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Fractal Patch Antenna based on Crystal Photonic applied to Intelligent Transportation Systems in the 40 GHz Millimeter Waveband

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Abstract

5G (and beyond) has very high bandwidth, short latency, better quality of service, and the right amount of capacity. Technological breakthroughs in mobile communication systems user equipments operating in the millimeter wavebands imply a high gain to compensate the effect of path loss. In this work, a novel photonic crystal-based microstrip patch antenna array with high gain is designed to be used in the next generation intelligent transportation ssytems, e.g., V2X, and other exciting applications. The Photonic Band Gap (PBG) structure and Finite Element Method were considered. By using the High Frequency Structure Simulation (HFSS) software, a fractal microstrip patch antenna operating in the U-band of the electromagnetic spectrum is conceived and modeled on a two-dimensional photonic crystal. The use of the PBG structure improves the antenna's gain and bandwidth, while the antenna's fractal form decreases its size and improves its input impedance. The operational frequency range is 41.72-45.12 GHz with a resonant band centered at 43.26 GHz. The proposed antenna is comprised of a 0.45 mm thick copper ground plane, a 0.9 mm thick FR-4 epoxy substrate with a relative transmittance of 4.4, and a 0.45 mm thick copper antenna patch. The achieved frequency band gain is 8.95 dBi.

1 INTRODUCTION

A fractal patch antenna based on crystal photonics is a type of antenna that uses fractal geometry and crystal photonics to achieve enhanced performance compared to traditional patch antennas. In the context of antennas, fractal geometry is used to design antenna structures that have a repeating pattern at different scales, leading to increased performance in terms of gain, directivity, and bandwidth. Crystal photonics, on the other hand, is a technology that uses the unique optical properties of crystals to manipulate and control light. Combining fractal geometry with crystal photonics allows for the creation of antennas with improved performance characteristics, such as increased gain, directivity, and bandwidth. These antennas are used in a variety of applications, such as wireless communications, satellite communications, and radar systems. The idea of fractal patch antenna based on crystal photonic is at research level and the performance improvement is not yet been clearly proven. Howell first presented the microstrip antenna in 1972. The patch antenna is a form of this small height and width antenna. The patch antenna may have any form, including circular, rectangular, triangular, and square, there are different feeding methods to feed the patch antenna [1]. These antennas have both benefits and disadvantages, they are light, have minimal manufacturing costs, operate at microwave frequency, high compatibility with integrated circuit technology and are compact; nevertheless, the most significant downside is that they have a poor gain. Various approaches are offered to achieve the required high gain in the millimeter wave bands, including using of metamaterials in the role of substrate [2], parasitic patch [3], air gap [4], slot [5], shorting pin [6], metamaterials [7], dielectric substrates [8], antenna array configurations [9], multilayered substrate technique [10] and incomplete ground [11]. Additionally, the use of a photonic crystal structure has been proposed to solve the problem of surface waves [12, 13]. Photonic crystals are periodic dielectric structures that do not allow electromagnetic waves of a specific direction to pass through them. The material used in the photonic band gap is a dummy material and placed alternately in the surrounding environment of an empty air cylinder, in different shapes such as square or circle, are placed in the antenna substrate. These methods are effective for increasing the antenna gain but some of them increase the cost and complexity of design and fabrication. In the design of this antenna, FR-4 substrate is used, which has a thickness of h=0.9 mm, the reason for this choice is that this substrate is suitable for high frequency applications and have a low relative permittivity, It is light and low cost, by reducing the antenna manufacturing cost, the total system cost is reduced, which is suitable to be used in 5G wireless systems.

The best source introduced for 5G and beyond is the opportunity to operate these mobile networks in the millimeter wave (mm Wave) bands. Challenges exist for high-frequency (mm Wave) bands, namely the obstruction by various obstacles, such as trees, buildings, and rain, which increase large-scale fading and path loss. The need for high capacity and rate in communication systems has led the research towards U-band, The U-band frequency range, is from 40 to 60 GHz.

5G Frequency Range 2 (FR2) is the second of the two fre-

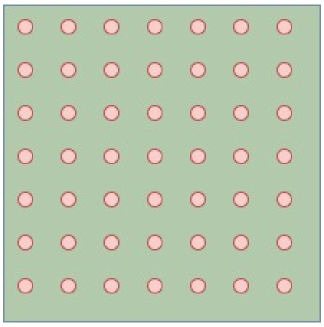

Figure 1. Structure of photonic crystal (for the ground and substrate)

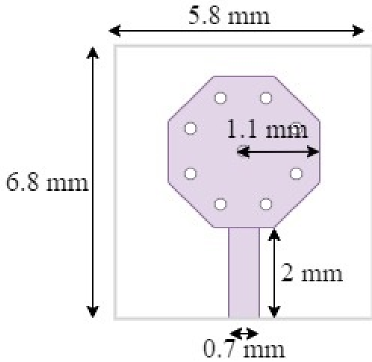

Figure 2. Configuration of the microstrip patch antenna

quency ranges of 5G New Radio (NR). This frequency band has received a lot of attention due to its short range efficient coverage and high bandwidth [14, 15, 16], and consists of the sub-millimetre wave bands and mm Wave frequency bands within (24.25- 52.6) GHzto support enhanced mobile broadband (eMMB) and ultra-reliable low-latency communications (URLLC). The use of the FR2 frequency range for the 5G of mobile phones causes many changes in the antenna systems in mobile phones. In FR2 networks, high antenna gains should be used at both base stations and user equipment sides to compensate for path loss.

The demand for autonomous vehicles is increasing every dayand includes vehicle-to-vehicle (V2X), vehicle-to-network (V2N), vehicle-to-people (V2P),vehicle-to-vehicle (V2V),vehicle-to-infrastructure (V2I). The use of communication between (V2X) is very important, e.g., in controlling traffic and preventing automotive traffic accidents. By using the positioning system, the blind spots of the vehicle can be identified. To enable the V2X deployment in FR2, a small and light antenna is needed with high gain. Microstrip patch antennas operating in FR2 can be easily used in the vehicle's structure due to their flatness, easy fabrication and possibility of bipolar/bidrectional operation.

The remainder of the paper is organized as follows. Section 2 addresses aspects of the antenna design, including the photonic band gap structure and antenna structureIn Section 3 the mathematical formulations considered for the antenna design are presented in detail. Section 4 describes the achieved results and discusses the lessons learned. Conclusions are drawn in section 5, where topics for further research are also addressed.

2 ANTENNA DESIGN

2.1 Photonic Band Gap Structure and Antenna Structure

Alternating dielectrics that control the propagation of electromagnetic waves passing through them are called photonic crystals. Photonic band gap (PBG) are intermittent structures and display broad band pass and stop band attributes at microwave frequencies.

PBG Constituent components are composed by introducing periodic disturbance like as photonic crystals rods, cavities and patterns in waveguides and substrates. As in a photonic crystal photon propagation is impeded by electrons, the electromagnetic waves in a PBG material are impeded due to the periodic discontinuity, hence making a slow wave structure. Within a PBG material, the modes of EM wave propagation have field distributions and dispersion properties which differ significantly from those in free space. Due to these unique properties of PBG materials they find potential applications in antennas, amplifiers, waveguide, filters, power combining, phased arrays, EMC measurements and many microwave devices [16].

The advantage of using this method is to improve gain, surface wave suppression and antenna bandwidth, loss in the patch. Photonic crystals can be created by creating cylinders in the structure of the antenna substrate. By increasing the radius of the cylinders and decreasing the distance between the cylinders, the gain of the antenna increases. The structure of the photonic crystal designed in the presented antenna is shown in Fig. 1.

The antenna is designed on FR-4 epoxy rectangular substrate permittivity is 4.4, loss tangent is 0.02, with length of substract Ls= 6.8 mm, width of the substract Ws=5.8 mm and thickness 0.9 mm. The shape of the antenna is a regular octagon made of copper, with 8 octagonal fractals created in it, the thickness of the copper patch is 0.045 mm, it is fed by a 50 Ω- microstrip line, with 0.9-mm strip width. The height of copper ground is 0.045 mm. The shape of the antenna and the fractal shape created in the patch reduces the size of the antenna and increases the resonance depth. Photonic crystal substrate is created by integrating the cylinders in a bed with a radius of 0.15 mm and a distance between each cylinder of 1 mm. As mentioned earlier, reducing the radius of the cylinders, and increasing the distance between the cylinders will reduce the gain and bandwidth of the antenna. The proposed antenna geometry is shown in Fig 2. The radius of the patch is 1.1 mm.

3 Mathematical Formulations

To design a patch antenna, it is important to consider several equations. The equations considered to calculate the patch length is as follows:

$$L = \frac{c}{2f_0\sqrt{\varepsilon_{eff}}} - 0.824h\left(\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)}\right) \tag{1}$$

where L is length of the patch, C is the speed of light, W is width of the patch, ε_{eff}, is the effective dielectric constant, f_0 is the operating frequency of the antenna and h is height/thickness of the substrate.

The patch width, W, can be calculated by the following equation:

$$W = \frac{c}{2f_0\sqrt{\frac{\varepsilon_R+1}{2}}} \tag{2}$$

where ε_R is the value of the dielectric constant of the substrate.

4 Results and discussion

In this section, a fractal patch antenna is proposed based on a photonic crystal substrate. In this design, a copper octagon is chosen as a radiation element. The diagram of return loss (S11), Voltage Standing Wave Ratio (VSWR), gain and directional radiation pattern is shown as radiation intensity. It can be seen in the diagram that this antenna has a resonance band at 43.26 GHz, as well as a frequency bandwidth that is in the range of 41.72-45.12 GHz, which covers part of the range of the n259 band (39.5-43.5 GHz).

The gain diagram of the designed antenna for the 43.26 GHz frequency is shown in Fig. 3. The obtained peak gain is 8.95 dBi, as shown in Fig. 3. This gain diagram of the antenna represents the enhancement in the power transmitted or received in different directions of radiation, for different angles. The return loss diagram presents its minimum value at 43.26 GHz, as shown in Fig. 4.

The radiation pattern represents the transportation or reception of a wave front at the antenna, describing its strength. Actually, according to the radiation pattern of the antenna, it is possible to understand the antenna's functionality and directivity. Fig. 5 shows the radiation pattern for the proposed patch antenna. E-Plane is the plane containing the electric field vector , and the direction of maximum radiation. H-plane is the plane containing the magnetic field vector and the direction of maximum radiation. In the E-plane and H-plane, where the maximum values of the gain at 43.26 GHz are shown.

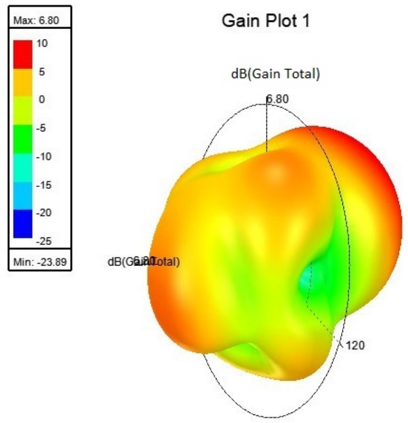

Figure 3. Gain plot for the microstrip patch antenna

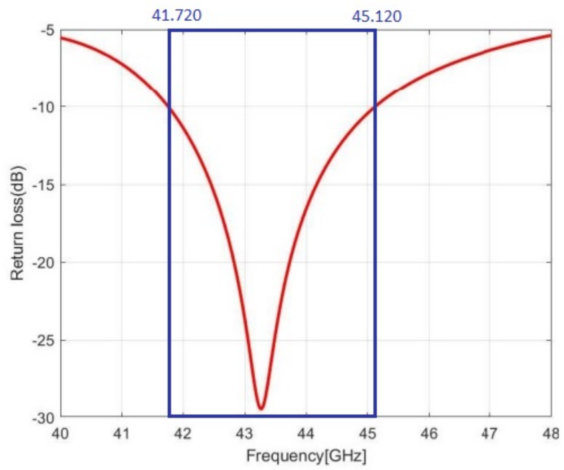

Figure 4. Return loss plot for the proposed microstrip patch antenna

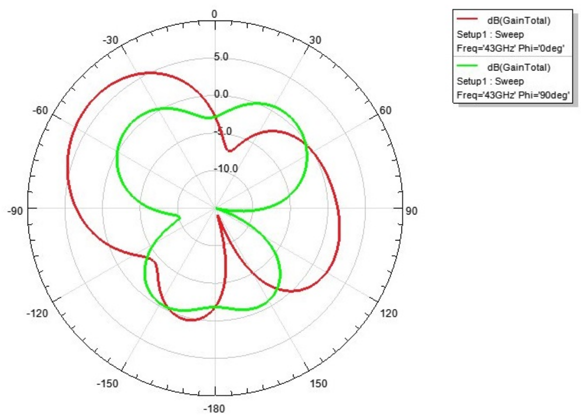

Figure 5. Radiation Pattern for the proposed microstrip patch antenna

5 Conclusion

The octagonal fractal antenna whose design was proposed in the paper offers several advantages, including a relatively small size, low-cost materials, and high efficiency. The bandwidth is 3.4 GHz and the resonance band with a gain of 8.95 dBi in the 43.26 GHz band has made this antenna suitable for use in the n259 frequency. These properties make it a potential candidate for use in a variety of communication applications, such as V-band and U-band communications and Vehicle-to-Everything (V2X) communications and satellite communications.

Future work will encompass produce the designed antenna and then test it in real environments with several vehicles.

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