A Nematic 5CB Liquid Crystal based Dual Band Microstrip Patch Antenna using Moth Flame Optimization

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Abstract. Microstrip patch antenna with different substrate materials which can operate in single and multiple resonating bands are useful for wireless applications. A 5CB nematic liquid crystal based microstrip antenna with dual band on a glass substrate having relative permittivity of 6.438 has been designed in this paper. Two glass substrates of 0.1mm thickness with 21x25mm² and 19x19mm² sizes have been placed on each other, in between 0.005mm glass substrate has been placed to fill 5CB nematic liquid crystal. On the top of the substrate ‘I’ slotted rectangular patch has been placed; the dimensions of the patch have been calculated by utilizing Moth Flame Optimization (MFO) method. The proposed antenna is resonating at 1.8 GHz and 9.2 GHz frequencies with S11 as -27dB and -19.42dB, respectively. Simulated results of designed antenna with MFO algorithm are compared with Genetic Algorithm (GA).

Keywords: 5CB nematic liquid crystal, Genetic Algorithm, Moth Flame Optimization

1. Introduction

LC’s (Liquid crystals) has huge amount of applications in many fields like optical switches, display devices, medical imaging, and antennas etc, because they produce different thermal, electrical and optical properties [1-10]. From the literature different types of liquid materials have been utilized to design antennas [11-13]. Because of having features like transparency and reconfigurability, they can attain better performance as compared with traditional antennas. Nematic 5CB liquid crystal (LC) has been used to design the modelled antenna in this article.

Microstrip patch antennas (MPA’s) play a vital role in communication applications due to light weight, compact in size and easy installation. The drawbacks of MPA’s can overcome by modelling on a proper substrate material with proper dielectric constant. In this article glass cell with three layers of glass substrate with reflection coefficient of 6.438 has been utilized to design antenna. Optimization techniques become most effective methods in the field of communication systems. Genetic algorithm (GA) is an efficient optimization algorithm having many applications in areas of electromagnetic fields. Genetic algorithm is used to design microstrip antennas to improve the performance and their
parameters like reflection coefficient, bandwidth, size and gain etc [14-16]. In this present work, MFO is utilized to design the patch of antenna, which has been discussed later in this paper. Here, glass substrate filled with 5CB LC is used to attain the dual working bands and MFO has been used to optimize the dimensions of the antenna to gain better bandwidth, high return loss and improved gain. The proposed antenna with working in dual band can be used in L, S and X band applications like radar, GPS, radio, telecommunications, satellite communications, and military etc.

2. Antenna design
Glass substrates of having 21mm x 25mm, 19mm x 19mm size and permittivity of 6.438 is utilized to model proposed antenna. In between the glass substrates; 0.005mm glass with air gap having 19mm x 19mm size is placed to fill the 5CB Nematic LC. The design of patch of the antenna is optimized. The MFO algorithm has been explained in the next section.

2.1 Moth Flame Optimization (MFO):
The mathematical modelling of MFO is designed depending upon the behaviour of moths and is well discussed in [17-19]. In this algorithm moths are the problem variables and candidate solutions are moth positions. By changing the positional vector, moths can fly in all the dimensions. In this MFO method, set of moths is indicated as a matrix format as shown in equation (1),

\[
M = \begin{bmatrix}
    m_{0,0} & m_{0,1} & \cdots & m_{0,j} \\
    m_{1,0} & m_{1,1} & \cdots & m_{1,j} \\
    \vdots & \vdots & \ddots & \vdots \\
    m_{i,0} & m_{i,1} & \cdots & m_{i,j}
\end{bmatrix}
\]  

Where, i represent the number of moths and j is the no. of dimensions, respectively. The fitness values of the moths are displayed in an array, which shown in Equation (2).

\[
OM = \begin{bmatrix}
    o_{m_1} \\
    o_{m_2} \\
    \vdots \\
    o_{m_i}
\end{bmatrix}
\]  

Where, i represent the moths. Flames is another main part of the MFO algorithm. In a similar way of matrix of the moths, the matrix of the flames also constructed as shown in equation (3),

\[
F = \begin{bmatrix}
    f_{0,0} & f_{0,1} & \cdots & f_{0,j} \\
    f_{1,0} & f_{1,1} & \cdots & f_{1,j} \\
    \vdots & \vdots & \ddots & \vdots \\
    f_{i,0} & f_{i,1} & \cdots & f_{i,j}
\end{bmatrix}
\]  

Where, ‘i’ and ‘j’ represents the number of moths and its dimensions. The dimensions of both M and F matrices are same. The fitness values for the flames are shown as a matrix in Equation (4)

\[
OF = \begin{bmatrix}
    o_{f_1} \\
    o_{f_2} \\
    \vdots \\
    o_{f_i}
\end{bmatrix}
\]  

\]
Where, ‘i’ represent the number of moths. Both flames and moths are the solutions in MFO algorithm. The flames and moths are differed by the updating process of moths and flames in all the iterations. The best position acquired from the moths is represented as the flame. To reach near global optimal point, the MFO algorithm is composed of three steps. The three steps of the MFO are shown as:

\[ \text{MFO} = (N, Q, T) \]  (5)

Where, N produces the fitness values of moths and its random population.

\[ N \rightarrow (M, OM) \]  (6)

Where, Q indicates the major function by which moth’s moves around the search space

\[ Q: M \rightarrow M \]  (7)

Where, T is true if it meets the termination standards and T is false if it does not meet termination criteria.

\[ T: M \rightarrow \text{(True, False)} \]  (8)

The function N has to create an initial solution and computes the objective function value.

```
for n = 1:i
    for d = 1:j
        M(n,d) = [ub (n)-lb (n)]*rand() + lb (n);
    end
end
OM = Fitness Function (M);
```

Where ‘ub’ represents the upper bound and ‘lb’ represents the lower bounds of the variables.

\[ ub = [ub1, ub2, \ldots, ubi] \]  (9)
\[ lb = [lb1, lb2, \ldots, lbi] \]  (10)

The Q function is the main function by which the moths move around the dimensions and the positions will be updated by using Equation (11).

\[ M_n = S(M_n, F_d) \]  (11)

Where \( M_n \) indicates the \( n^{th} \) moth; and \( F_d \) indicates the \( d^{th} \) flame, and \( S \) indicates the spiral function and represented as follows:

\[ S(M_n, F_d) = D_n e^{a \cdot \cos(2\pi t)} + F_d \]  (12)

Where \( D_n \) represents the space between \( n^{th} \) moth and \( d^{th} \) flame, \( a \) is a constant to describes the shape of the spiral, and \( t \) is a random value between \(-1\) and \(1\). \( D \) is computed by using Equation (13).

\[ D_n = |F_d - M_n| \]  (13)

The amount of flames is reduced adaptively as described in Equation (14).
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L-1FlameNo=rand L-k* L-1/g167/g183/g168/g184/g169/g185 (14)

Where k is the present number of iterations; L represents the amount of flames; and T is the amount of iterations.

2.2 Antenna design using MFO:

The initial antenna was designed having the rectangular patch length of 9.7 mm and patch height of 9.9 mm. MFO algorithm has been applied to optimize the antenna design to achieve high gain and better bandwidth. The rectangular shaped antenna having three “I” slots have been obtained as a result of MFO algorithm. To achieve the best performance, MFO method is run for 25 times with the control parameters by using MATLAB software. The control parameters for MFO algorithm are depicted in table 1. The final design of antenna after using MFO is shown in figure (1), is designed using Ansys HFSS which is a 3D EM(electromagnetic) simulation software for designing and simulating antennas, antenna arrays, high-speed interconnects, RF or microwave components, connectors and filters etc

Table 1: MFO algorithm control parameters

| Parameters | MFO |
|------------|-----|
| Population Size | 50 |
| T | 250 |
| a | 0.5 |
| t | [-1,1] |

The width of the rectangular patch is calculated by using formula (15),

\[ W_p = \frac{C}{2f_r \sqrt{\frac{1}{\epsilon_r + \frac{1}{2}}} } \] (15)

Where, \( f_r = 2 \text{ GHz} \), \( \epsilon_r=13.876 \) and \( C=3x108\text{ m/s} \)

The effective dielectric constant of the antenna is calculated by using formula (16),

\[ \epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[ 1 + 12 \frac{b}{w} \right]^{-\frac{1}{2}} \] (16)
The effective length of patch is calculated by using formula (17),
\[ L_{\text{eff}} = \frac{C}{2\sqrt{\varepsilon_{\text{reff}}}} \]  
(17)

The actual length of patch is calculated by using formula (18),
\[ L_p = L_{\text{eff}} - 2\Delta L \]  
(18)

Where, \( \Delta L = 0.412h \left( \frac{W}{h} + 0.264 \right) + 0.258 \left( \frac{W}{h} + 0.8 \right) \)

with \( h=2.005 \text{mm} \)

The geometry values of the designed antenna using MFO algorithm are shown in Table 2.

| Parameters | Value (in mm) |
|------------|---------------|
| L_1        | 21            |
| W_1        | 25            |
| L_2        | 19            |
| W_2        | 19            |
| L_3        | 9.7           |
| W_3        | 9.9           |
| L_4        | 7.3           |
| W_4        | 1.5           |
| L_5        | 3.5           |

| Parameters | Value (in mm) |
|------------|---------------|
| W_5        | 4             |
| L_f        | 9.4           |
| W_f        | 1             |
| G          | 0.5           |
| L_g        | 4             |
| W_g        | 7             |
| G_1        | 0.005         |
| W_6        | 1             |
| W_7        | 1             |

3. Results and discussions:

(a) (b) (c)

**Figure 2:** comparison of the simulated (a) reflection coefficient, (b) VSWR, and (c) Gain for the designed antenna without optimization, using GA and using MFO

Figure 2(b) indicates the reflection coefficient of the proposed antenna without optimization, using GA and using MFO. From figure 2(a), proposed antenna using MFO shows better results and is working in dual band, which are operating from 1.15-3.3 GHz with \( S_{11} \) of -27dB and 7.58-10.52 GHz with \( S_{11} \) of -19.42dB. The amount of conflict between antenna and feed line connecting to it can be represented by Voltage Standing Wave Ratio (VSWR). A VSWR value below 2 is considered best for many antenna applications. Figure 2(b) indicates the VSWR of the designed antenna without optimization, using GA and using MFO.

(a) (b)

**Figure 3:** Simulated 3D Gain plot at (a) 1.8 GHz, (b) 9.2 GHz
Figure 2 (c) shows the peak gain plot for designed antenna without optimization, using GA and using MFO. From the figure 2 (c), proposed antenna with MFO algorithm has achieved high gain at two resonant frequencies as 5.62dB at 1.8GHz and 10.28dB at 9.2GHz. Figure (3) shows 3-D plot of gain for designed antenna using MFO at 1.8GHz and 9.2GHz frequencies.

Table 3: Comparison table for proposed antenna without optimization, using GA and using MFO

| Proposed Antenna  | Working Band (GHz) | Bandwidth (GHz) | Resonant Frequency (GHz) | S11 (in dB) | Gain (in dB) |
|-------------------|--------------------|-----------------|--------------------------|-------------|-------------|
| Without Optimization | 1.475 - 2.2        | 0.725           | 1.9                      | -15.27      | 4.3         |
| Using GA          | 7.8 - 9.45         | 1.65            | 8.7                      | -12.89      | 5.7         |
| Using MFO         | 1.15 - 3.3         | 2.15            | 1.9                      | -19.16      | 4.4         |
|                   | 8.05-10.22         | 2.17            | 9.1                      | -15.46      | 7.8         |
|                   | 1.15 – 3.3         | 2.15            | 1.8                      | -27         | 5.62        |
|                   | 7.58 - 10.52       | 2.94            | 9.2                      | -19.42      | 10.28       |

Figure 4: Simulated Co and cross polarization of (a) E-plane at 1.8 GHz, (b)(a) H-plane at 1.8 GHz (c) E-plane at 9.2 GHz and (d) H-plane at 9.2 GHz

Radiation patterns of E-plane co and cross-polarization, H-plane co and cross-polarization at resonance frequencies 1.8GHz and 9.2GHz are illustrated in figure 4. The Omni-directional pattern is attained in E-plane co-polarization and bi-directional pattern is attained in E-plane Cross-polarization for both the resonant frequencies. Similarly, Omni-directional pattern is attained in H-plane co-polarization and butterfly type bi-directional pattern is attained in H-plane co-polarization for both the resonant frequencies.
4. Conclusion:

Design of a dual band 5CB Liquid Crystal microstrip patch antenna using MFO algorithm is proposed in this paper. Glass substrates having relative permittivity of 6.438 with thickness of 0.1mm are utilized for modelling and prototyping of proposed antenna. Two glass substrates with 21x25mm and 19x19mm size have been placed on each other, in between 0.005mm glass substrate with air gap has been placed to fill 5CB LC. On the top of the substrate patch has been developed using MFO algorithm to achieve the required antenna parameters. The proposed antenna is operating from 1.15-3.3 GHz with $S_{11}$ of -27dB and 7.58-10.52 GHz with $S_{11}$ of -19.42dB. By comparing the simulation results of proposed antenna using MFO algorithm with proposed antenna without optimization and proposed antenna using GA, we can observe that gain, bandwidth and reflection coefficients are having better values by using MFO algorithm.

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