Tunable microstrip liquid crystals patch antennas

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Abstract. A patch antenna based on liquid crystals for the 5G GHz range was simulated. The variation of the antenna frequency range after doping magnetic nanoparticles was verified. The high-frequency patch antenna parameters are calculated considering the dependence of the reflectivity of the antenna 11 on the dielectric anisotropy, gain, directivity and phase shift. The ability to control the frequency range of the patch antenna is shown. The phase distributions were demonstrated for 5CB crystals with a slight variation in the dielectric constant tensor and crystals with magnetic permeability.

1. Introduction

The fifth generation of 5G wireless mobile communication provides for the operation of networks at low (up to 2 GHz), medium (2-10 GHz), and high (over 10 GHz) frequencies. Frequencies of 24.5-29.5 GHz are used to transmit signals at a higher speed. In this case, 5G communication is carried out on millimeter waves. Antennas with liquid crystals are used along with the known antennas that change their resonance properties due to mechanical changes in size, containing semiconductor devices such as pin-diodes, varactors, ferroelectrics [1]. The advantages of such antennas are a fast and straightforward change of the resonant frequency under the influence of the bias voltage, small dimensions in height, and power consumption compared to semiconductor counterparts. Due to the anisotropy of the dielectric properties of nematic liquid crystals, a change is achieved that is especially pronounced at high frequencies. The use of liquid crystals with increasing frequency leads to a decrease in dielectric losses [4]. The main disadvantages of liquid crystal antennas are low gain and radiation efficiency [3]. Several patches are used to improve these characteristics of antennas, for example, three microstrip sections as emitters and a tunable high-resistance resistor [3]. It is known that the introduction of nanoparticles changes the dielectric anisotropy of liquid crystals [5, 6], which will make it possible to control the position of the resonant frequency of the antenna over a broader range. Therefore, studies of tunable 5G patch antenna parameters based on liquid crystal crystals with embedded nanoparticles are relevant.

2. Modelling Tunable 5G LCD patch antenna

Modeling of a tunable patch antenna operating at a frequency of 28 GHz has been carried out. For this, 5CB liquid crystals were placed in the cavity of the patch antenna. Liquid crystals 5CB have a dielectric loss tangent of 0.03. And also, their complex part of the dielectric constant decreases sharply in the high-frequency region according to the empirical Cole-Cole equation for the case with distributed relaxation time (ε⊥≈2.7 and εII≈2.9) [7,8]. A schematic representation of a patch antenna with designations is shown in Figure 1.1 (a). The exact geometric parameters of the antenna are shown in Table 1.1.
The finite element method was used to simulate the patch antenna. The patch antenna is placed in the air domain (Figure 1.1 (b)). The antenna is driven by a discrete port. The copper surfaces in Figure 1.1 (a), marked in yellow, are introduced into the numerical model in the form of the transient boundary condition with a conductivity $\sigma = 56$ MS/m with an adequate thickness of 18 $\mu$m. Unlike ideal conductors often used to design antennas, this approach produces more physical results. A boundary condition of the PMC type was used on the plane of the ball section to speed up the calculations due to the mirror symmetry of the antenna geometry.
A rigid thin polyimide film was selected to ensure a high Q-factor of the antenna resonator and a significant phase shift. The real part of the complex dielectric constant of such a film is $\varepsilon = 3$ (AP9111R or CG352535E), the tangent of the dielectric loss angle $\tan(\delta) = 0.003$, the thickness $d = 0.1$ mm. The patch sizes $w_p$ and $l_p$ are set slightly differently to mismatch the TM mode's excitation by the magnetic field and dominantly excite the TE01 mode by the electric field. The choice of such dimensions is essential to maintain the polarization of the antenna radiation. The parameters $l_s$ and $w_s$ are subscripts and determine the efficiency of radiation input to the antenna. The choice of $w_{line}$ corresponds to the parameters of the microstrip line, which provides radiation input to the antenna to match the source with an impedance of 50 Ohm.

Frequency dependences of the signal reflection coefficient $S_{11}$ were plotted for two spatial crystal orientations. As shown in Figure 1.2 (a), when the orientation of the liquid crystals changes, the resonance shifts, but the directional pattern remains unchanged (Figure 1.3). The phase shift of the electric field in the far zone is about 40 degrees in a reasonably wide frequency band, shown by arrows in Figure 1.2 (a, b).

The maximum efficiency of the received antenna is found not for the center frequency, but along the intersection point of the $S_{11}$ curves, where the reflectance is at the level of -4 dB. In conclusion, it should be noted that the developed patch antenna is quite effective for creating phased antenna arrays.
The final characteristics of a simple patch antenna are shown in table 1.2.

Table 1.2. Antenna parameters

| Parameter               | Value          |
|-------------------------|----------------|
| S11                     | -17dB          |
| Gain                    | 5.7dB          |
| Focus                   | 6.9dB          |
| Maximum far-field phase shift | ±20 degrees   |

3. Tunable 5G patch antenna based on liquid crystal crystals with the addition of Janus-like magnetic particles

The geometric parameters of the previous antenna were optimized to simulate a tunable patch antenna operating at 28 GHz with Janus-like particles. It is assumed that liquid crystals are controlled by external electric and magnetic fields. The magnetic permeability tensor is added to the numerical model, taking into account the average dispersion of magnetic particles for this range. It is known that the real part of the magnetic permeability of round-shaped iron oxide nanoparticles in the region of 10 GHz and more weakly changes close to 1, and the imaginary part is equal to 0 [9]. The magnetic permeability of composites based on micron-sized powders of carbonyl iron has a pronounced dispersion, the real part in the region of 10-40 GHz varies from 1.7 to 0.7, the imaginary part - from 1.5 to 0.7 [10], and it was found that the dielectric and magnetic permeabilities increase logarithmically with increasing volumetric iron content. Considering that iron oxide nanoparticles can be used in the form of long rods and high range, it can be assumed that the magnetic permeability will change depending on their orientation within the following limits – (μ⊥ = 1.1 and μ∥ ≈ 1.4). A schematic representation of a patch antenna with designations is shown in Figure 1.1 (a). Antenna geometric parameters are shown in the table below.

Table 2.1. Parameters of a tunable 5G patch antenna for phased array

| Parameter               | Value, mm   |
|-------------------------|-------------|
| Substrate length, l_s   | 7           |
| Substrate width, w_s    | 7           |
| Patch length, l_p       | 3.1         |
| Patch width, w_p        | 3.9         |
| Construction strip length, l_s | 0.65 |
| Building strip width, w_line | 0.2 |
| Microstrip line width, t | 0.48 |
| Substrate thickness, d_s | 0.1 |
| Liquid crystal layer thickness, d_{LC} | 0.1 |
| Foil thickness          | 0.018       |
Similarly to the previous case, to ensure a high Q-factor of the antenna resonator, as well as a higher phase shift, a polyimide film with a dielectric constant $\varepsilon_s = 3$ (AP9111R or CG352535E), a tangent of the dielectric loss angle $\tan(\delta) = 0.003$ and a thickness $d_s = 0.1\text{mm}$.

![Figure 2.1](image)

**Figure 2.1** - (a) Reflection coefficient $S_{11}$ for two polarizations of LC 5SB with the addition of Janus-like magnetic particles. (b) Phase shift of the electric field in the far zone.

Frequency dependences of the signal reflection coefficient $S_{11}$ were plotted for two spatial crystal orientations. As can be seen from Figure 2.1 (a), when the orientation of the liquid crystals changes, the resonance shifts, and for the case of LCs with the addition of magnetic nanoparticles, the resonance bands are shifted to the low-frequency region, and the distance between the two $S_{11}$ peaks is reduced by more than 250 MHz.

The phase shift of the electric field in the far zone is of the order of 40-50 degrees, which suggests that the use of magnetic particles to control patch antennas allows achieving a more significant phase shift and, potentially, with an increase in the magnetic permeability anisotropy, to achieve better patch antenna configurations for the 28 GHz range.

As in an antenna without magnetic particles, the maximum phase shift efficiency is found not for the center frequency but for the intersection of the $S_{11}$ curves, where the reflection coefficient is at a level of ~ -4dB. The final characteristics of a simple patch antenna are shown in table 2.2.

| Parameter                  | Value     |
|----------------------------|-----------|
| $S_{11}$                   | -15dB     |
| Gain                       | 5.4dB     |
| Focus                      | 6.7dB     |
| Maximum far-field phase shift | $\pm 25$ degrees |

4. Conclusion

The results of modeling a patch antenna based on liquid crystals with Janus-like magnetic nanoparticles show that the gain and directivity do not change. The phase shift of the electric field in the far zone exceeds 5 degrees, a similar change for an antenna with undoped liquid crystals. The
prospects of using external electric and magnetic fields to control the phase shift of a patch antenna with magnetic nanoparticles are shown.

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