth Enhancement of Patch Antennas

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Abstract

The microstrip patch is one of the most preferred antenna structures for low-cost and compact design of wireless communication systems and RF sensors. To overcome several intrinsic limitations of the patch antenna such as narrow bandwidth, low gain, and degradation of radiation efficiency at higher frequencies, we propose a novel technique for gain and bandwidth enhancement based on the photonic band-gap (PBG) concept. The Ku-band prototype demonstrates over 3 times bandwidth improvement, and 1.6 dB higher gain or 45 % increase in effective radiated power (ERP), compared with a regular patch with identical dimensions. System design issues such as co-site interference can also be alleviated by the improved beam patterns of the new PBG antenna.

Key Words: Patch Antenna, Gain, Surface Wave, Radiation Efficiency, Photonic Band-Gap (PBG)

Introduction

Microstrip patch antennas offer an attractive solution to compact, conformal and low-cost design of many wireless application systems such as ATM Wireless Access (AWA) [1] and millimeter-wave automobile sensors [2]. For easy integration with the RF front-end, patch antennas on substrate with high dielectric constant (Si, GaAs, etc.) are preferred. However, this usually results in very narrow bandwidth (~1%), and degradation in radiation efficiency and total antenna gain, particularly at higher frequencies. Recently there has been a great interest in realizing high efficiency patch antennas on high permittivity substrates, including the use of the latest micromachining technology [3].

We propose here a novel technique for gain and bandwidth enhancement of patch antennas based on the concept of photonic band-gap (PBG) structures [4]. By surrounding the patch antenna with a square-lattice of small metal pads with grounding vias, we observe a substantial suppression of surface waves excited in the dielectric substrate, which not only improves the antenna gain or effective radiated power (ERP), but also increases significantly its frequency bandwidth. Reduction in mutual coupling and co-site interference are some other potential benefits of the newly proposed PBG antenna.

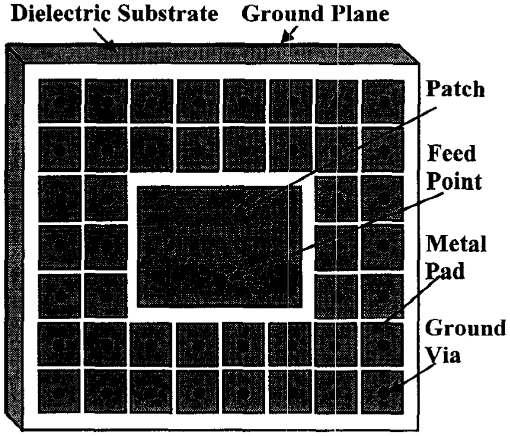

Fig. 1 Schematic of the proposed microstrip patch antenna surrounded by a PBG lattice.

Design of the PBG Patch Antenna

Fig. 1 shows the schematic of the proposed PBG patch antenna surrounded by a square lattice of metal pads with grounding vias. A distinctive stopband exists for frequencies above the resonance of the two-dimensional PBG lattice, similar to that of the 3D structure as described in [4]. As a result, surface waves excited in the dielectric substrate will be suppressed, and improvement in both radiation efficiency and beam patterns can be expected.

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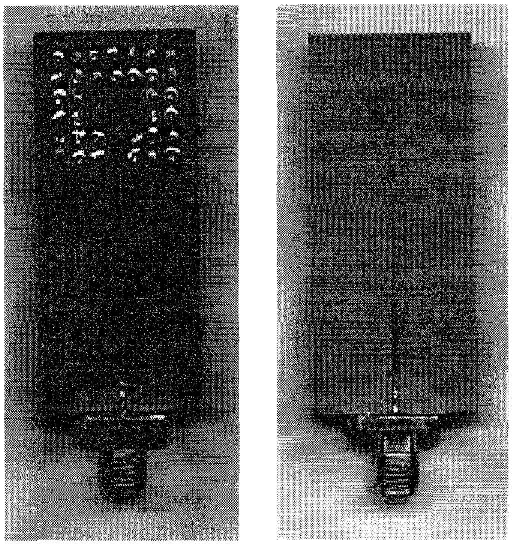


Fig. 2 Ku-band prototype of (a) the proposed PBG patch and (b) a reference patch antenna.

To confirm the proposed design concept, a Ku-band prototype was fabricated and tested. The antenna design started from a reference patch antenna on 25 mil thick Duroid with ε_r=10.2. An inset feed scheme is employed to match the patch antenna to a 50 Ω microstrip feedline. For a center frequency of 14 GHz, the size of the patch antenna was found to be 120 mil long and 168 mil wide by using an FDTD simulation code [5]. Meanwhile, the PBG patch has the same dimensions with the reference antenna, except for the surrounding PBG lattice. The PBG pads are 88 mil squares with 8 mil gaps, and the grounding via in the center of each pad has a diameter of 8 mil. Fig. 2 shows the pictures of the fabricated PBG and reference patch antenna. The total width of the antenna substrate is 800 mil, corresponding to approximately one free-space wavelength at the center frequency. A relatively long (1.4 in) microstrip feedline is used to facilitate the E-plane pattern measurement.

Fig. 3 shows the measured input return loss of the two antennas. The reference patch has a minimum return loss of -11.6 dB at 14.0 GHz, and bandwidth (VSWR<2) of 1.6 %. Although the return loss level can be improved by further optimization of the inset feed position, the bandwidth will remain narrow (around 1~2 %) on this type of high permittivity substrate, as also demonstrated recently in [3]. On the other hand, the PBG patch antenna measured a peak return loss of -24.4 dB at 14.75 GHz, and a bandwidth of 5.4 %, which is 3.4 times wider than that of the reference patch.

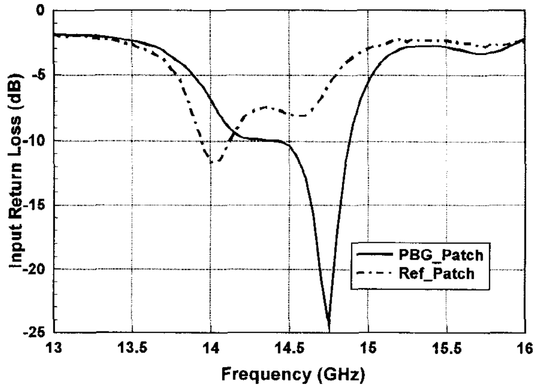
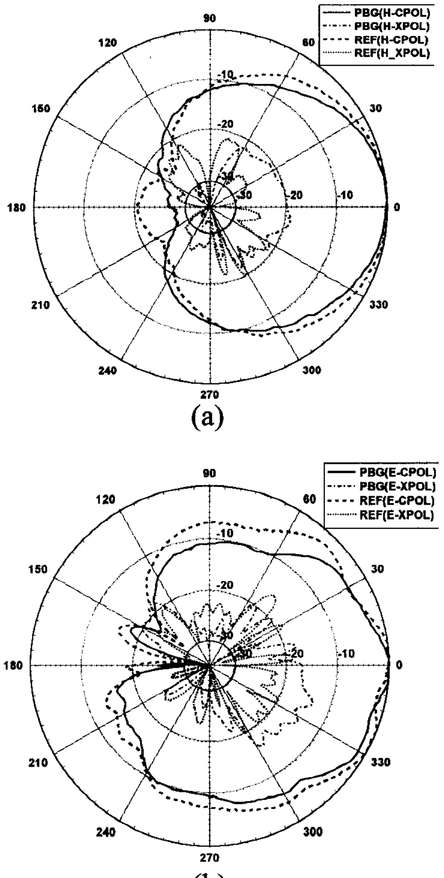


Fig. 3 Measured input return loss of the PBG and reference patch antennas.

Radiation Patterns

Fig. 4 shows the measured the H- and E-plane radiation patterns of the two patch antennas, including both co- and cross-polarization patterns. While the patterns have been normalized here for easy visualization, the peak power received by the PBG patch is 1.8 dB higher in the H-plane and 1.6 dB higher in the E-plane. The measurement was taken at 14.15 GHz where the two patches have identical return loss (-9.4 dB). Since all other parameters are the same, the increased power indicates a gain enhancement with the PBG antenna, which will be discussed further in the next section.

As can be seen from Fig. 4, the PBG patch has reduced radiation power along the dielectric substrate (90 degree from broadside) and smaller ripples in its E-plane pattern, indicating an effective suppression of surface waves. The radiation power at the H-plane edges remains the same as the reference patch since no surface wave is excited and propagates in that direction. The backlobe of the PBG patch is lower than that of the reference because of the same surface wave suppression effect. The slight asymmetry in the E-plane patterns are due to the blocking of the SMA connector. Meanwhile, the PBG antenna does show slightly higher cross-polarization compared to the reference patch. Nevertheless, the -19.1 dB (H-Plane) and -14.7 dB (E-Plane) cross-polarization levels are still reasonably low, and may have been caused partly by the uneven surface of the antenna due to the soldering of the grounding vias, which can be improved by using alternative fabrication techniques such as plating.



(a)

(b)

Fig. 4 Measured radiation patterns at 14.15 GHz for the PBG and reference patch antennas: (a) H-Plane and (b) E-Plane.

Gain and Radiation Efficiency

The gains of the proposed PBG and reference patch antennas are measured by using the gain-transfer technique [6]. Based on the relative gain of the patch measured with respect of a standard-gain horn antenna, we can de-embed the net gains of the two patch antennas, as shown in Table I. The de-embedded gains of the PBG and reference patch are 6.77 dB and 5.16 dB, respectively, showing a 1.61 dB gain enhancement with the PBG antenna. This is equivalent to a 45 % increase in the effective radiated power (ERP) by the PBG antenna, assuming that everything else is the same in the whole RF system. This measurement result is also in consistence with the pattern measurement results described in the previous section.

Meanwhile, by integrating the radiation patterns as shown in Fig. 4 to obtain the antenna directivities, and comparing them with the measured gains, we can calculate the radiation efficiencies of the two antennas. The calibrated radiation efficiencies of the PBG and reference antennas are found to be 85 % and 83 %, respectively. It should be pointed out here that the radiation efficiency measured in this way is the efficiency of total radiation, which should be close for both patch antennas, since they are expected to dissipate similar amount of metal and dielectric losses. The surface wave suppression effect as evidenced by the radiation patterns shown in Fig. 4, however, is important because it reduces the radiation energy along the substrate and backside of the antenna, which is the major cause of mutual coupling in antenna arrays, or co-site interference within multiple RF-system environments.

It should also be pointed out that although it is possible to realize higher gain using an array of multiple patches, the associated feeding network for such an array is not only complicated but will also introduce additional feedline losses which tend to reduce the gain. Also, the array approach does not provide a direct solution to the surface wave problem as mentioned above.

Conclusion

In conclusion, we have proposed and demonstrated a novel approach for gain and bandwidth enhancement of microstrip patch antennas. The design is compact and robust, requiring only one single layer of dielectric material, and is compatible with standard planar fabrication technology. The multi-fold improvement in antenna performances (wider bandwidth, improved gain, lower backside radiation, beam shape control and surface wave suppression) resulted from this single approach indicates great potentials, especially for applications at microwave and millimeter-wave frequencies.

Acknowledgment

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Table I
Measured Gain of the PBG and Reference Patch Antenna

	PBG Patch	Reference Patch
Frequency (GHz)	14.15	14.15
Measured Gain (dB)	5.02	3.41
Mismatch Loss (dB)	0.53	0.53
Connector Loss (dB)	0.38	0.38
Feedline Loss (dB)	0.84	0.84
De-Embedded Gain (dB)	6.77	5.16