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REGULAR ARTICLE

Design and Analysis of a High Gain Dual Band Symmetric Slot Microstrip Patch Antenna Using 5CB Nano Doped NLC for S- and Ku- Band Applications

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In this research work, we have proposed an antenna design with a defective ground structure (DGS) to increase the gain and produce dual bands without altering the antenna's basic construction. The antenna's construction consists of two glass layers, namely lower and upper glass materials with dimensions of 21 × 25 mm² and 19 × 19 mm², respectively. Both glass dielectric materials have the same dielectric constant of 5.25, a tangent loss of 0.008, and a thickness of 1 mm. The radiating element of the design has a dimension of 15 × 16 mm². The proposed design resonates at 6.2 GHz (C-band) with an S_{11} magnitude of – 16 dB and achieves a peak gain of 4 dBi when there is only an air gap between the glass plates. It resonates at 2.9 GHz and 13.2 GHz frequencies with S_{11} magnitudes of – 26.5 dB and – 37 dB when we fill the space between the two glass plates of the design with 4-Cyano-4'-pentylbiphenyl (5CB) nematic liquid crystal (NLC) doped with Cerium Oxide (CeO_2) nanoparticles (NP) of 6 wt % to achieve good efficiency and gain and we have noticed that low concentration profile of nano particles has no impact on resonant frequency and tuning range. We have achieved superior antenna performance, resulting in the generation of dual bands for both S and Ku bands, with peak gains of 5.6 dBi and 7.5 dBi at the corresponding resonant frequencies. Furthermore, the addition of CeO_2 nanoparticles to the 5CB LC lowers the transition temperature. The results are compared and analyzed with the body of data available.

Keywords: 4-Cyano-4'-pentylbiphenyl (5CB), S_{11}, CeO_2 NP's, Peak gain.

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1. INTRODUCTION

Liquid crystals (LCs) are dielectric materials that exist in a state between that of a liquid and a solid. Despite having a liquid-like appearance, they also possess anisotropic characteristics like nematic, smectic, and cholesteric. For more than a few decades, these materials have been particularly well-known for their usage in display-type applications that include digital cameras, cell phones, calculators, laptops, etc. There are various types of LCs available, such as MBBA, 6CB NLC, 5CB NLC, and many more. LCs contain many advantages and they possess properties like optical, thermal, and physical [1]. Recent experiments on liquid crystals doped with nanoparticles like ZnO [2], TiO_2 [3], and $BaTiO_3$ [4] to improve the performance of displays using LC materials. We must use tunable materials for achieving better antenna performance that include liquid crystals (LCs), VO_2, and graphene. Apart from other tunable materials, liquid crystals (LCs) are very popular, as the relative permittivity of an LC material can change when we apply an electric field to it, and the polarization of the *E*-field can change the orientation of the LC molecules, rather than that of polyimide, FR4, RTduroid, and other dielectric substrate materials. This phenomenon greatly enhances antenna performance and facilitates the design of compact-sized antennas.

Researchers are very interested in constructing an antenna based on LCs. Research on the dispersion of gold nanoparticles in nematic 5CB by Kumar [5] demonstrated that these nanoparticles can influence the alignment of nematic liquid crystals. This method helps in the development of electro-optical systems that are tunable. To design reconfigurable antennas for millimeter-wave frequency bands for satellite communication systems Kouki et al. [6], used SIW technology and nematic liquid crystal (K15) to design a unique patch design that can be tuned depending on the magnetic field. An antenna is designed using liquid crystal placed between radiating patch and ground to enhance its radiation performance in Ka band. To overcome significant obstacles in the construction of small profile LC based embedded antennas, Kim [7] presented a novel antenna design. This concept creates a chamber for the injection of liquid crystals using a three different layered PCB design. Using a flexible liquid crystal polymer, Venkateswara Rao [8],

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proposed an antenna and achieved circularly polarization using metamaterials for wireless, vehicle communications and other Wi-Fi applications. A small size LC based MIMO antenna for achieving flexibility is proposed by cDu [9]. To operate at microwave frequencies Kim [10], demonstrated an antenna design and shift in resonant frequency can be achieved by varying the liquid crystal's dielectric constant. In this research article, we have proposed a symmetric slot patch antenna with a defective ground structure (DGS) based on 5CB NLC doped with CeO_2 nanoparticles (NP) combination that has been utilized as a dielectric medium to achieve better performance rather than air dielectric medium. The proposed design has two glass substrate layers with an air gap.

2. METHODOLOGY OF THE DESIGN

2.1 Characterization of 5CB Material and Its Doping with CeO_2 Nanoparticles

The German company Sigma Aldrich provided the materials used in this study. We used differential scanning calorimetry (DSC) methodology and polarising optical microscope (POM) to determine the phase transition temperatures for the 5CB and 5CB doped with CeO_2 nanoparticles. Through experimentation, we have obtained the transition temperature values for both pure 5CB and 5CB liquid crystal material doped with CeO_2 nanoparticles indicated in Table 1 and 2 respectively. Figure.1 illustrates the chemical structure of a pure 5CB, while Figure 2 shows the heat flow curves for both 5CB and 5CB doped with CeO_2 nanoparticles.

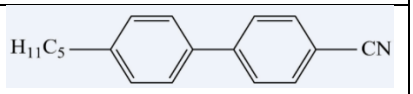
LC Type	Chemical Structure
5CB	

Fig. 1 – Atomic structure of a 5CB material

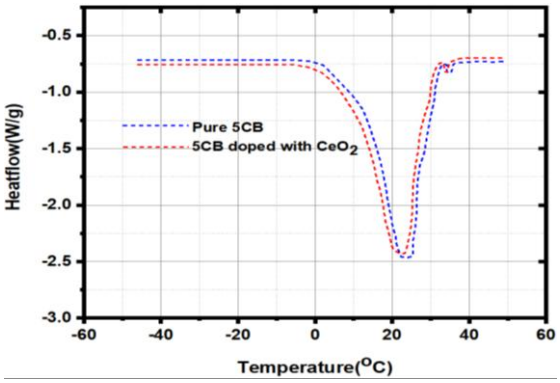


Fig. 2 – Obtained heat flow graph for both pure 5CB and 5CB doped with CeO_2 nanoparticles

Table 1 – Temperature of 5CB LC material

Type of LC name	Methodology	TNC	TIN
5CB	DSC	24.4	35.1
	POM	24.3	35.1

Table 2 – Temperature of 5CB LC doped with CeO_2 NP

Type of LC name	Methodology	TNC	TIN
5CB doped with CeO_2 NP	DSC	24.1	33.9
	POM	24.1	34.0

Here, TNC indicates the transition temperature between nematic and crystalline states, and TIN indicates the transition temperature between isotropic and nematic states.

2.2 Antenna Modelling and Its Description

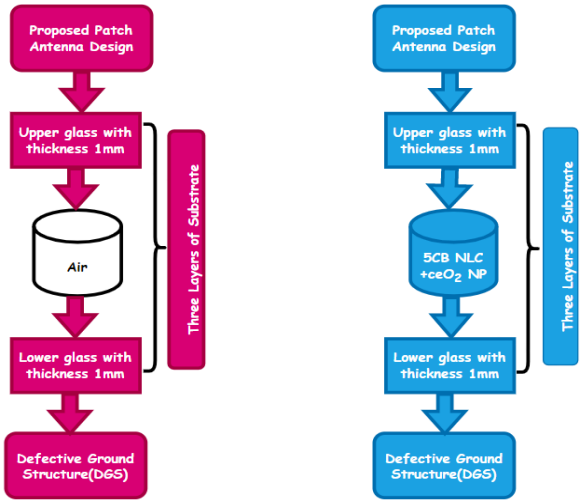


Fig. 3 – Proposed antenna design methodology (a) with air (b) 5CB NLC doped with CeO_2 NP

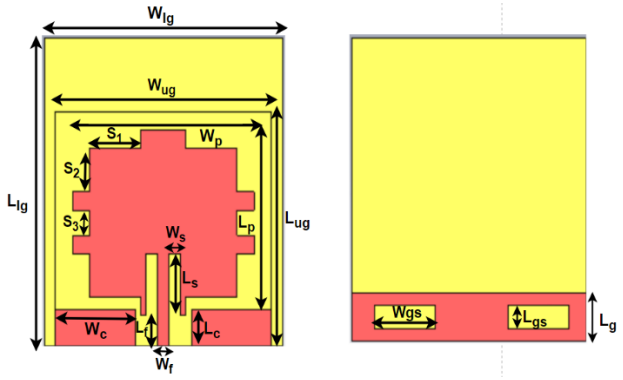
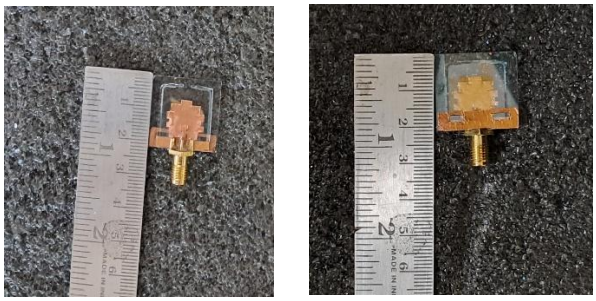


Fig. 4 – Simulated views of the proposed design (a) front side (b) back side

Table 4 – Proposed antenna dimensions

L_{lg}	W_{lg}	L_{ug}	W_{ug}	L_p	W_p	L_c	W_c	L_s
21	25	19	19	15	16	3	7	7.5
W_s	L_f	W_f	S_1	S_2	S_3	L_g	L_{gs}	W_{gs}
2	3	2	6	5	2	4	2	5.5

Figure 3 clearly explains the design methodology of the proposed structure. It has been constructed with three layers, a DGS layer (defective ground structure) using copper material with a thickness of 0.035 mm that acts as the bottom ground layer; two stacked glass substrates with a 0.006 mm air gap to accommodate 5CBNLC doped with CeO_2 NP and a radiating patch is



(a) (b)

Fig. 5 – Fabricated prototype's (a) front side and (b) back sides

designed using copper material with symmetrical slots. We have placed a symmetric slot microstrip patch on top of the upper-glass. The glass material present in the lower part of the structure has dimensions of 21 × 25 mm², while the glass material in the upper part has dimensions of 19 × 19 mm² as shown in Fig. 4. Each glass layer in the proposed construction has a permittivity of 5.25 and 1 mm of thickness. The dimensions of the proposed design are illustrated in Table 4 and fabricated model illustrated in Fig. 5.

3. RESULTS AND DISCUSSION

3.1 Analysis of an Antenna when the Dielectric Medium is Air

When evaluating the performance of any antenna design, S_{11} is an essential metric to keep in mind. Using the simulation tool like CSTMW studio, it has been established that the proposed antenna design, which utilizes air gap as a dielectric medium has been resonated over the frequency range of 5.8 to 6.7 GHz and possesses an impedance bandwidth of 0.9 GHz that has attained an S_{11} magnitude of – 16 dB. During the process of analysing the antenna with a network analyzer, the antenna was able to obtain an impedance bandwidth of 0.6 GHz over the frequency range of 6 to 6.6 GHz, with an S_{11} magnitude of – 12.1 dB. Figure 6 shows the proposed design, which is resonating at 6.2 GHz.

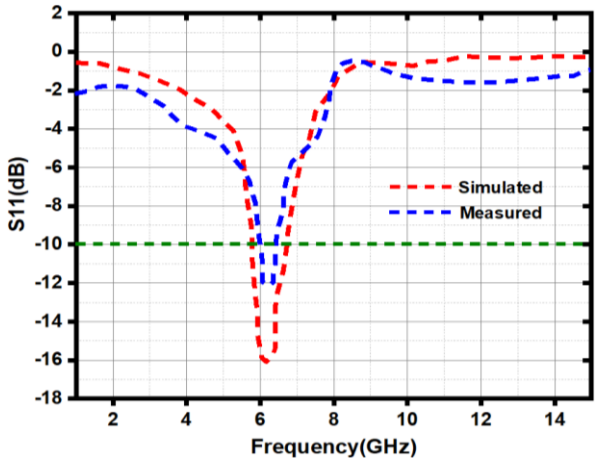


Fig. 6 – Proposed antenna's S_{11} for both measured and simulated cases with an air gap as the dielectric medium

3.2 Analysis of Proposed Design when the Dielectric Medium is 5CB NLC Doped with CeO_2 NP

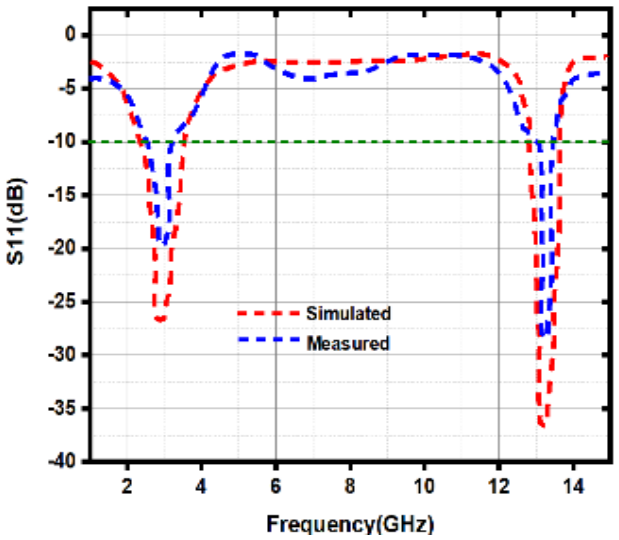


Fig. 7 – Obtained S_{11} of the proposed antenna when 5CB and CeO_2 particles combination as a dielectric medium

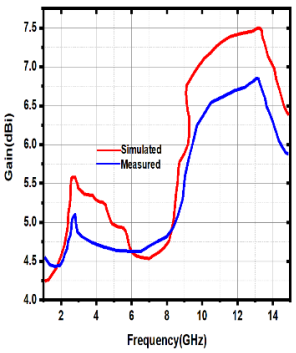


Fig. 8 – Gain variation with respect to frequency of the proposed antenna when 5CB and CeO_2 particles combination as a dielectric medium

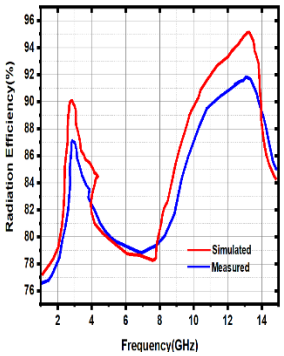


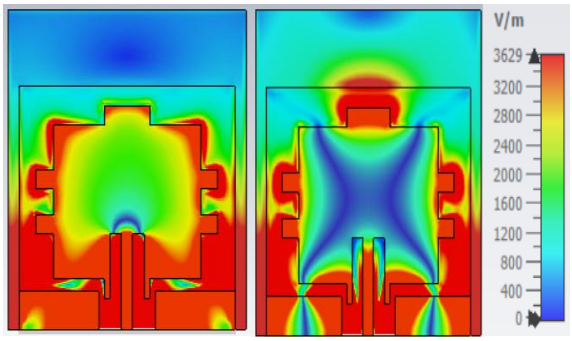
Fig. 9 – Radiation efficiency variation with respect to frequency of the proposed antenna

Figure 7 reveals that the antenna design resonates at two distinct frequencies. The initial operational bandwidth ranges from 2.5-3.4 GHz with a peak gain of 5.6 dBi, whle the second band resonates from 12.8 GHz – 13.6 GHz with a peak gain of 7.5 dBi. The measurement results confirm that the antenna resonates from 2.6 GHz to 3.2 GHz, while the second band spans from 13-13.5 GHz, achieving a maximum S_{11} magnitude of – 26 dB. Figure 8 indicates gain of the prescribed structure. Figure 9 shows the radiation efficiency plot of the proposed structure.

4. *E*- AND *H*- FIELD DISTRIBUTIONS

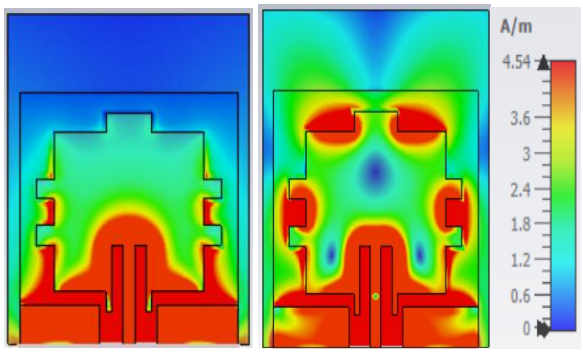
Figure 10 shows the *E*-field distributions at frequencies of 2.9 GHz and 13.2 GHz, while Figure 11 shows the *H*-field distributions at the same frequencies. Fig. 10 and 11 illustrate that perpendicularity between the *E*- and *H*-fields distributions. Figure 12 illustrates the surface-current distribution at 2.9 GHz and 13.2 GHz

frequencies. The feed line of the proposed design has the largest surface current distribution, as seen in Fig. 12.



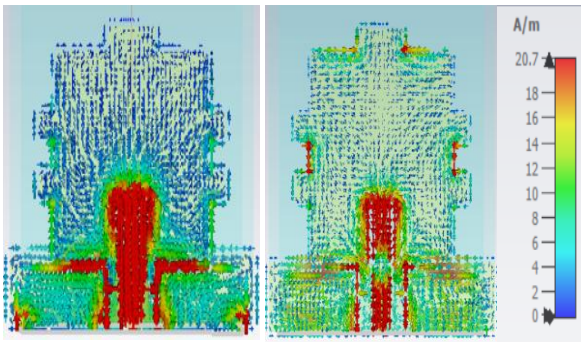
(a) (b)

Fig. 10 – Distribution of *E*-filed for the proposed antenna (a) at 2.9GHz (b) at 13.2GHz



(a) (b)

Fig. 11 – Distribution of *H*-filed for the proposed antenna (a) at 2.9GHz (b) at 13.2GHz



(a) (b)

Fig. 12 – Distribution of surface current for the proposed antenna (a) at 2.9GHz (b) at 13.2GHz

5. CONCLUSION

In this article, a novel symmetrical slot microstrip patch antenna utilizing a 5CB doped with CeO_2 NPs was introduced for S and Ku frequency band communication applications. It is also clear that doping of pure 5CB with CeO_2 nanoparticles lowers its transition temperatures. When an air gap exists between two plates, the proposed design employs at a single frequency band C; filling the air gap with 5CB-doped CeO_2 nanoparticles results in two separate bands, S and Ku. One of the most advantageous features of this design is, it can simultaneously function in two different frequency bands without requiring any changes to its physical dimensions. The proposed design resonates from 2.5 GHz to 3.4 GHz, with a maximum peak gain of 5.6 dBi and a maximum radiation efficiency of 90 %. Additionally, the proposed structure achieved a maximum peak gain of 7.5 dBi. The proposed design is suitable for S and Ku band applications with a compact size.

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Розробка та аналіз дводіапазонної симетричної щілинної мікросмужкової патч-антени з високим коефіцієнтом підсилення з використанням 5CB нанолегованого НРК для застосувань у S- та Ku-діапазонах

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У роботі запропоновано конструкцію антени з дефектною структурою заземлення (DGS), що дозволяє збільшити коефіцієнт підсилення та забезпечити роботу у двох частотних діапазонах без зміни основної будови антени. Конструкція антени складається з двох скляних шарів (нижнього та верхнього) розмірами 21×25 мм^2 та 19×19 мм^2 відповідно. Обидва скляні діелектричні елементи мають однакову діелектричну проникність 5,25, тангенс кута діелектричних втрат 0,008 і товщину 1 мм. Випромінювальний елемент конструкції має розміри 15×16 мм^2. Запропонована конструкція резонує на частоті 6,2 ГГц (C-діапазон) із рівнем параметра S_{11} – 16 дБ та досягає пікового коефіцієнта підсилення 4 дБі, коли між скляними пластинами знаходиться лише повітряний проміжок. У разі заповнення простору між двома скляними пластинами нематичним рідким кристалом (NLC) 4-ціано-4'-пентилбіфенілом (5CB), легованим наночастинками (NP) оксиду церію (CeO_2) у концентрації 6 % за масою, антена резонує на частотах 2,9 ГГц та 13,2 ГГц (значення S_{11} становлять – 26,5 дБ та – 37 дБ відповідно). Це дозволяє досягти високої ефективності та коефіцієнта підсилення; при цьому було встановлено, що низька концентрація наночастинок не впливає на резонансну частоту та діапазон перестроювання. Нам вдалося досягти покращених характеристик антени, що забезпечило роботу у двох діапазонах (відповідних діапазонам S та Ku) із піковими коефіцієнтами підсилення 5,6 дБі та 7,5 дБі на відповідних резонансних частотах. Крім того, додавання наночастинок CeO_2 до рідкого кристала 5CB знижує температуру фазового переходу. Отримані результати порівнюються та аналізуються з наявними в літературі даними.

Ключові слова: 4-ціано-4'-пентилбіфеніл (5CB), S_{11}, Наночастинки CeO_2, Пікове підсилення.