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# Photonic band gap structure integration in topology for the design and manufacture of Quasi-Yagi antennas

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***Abstract*—This paper presents an opportunity to integrate an innovative photonic band gap (PBG) structure (based on the metamaterials concept) into design topology and manufacture Quasi-Yagi antennas. The design aims to implement PBG structure directly into the antenna design. That allows a galvanic connection between the antenna and the metamaterial to improve Quasi-Yagi characteristics. Various simulations and measurements have been made showing the synthesized antenna system functionality and its applicability for different practical applications in communication systems - due to the operating frequency 2.4GHz.**

***Keywords— photonic band gap, PBG, periodic structures, metamaterials, Quasi-Yagi, antennas, radiation pattern, far-field***

## I. Introduction

In recent years, there have been lot of techniques to improve the characteristic of antennas of different types. Kind structures used to improve antenna parameters are: Electromagnetic band-gap (EBG) [1 ÷ 3], defected ground planes (DGP) [4, 5], and considered in this research work photonic band gap (PBG) [6, 7] structures. These kind of periodic structures are found in the literature as metamaterials. Various studies show the integration of EBG and DGP structures in different planar antennas to improve their characteristic [8, 9]. In turn, the PBG structure is suitable for integration in antennas, where an increase in antenna aperture can be allowed. These types of antennas are, for example, horn antennas and Quasi-Yagi. In Quasi-Yagi, the gain increase is associated with an increase in the number of antenna directors, which increases antenna sizes. Instead of directors, the photonic structure can be used, which, unlike the conventional topology of Yagi, also increases the gain, and the antenna radiation pattern narrows. For Quasi-Yagi antennas, adding multiple directors to increase the gain and shrink the radiation pattern (RP) is hard to optimizer that can be replaced by integrating a photonic structure. In this way, PBG increases the gain by the same order as multiple directors, but also proof of concept structure PBG integration reduce the RP beamwidth of the directional action diagram in E and H planes.

Presented research show an opportunity to integrate a PBG structure into the Quasi-Yagi antenna design topology (widely used in various communication systems [10, 11]). The design aims to incorporate a PBG structure directly into the antenna design. This allows a galvanic connection between the antenna and metamaterial. Various simulations and measurements have been made, showing the synthesized antenna system functionality and its applicability for various practical applications in communication systems; applications are considered to increase UAVs range, which is increasingly used in various industries [12 ÷ 14].

## II. Photonic Band Gap Structure

One-dimensional (1D) photonic crystals, encountered in literatures as the Bragg mirrors, mainly used in optics, have been of scientific interest in antenna and microwave design in recent years. Where the 1D PBG concept is based on a periodic structure consisting of two materials. Thus, this multilayered periodic structure forms passbands and stopbands when an electromagnetic wave passes through it [16, 17]. These characteristics in the frequency domain depend on several parameters, such as operating frequency and corresponding RF device wavelength, material parameters - refractive index, dielectric constant, geometric dimensions of the structure, layers number, etc. Considering the described parameters, a PBG structure can be designed to accomplish requirements - to have a passband and stopband for a precisely defined frequency.

In this work, a simplified 1D photon band gap structure - based on the Bragg mirror concept is designed - figure 1, consisting of alternating dielectric layers: $\varepsilon r \approx 1$ for the odd layers and $\varepsilon r > 1$ for the even structure layers.

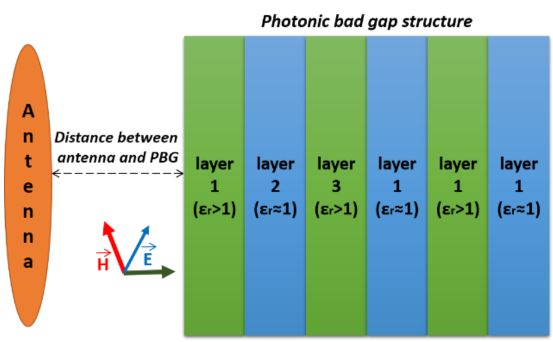


Fig. 1. *Segments distributions of the considered photonic structure in relation to the antenna.*

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Using the theoretical methodologies from [18 and 19], we have the fundamental formulas for determining the structure dimensions:

$$layer_{even} = h_{air} = \frac{c}{4f_0} = \frac{\lambda}{4} \qquad \text{for } even\ leayer \qquad (1)$$

$$layer_{odd} = h_{diel} = \frac{c}{4f_0\sqrt{\varepsilon_r}} = \frac{\lambda_g}{4} \qquad \text{or } odd\ leayer \qquad (2)$$

In the considered case, a 6-layer Bragg mirror model is used - the even layers -2, 4, and 6 are air, and the odd layers - 1,3,5, are a dielectric (εr=4.8), and the investigated structure is designed for operation frequency fo = 2400MHz. Determining the initial structure dimensions, it becomes clear how to optimize the structure to improve the antenna radiation characteristics. The reflection and transmission coefficients must be approximately equal to -3dB for the center frequency for which we want the structure to have enhancing properties relative to a given antenna[19, 20]. Thus, we design the PBG so that when energy is radiated from an antenna, half of the power passes through the structure, and the other half is reflected back into the antenna. After which, it is reflected back into the antenna aperture and re-radiated, repeating described process. In theory, this process would repeat itself infinitely. Still, in practice, the attenuation from the electromagnetic wave propagation is dependent on the antenna's operating frequency. In reality, the process ceases to repeat itself when the attenuation from wave propagation becomes so great that it is impossible to re-reflect the wave incident on the antenna. Figure. 2 shows the pass and stop band on the frequency domain of the design PBG structure after its optimization according to the indicated methods.

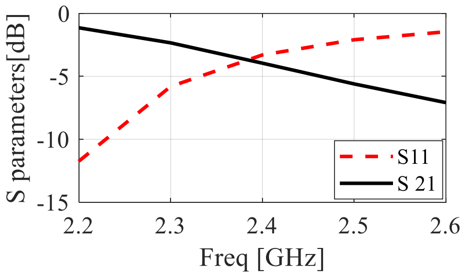


Fig. 2. *PBG strcuture S parameters*

## III. The Quasi-Yagi Antenna

The Quasi Yagi antenna in this article consists of two dipole antennas crossed by a ground plane in a planar design. The excitation network is a standard microwave line for the center frequency, which grows into a microstrip - CPS balun feeding the energy to a coplanar line that feeds the two dipole elements. The purpose of the CPS balun is to delay the power supplied to one of the dipoles by changing its phase by 180º, which also ensures the antenna's directivity. A conventional Quasi-Yagi is designed - figure 3. The designed antenna according to the methodology presented in [21, 22]. The Yagi with five directors designed. The quasi-yagi with an integrated photonic structure has also been created. The quasi-yagi is designed (using openEMS) for a center frequency of 2400MHz, made on a dielectric substrate with $\varepsilon_r$ = 4.8 and a loss tangent of 0.03. Table 1 presents the dimensions of the designed antenna.

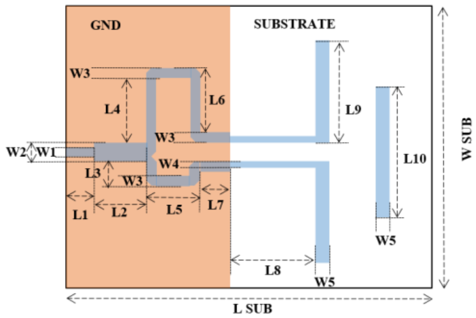


Fig. 3. *The Quasi yagi antenna*

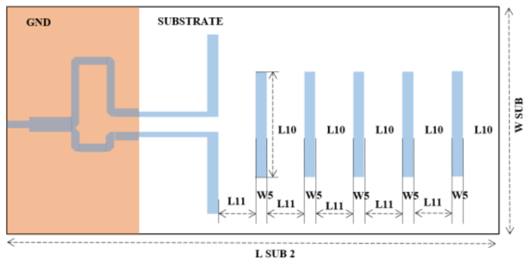


Fig. 4. *The five directors Quasi yagi antenna*

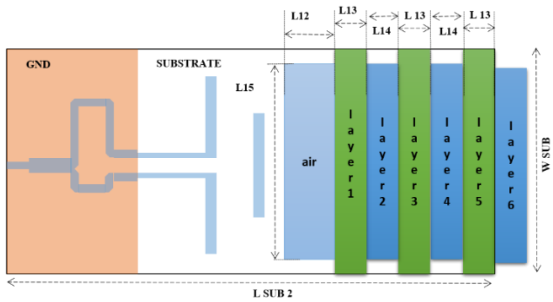


Fig. 5. *The Quasi yagi antenna with an integrated PBG structure*

TABLE I. The Quasi-Yagi Antenna Dimensions

| ***Segment*** | ***Dimensions [mm]*** |
|---|---|
| W1 | 3 |
| W2 | 6 |
| W3 | 3 |
| W4 | 1.5 |
| W5 | 3.5 |
| L1 | 6 |
| L2 | 16 |
| L3 | 6 |
| L4 | 22 |
| L5 | 10 |
| L6 | 21 |
| L7 | 5 |
| L8 | 24 |
| L9 | 27 |
| L10 | 32 |
| L11 | 18 |
| W SUB | 81 |
| L SUB | 98 |
| L SUB 2 | 180 |
| L12 | 19 |
| L 13 (layers 1,3,5) | 16 |
| L 14 (layers 2,4,6) | 11 |
| L 15 | 70 |
| Antenna height | 1.5 |
| PBG height | 9 |

## IV. The Designed Quasi-Yagi Antenna

Quasi Yagi test models presented in the previous point have been made - figure 6. Figure 7 shows the simulation and measurement of S11 parameters of the proposed antennas.

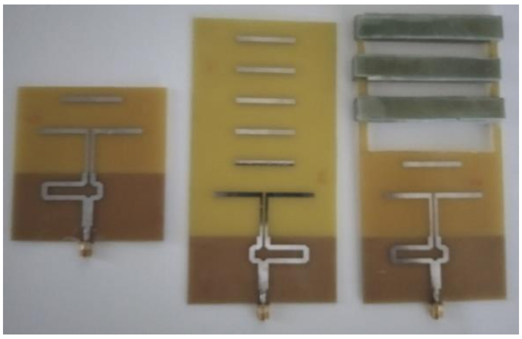

Fig. 6. *The made Quasi yagi antennas*

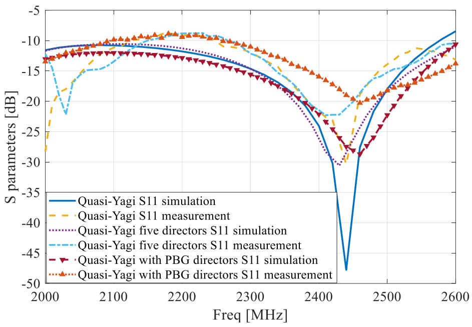


Fig. 7. *The Quasi yagi antennas S11 parameters*

Two models of each antenna are manufactured so their actual RP and gain could be measured, and both parameters measured using the method of both antennas [23]. For the gain measurements Signal haunt - Tracking Generator USB-TG44A and spectrum analyzer USB-SA44B, equipment was used (set to the corresponding operating frequency of the antennas). Table 2 shows a comparison between the simulated and measured antenna gains.

To perform gain measurements, the connection equation according to the Friss model for two identical antennas has been used - an equation having the form:

$$G_{Db} = 0.5[20log_{10}\left(\frac{4\pi R}{\lambda}\right) + S21] \qquad (3)$$

Where: G = Grt = Grx, Grx – the receiving antenna gain, Grx – the transmitting antenna gain, R – the distance between both antennas, λ – the wavelength in free space,

$$S11 = 10log_{10}(\frac{P_{rx}}{P_{tx}}) \qquad (4)$$

Prx – the receive power, Ptx – the transmit power.

TABLE II. THE QUASI-YAGI ANTENNA GAIN COMPRASION

| *antenna* | *Simulated Gain [dBi]* | *Measured Gain [dBi]* |
|---|---|---|
| *Quasi-Yagi* | 5.1 | 4.9 |
| *five directors Quasi-Yagi* | 7.5 | 6.9 |
| *Quasi Yagi with an integrated PBG structure* | 7.8 | 7.2 |

It is important to mention that distances between the antenna and the photonic structure is theoretically approximately equal to λ/4. Still, to achieve optimal results, the distance should be found using parametric optimization. Figures 7 show the change in gain as the distance between the antenna and the PBG structure changes. In the general case, the structure's thickness is approximately equal to 5h$_{SUB}$, where h$_{SUB}$ is the thickness of the substrate on which the antenna is designed. However, further studies were done with different thicknesses of the PBG structure to see the variation of the gain with a change in the structure's thickness – fig. 8.

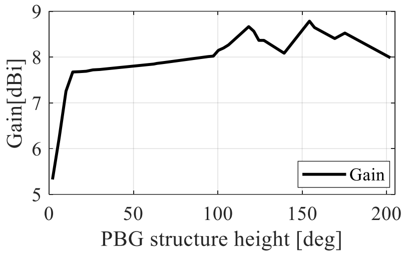


Fig. 8. *Quasi Yagi gain variation with an integrated PBG structure, with distance between antenna and structure variation*

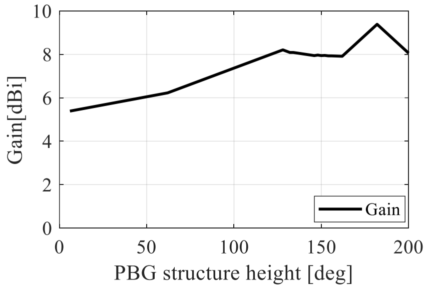


Fig. 9. *Quasi Yagi gain variation with an integrated PBG structure, with structure thickness variation*

The antenna's radiation patterns are measured by an automatic antenna measurement system [24]. Figures 10 ÷ 12 show the comparison between simulated and measured results of each Quasi Yagi design antenna. Table 3 compares the widths of the RP in the two planes of electromagnetic wave propagation.

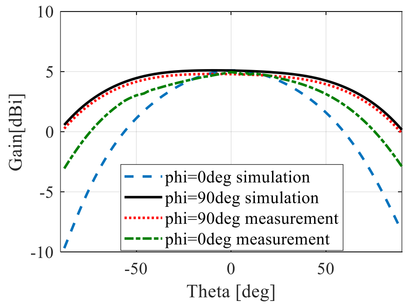


Fig. 10. *Quasi Yagi radioation patern*

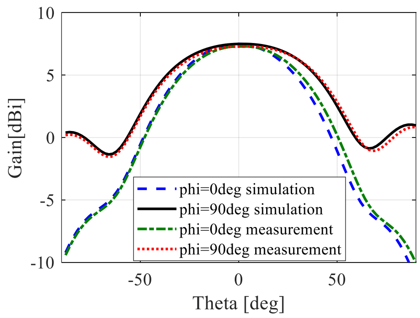


Fig. 11. *Five directors Quasi Yagi radioation patern*

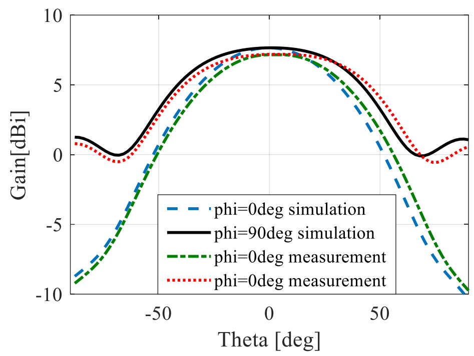


Fig. 12. *Quasi Yagi with PBG structure Five directors radioation patern*

TABLE III. THE QUASI-YAGI ANTENNAS RP BEAMWIDTH COMPRASION

| ***antenna*** | ***Simulated beamwidth phi=0/90 [deg]*** | ***Measured beamwidth phi=0/90 [deg]*** |
|---|---|---|
| *Quasi-Yagi* | 94º/155º | 92º/153º |
| *five directors Quasi-Yagi* | 78º/89º | 77º/90º |
| *Quasi Yagi with an integrated PBG structure* | 77º/89º | 77º/90º |

## CONCLUSION

The presented work fully considered the possibility of integrating a photonic band structure into the quasi-Yagite topology. . From obtained results from the research done, confirmed by measured results, it is clear that the integration of PBG in the topology of Quasi-Yagi antennas is appropriate. Integrating a photonic structure rather than a Quasi-Yagi with multiple directors allows for easy high-gain antenna design. Unlike a PBG structure, a multi-director antenna needs to be further optimized to obtain optimal results.

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