Harmonic-less Annular Slot Antenna (ASA)
using a novel PBG structure for slot-line printed devices

N. BOISBOUVIER [1,2,*], F. LE BOLZER[1], A. LOUZIR[1], A.-C. TAROT[2], K. MAHDJOUBI[2]
[1] Thomson, Corporate Research, 1 avenue Belle-Fontaine, BP19, 35511 Cesson-Sévigné Cedex, France
[2] IETR, UMR CNRS 6164, Université de Rennes1, Campus Beaulieu, 35042 Rennes Cedex, France
{nicolas.boisbouvier@thomson.net or nicolas.boisbouvier@univ-rennes1.fr}

Abstract
A novel PBG structure well-suited for slot-line printed devices and its application to control harmonic frequencies of an Annular Slot Antenna (ASA) are proposed. This novel PBG structure is the dual of the well-known Radisic PBG structure for microstrip printed devices [1]. It consists of etching metallic discs on the opposite side of the slot-line.

I. Introduction

PBG structures have already been the subject of much research since the precursory work of Yablonovicth [2]. Those PBG structures have the ability to control the propagation of electromagnetic waves by exhibiting no wave propagation over certain frequency bands. Numerous applications on microwave printed devices, especially on microstrip filters, have then been proposed.

Radisic et al. [1] proposed a microstrip PBG filter which proved to be very convenient in order to control harmonic frequencies of antennas or power amplifier [3]. The Radisic approach was to introduce the PBG structure on the feed line of a printed antenna and later Horii et al. [4] proposed a more compact solution which consists of etching the PBG structure directly in the ground plane just beneath the patch. Afterwards Hui et al. [5] proposed to etch annular rings instead of circles and to restrict the etching area only to the periphery of the patch antenna.
In all cases, the idea is to size the PBG structure in order to overlap the stop band created by the PBG structure and unwanted frequencies.

In this article, we propose a novel PBG structure especially suitable for slot-line printed devices and its application to suppress harmonic resonances of an ASA.

II. PBG structure for slot-lines printed devices

The idea is to propose the dual structure of the Radisic PBG structure. Instead of discs in the ground plane of microstrip lines, periodically spaced metallic discs are etched on the opposite side of the slot-line [6]. Figure 1 illustrates this duality.

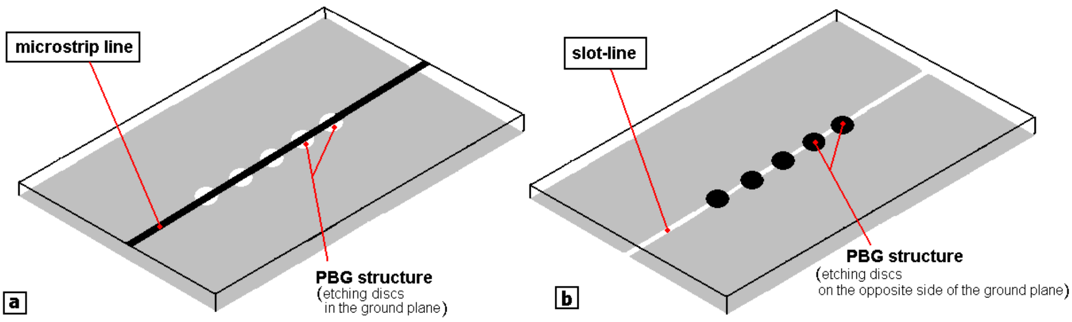

Figure 1 : PBG structure for (a) microstrip line (Radisic PBG structure) and for (b) slot-line

As for the Radisic dual structure, the center frequency of the stop band can be controlled by varying the distance “a” between metallic discs. This parameter should be approximately half of a guided wavelength (λg) in the slot-line at the expected stopband frequency : $\lambda g=2a$.

Then the shape, the size and the number of periods determine the depth and width of the stopband. A range for the ratio r/a is optimal : 0.15 < r/a < 0.3.

The filtering behaviour of this novel PBG structure has been confirmed by comparing transmission and reflection coefficients of a single slot-line (Figure 2a) and the same slot-line in the presence of the PBG structure (Figure 2b). The slot-line is fed by electromagnetic coupling to microstrip lines at each of its extremities and the PBG structure is designed for a center frequency of stop band at 6GHz. Figure 3b shows theoretical results of the return loss obtained from an EM simulation on Ie3D (Zeland) : A significant stop band appears at the expected frequency.

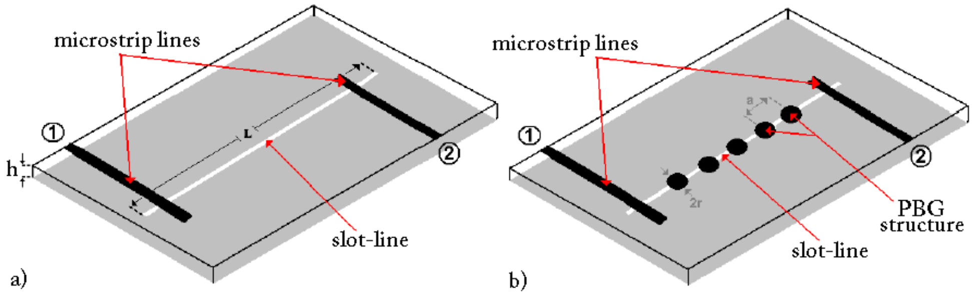

Figure 2 : Validation of the novel PBG structure : a slot-line fed by two mistrosrip lines (a) without and (b) with the PBG structure.

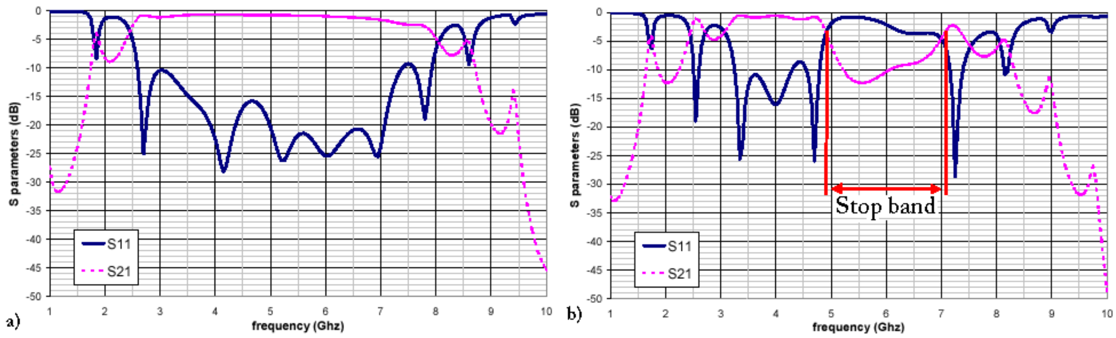

Figure 3 : Simulated S-parameters of the slot-line (a) without and (b) with the PBG structure

III. Application to harmonic control on Annular Slot Antenna (ASA)

This PBG structure is now applied to an ASA in order to control its harmonic frequencies.

III.1 Design of the ASA

The Annular Slot Antenna, presented in Figure 4, consists of an annular slot cut into a metallic layer and backed by a substrate.

The substrate used is a 0.81mm thick Rogers4003 substrate (ε_r=3.38). The 0.4mm wide slot has a radius R=16.4mm which correspond to an annular perimeter equal to a guided wavelength in the slot.

(λ_s=2πR=103mm=> f=2.4GHz).

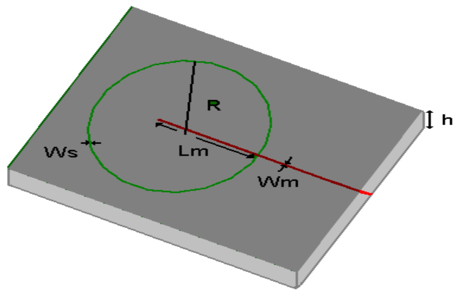

Figure 4 : The Annular Slot Antenna (ASA)

A microstrip line is placed on the back of the substrate to feed the antenna. This feeding technique insures the highest EM coupling between the slot and the microstrip line when this last is situated in a short circuit plane of the slot. That's why the microstrip feeding line (0.3mm wide) extends 20mm across the slot, which corresponds to one-quarter wavelength at the operating frequency.

Because of the nature of the transition, this feeding technique present resonance only at each odd multiple. Indeed, as shown in Figure 7, the antenna resonates at 2.4GHz, the second resonance is not excited and only the third resonance appears at about $3f_1$ i.e. 6.9GHz.

III.2. Suppression of harmonic resonances of an ASA

In order to suppress the third resonance, the novel PBG structure is etched under the annular slot. This PBG structure is sized so as to make the stopband created by the PBG structure overlap the unwanted harmonic frequency i.e. 6.9GHz.
This leads to a spacing between patterns equal to 14.7mm. As shown in Figure 5, seven discs can be positioned under the slot with a radius of 4.2mm (r/a=0.29).

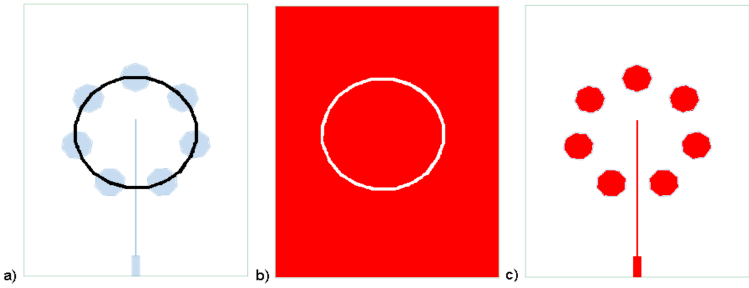

Figure 5 : ASA topology with one PBG structure
(a) transparency view (b) front view (c) back view

Figure 7 presents simulated return loss of this antenna topology. As expected the resonance at the harmonic frequency of the antenna is suppressed. Furthermore the first resonance of the antenna is shifted to lower frequencies : f_2=2GHz. This frequency shift could be explained by the slow-wave effect introduced in the slot and created in the passband of the PBG structure. It could be used to reduce the ASA's dimensions.
Figure 8 presents its radiation pattern which is roughly unperturbed by this PBG structure : As for the conventional ASA, it is observed that the antenna exhibits minimum radiation in the zenith direction and is fairly symmetrical in azimuth.

Nevertheless another resonance appears at approximately $2f_2$=3.8 GHz.

In order to suppress this second harmonic resonance, a more conventional PBG structure has been sized on the feeding microstrip line. As shown in Figure 6. This PBG structure consists of etching discs on the ground plane of this microstrip feeding line. Its stopband is centred at 3.8GHz which leads to a spacing between discs equal to 23.8mm. In order to keep dimensions of the breadboard constant, only two circles are positioned under the microstrip line as shown in Figure 6.

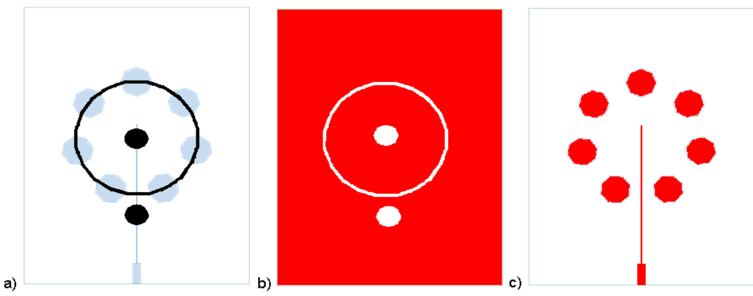

Figure 6 : ASA topology with two PBG structures
(a) transparency view (b) front view (c) back view

As shown in Figure 7, this ASA with two PBG structures presents a resonance at 2GHz with no harmonic frequencies. It's radiation pattern is still unchanged.

IV. Conclusion

This article presents a novel PBG structure for slot-line printed devices. The PBG structure is used in order to suppress the third harmonic frequency of an Annular Slot Antenna (ASA). The combination of this PBG structure and a Radisic one allows the suppression of harmonics of the ASA up to the fourth order. This novel PBG structure is particularly well-suited for printed slot-line structures.

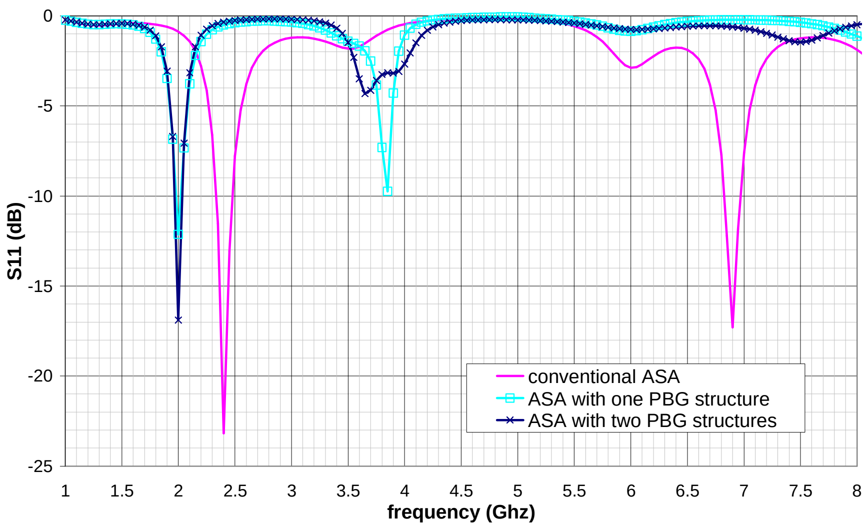

Figure 7 : Return loss of an ASA with and without PBG structures

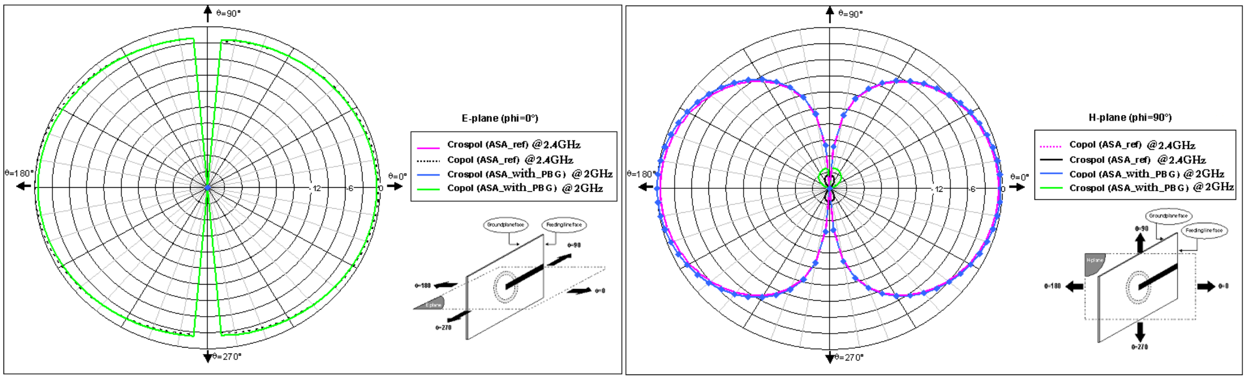

Figure 8 : Radiation pattern of an ASA with and without PBG structures

V. References

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