A cross polarized antenna with reflector based on electromagnetic bandgap (EBG) material

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Abstract

In this paper a gain improved cross polarized dipole antenna based on a Mushroom-Jerusalem-Cross hybrid electromagnetic bandgap (MJCH-EBG) structure is presented. For low frequencies these structures behave like metal surfaces. For a specific bandwidth at higher frequencies, that has to be dimensioned, they are highly resistive and represent a perfect magnetic conductor. This effect can be used to realize reflectors and to suppress surface waves at antennas. This helps to miniaturize these kind of antennas. Design, simulation, measurement and analysis is performed for this antenna at 10.7 GHz.

1. Introduction

In recent years, photonic and electronic bandgap structures have gained new attention in the context of microwave applications as well as other metamaterials. Surface wave suppression to improve antenna characteristics as well as miniaturizing antennas with reflectors are good examples. In this paper, a MJCH-EBG structure is used to achieve these effects. The feeding network including baluns and matching network for these balanced antennas was designed as well as a broadband dipole as radiating element. The necessary reflector was dimensioned to achieve a phase jump of $\alpha = 0^\circ$ and to attach the dipole with virtually no distance to the reflector to achieve a single four layer PCB implementation.

2. Basic principle of a EBG reflector

To achieve the mentioned suppression of TM and TE waves, the EBG material has to be operated in the frequency range around the resonance frequency of the unit cell (see Figure 1) where it is highly reactive (see [1, 2]). The lower edge of the frequency range is determined by means of the maximum propagation frequency of TM waves. The upper edge is defined by the minimum propagation frequency

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of TE waves. It has to be mentioned that the effect is only valid for unit cells that are smaller than $\lambda/10$. Otherwise there will be a wave propagation at the resonance frequency [3] or the Bragg reflection is the dominant effect at the size of the unit cell of $\lambda/2$. For the application as a reflector, the phase jump at the surface is steered. For a simple metal surface, this phase jump α amounts to $180\,^\circ$ which allows a distance to the radiating element of $\lambda/4 \mathrel{\hat{=}} 90\,^\circ$ electrical length. A EBG structure can be dimensioned for $\alpha = 0\,^\circ$. Thus, the antenna can be shrunk and the dispersion and phase can be controlled [3]. An additional gain of more than 3 dB for these types of antennas poses another positive effect [2]. Thorough investigations preceeding the antenna design resulted in the following parameters for the MJCH-EBG reflector (publication pending): $p = 1.85\,\text{mm}$, $h = 1.5\,\text{mm}$, $r = 0.15\,\text{mm}$, $g = 0.15\,\text{mm}$, $st = 0.1\,\text{mm}$, and $d_\text{m} = 0.5\,\text{mm}$. The resulting bandgap covers the required frequency range.

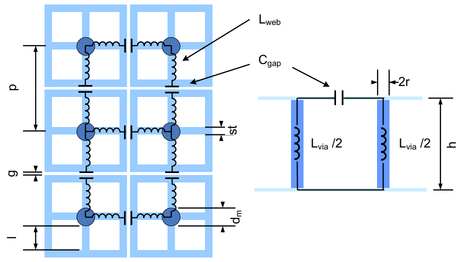
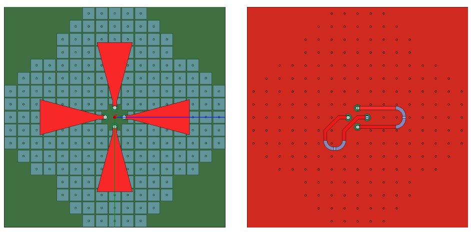


Fig. 1: MJCH structure and unit cell with equivalent circuit components

3. Antenna design

The antenna was integrated on a 4 layer PCB with Rogers RO4003 and RO4403. The first layer contains the radiating cross dipoles. On the second and third layer the MJCH-EBG structure is implemented. The feeding network is placed at the bottom side and therefore is not influencing the antenna radiation pattern. A broadband balun (as published in [4]) and a matching network with open stubs ensured an improved performance and the usability in a standard 50 Ω system environement. The structure was optimized in a circuit simulator and achieved an insertion loss of $S_{21} = 1.1\,\text{dB}$ and a matching of $S_{11} = -10.9\,\text{dB}$. For 3D simulation time purposes, the structure was reduced to mushrooms without Jerusalem cross and the number of EBG unit cells was limited to 3 around the dipoles but the feeding via the through holes was modeled (see Fig. 2(a) and 2(b)). The feeding paths towards the via holes were seperated by a certain distance to minimize the coupling between the two dipoles that are used for polarization separation. The coupling of the feeding was kept below 45 dB. The 3D simulation resulted in a gain of $G = 8.2\,\text{dBi}$ and a HPBW (half-power beamwidth) of $\beta = 52\,^\circ$. The axial ratio between the two dipoles is higher than $30\,\text{dB}$ in the main direction and higher than $20\,\text{dB}$ throughout the rest of the half space. This points to the fact that the polarization separation is adequate in simulation.



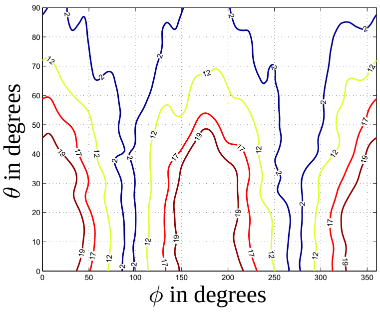
(a) Dipoles and MJCH-EBG (top view)

(b) Feeding Network (bottom view)

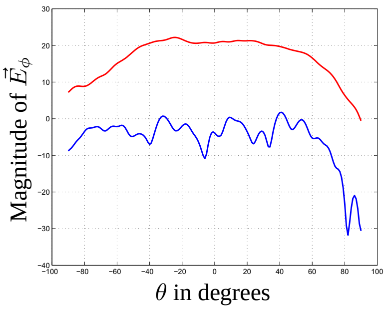
Fig. 2: Proposed PCB structure of crossed dipole on MJCH-EBG

4. Measurement results

A near field measurement of the realized antenna with MJCH-EBG was performed to verify the performance. The normal vector to the PCB defines the z-axis. θ and ϕ are the other spherical coordinates as depicted in [5]. Both ports were measured and similar results can be found. Therefore only the result of one port is presented. This is the dipole oriented in y direction. Hence, the $E_\phi(\theta = 0°; \phi = 0°)$ is parallel to the dipole. A normalized contour plot (Fig. 3(a)) and the cardinal plot (Fig. 3(b)) show that the axial ratio is above 20 dB over a broad beamwidth and a clear maximum of directivity is at $\phi = 180°$ and $\phi = 0°$ as expected. A directivity peak of 9.7 dB in main direction even exceeds the simulation results. The imperfect matching network and balun cause some attenuation in the feeding path and therefore a gain of 2.3 dB has been realized.



(a) Contour plot of $\vec{E}_\phi$



(b) Cardinal cut, *blue:* plain parallel dipole, *red:* plain orthogonal to dipole

Fig. 3: Measured $\vec{E}_\phi$ at 10.7 GHz

5. Conclusion

It can be stated that the implemented cross dipole antennas on a MJCH-EBG reflector performs better than a standard dipole which is placed $\lambda/4$ away from a metal reflector in terms of directivity and size. It proves to be a valid approach towards miniaturization of antennas (here factor 9).

6. Acknowledgement

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