Triple-band Modified Printed Inverted-F Antenna Design for WI-FI-7 Applications

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***Abstract*—WI-FI-6/6E is now commercialized and the WI-FI community is currently developing the IEEE 802.11be standard, namely WI-FI-7, which will offer enhanced throughput and higher data rate than its predecessors. In this article, a compact triple-band printed inverted-F (IF) antenna operating at 2.4 GHz, 5 GHz, and 6 GHz frequency bands is designed for WI-FI-7 applications. We design a novel antenna structure that is well-suited for triple-band operation. The core idea is to use a stripline as a feeder that also couples two modified IF designs. A nature-inspired optimization method, namely the artificial hummingbird algorithm (AHA), is used to achieve an optimal design solution for the triple-band IF antenna. Computed results demonstrate that the proposed antenna achieves satisfactory results regarding the reflection coefficient and the realized gain in all the frequency bands of interest.**

***Index Terms*—WI-FI-7, inverted-F antenna, artificial hummingbird algorithm, antenna design.**

I. INTRODUCTION

Wi-Fi is considered a mature technology, however, it is constantly innovating to facilitate the requirements that modern society poses [1], [2]. Wi-Fi-4 (IEEE 802.11n) was the first to accommodate multiple input multiple output (MIMO) support, at 2.4 GHz and 5 GHz. The next cornerstone was the introduction of Wi-Fi-5 (IEEE 802.11ac), which operates at 5 GHz. On February 1st, 2021, Wi-Fi-6 (IEEE 802ax) received its final approval. Its operational frequency band is defined at 6 GHz, aiming to enhance throughput-per-area in dense networks [3]. Wi-Fi-7 (IEEE 802.11be) is expected to be the next amendment of the 802.11 IEEE standard, operating at 2.4 GHz, 5 GHz, and 6 GHz bands. Some of its features include the 320 MHz channel bandwidth, both multi-band and multi-channel aggregation and operation, multi-access point coordination, and link enhancement [1], [2].

Towards this end, the antenna design for the new expected IEEE 802.11be Wi-Fi standard is a challenging topic. The selection of microstrip patch antennas is straightforward since their major advantages, like low cost and small size, make them an attractive solution. However, their design is a demanding and, at the same time, challenging problem due to a relatively large number of parameters that need to be tuned. In addition, antennas for Wi-Fi-7 require triple-band operation, large bandwidth, and MIMO functionality. The Inverted-F (IF) antenna has been studied in the literature due to its characteristics, e.g., compactness, omnidirectional radiation pattern, and efficacious performance [4]. However, triple band operation in antenna design can be considered a challenging task with medium or even high complexity. To address many of the issues that arise in a conventional design process, optimization techniques are often employed. Especially, bio-inspired techniques have found considerable success in the optimization of microstrip antennas [5].

In this paper, we apply an emerging nature-inspired algorithm, namely, the artificial hummingbird algorithm (AHA) [6], to design the proposed antenna structure. The novel antenna structure consists of a combination of two inverted F-antennas and is suited for the triple-band operation. To the best of the authors' knowledge, this is the first time the proposed structure is applied to antenna design optimization problems.

This work is organized as follows: Section II reviews the current literature, whereas, in Section III, the optimization algorithm for the antenna design is presented. Section IV discusses the proposed antenna characteristics, whereas in Section V the numerical results and the simulated design is provided. Section VI concludes this work.

II. RELATED WORK

In the literature, several applications concerning WI-FI-7 have been proposed, e.g. telecommunications [7], healthcare internet of things [8], and feedback overhead reduction [9]. In addition, a few design efforts have been conducted on developing microstrip patch antennas to meet the specifications of WI-FI-7. In [10], the authors propose a low-profile antenna fed by a single rotated L-probe, where circular polarization (CP) is accomplished using an additional wave resonance surface on the finite meta-surface. In [11], a two-port antenna is designed, achieving full-duplex (FD) operation. The antenna

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achieves a wideband inter-port isolation, via a broadband balun with a differential feeding port.

III. ALGORITHM DESCRIPTION

Artificial hummingbird algorithm (AHA) is a nature-inspired optimization technique that models the flight skills and the foraging strategies of hummingbirds [6]. AHA is composed of three entities; the hummingbirds, which represent the population, the food sources, i.e., the solution vectors, and the nectar refilling rate that corresponds to the fitness function value. Every time that a hummingbird visits a food source, a counting value is updated and stored in a matrix, i.e., the visit table. The position of each hummingbird is defined through a specific food source that is assigned to that particular hummingbird.

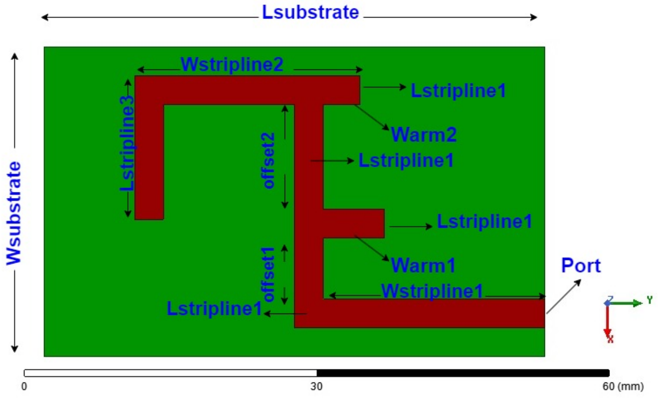
AHA (like every evolutionary algorithm) tries to balance the exploration and exploitation phases. The optimization is performed using three mechanisms, i.e., the guided mechanism, the territorial mechanism, and the migration mechanism. During the first one, each hummingbird seeks the highest nectar value among the existing food sources, updating the visit table. After selecting a food source, the hummingbird employs three different strategies to visit it; the omnidirectional, the axial, and the diagonal. The exploitation phase is performed as a local search within the hummingbird's territory. However, often the food sources that are assigned to the population members lack food. In such cases, the exploration phase takes place, which refers to the migration mechanism. The key structure of the AHA optimization algorithm is presented in Algorithm 1.

Algorithm 1 Key structure of the AHA optimization algorithm

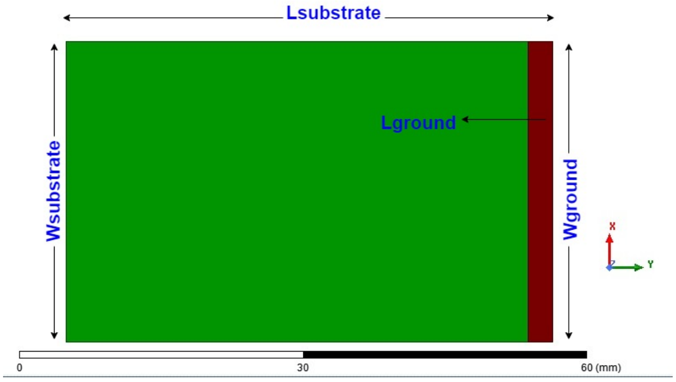
```
Initialize the tuning parameters
while $t \leq MaxIter$ do
    Guided foraging
    Territorial foraging
    Migration foraging
end while
```

IV. ANTENNA DESIGN

In this work, the AHA optimization algorithm is utilized for the design of a modified printed IF antenna. The proposed device operates at three frequency bands; 2.4 GHz, 5.85 GHz, and 6.5 GHz. The top and bottom views of the designed IF antenna's geometry are depicted in Fig. 1. We can conclude that a total of ten unknown geometrical parameters are required to fully describe the proposed antenna design. In the simulated designs, the green color represents the substrate and the red color refers to the patch metal foil. To achieve a triple-frequency operation, a modified dual IF patch is printed on a single layer. A stripline, with a source port at the edge of the substrate, acts as a feeder to the antenna. The two IF designs are coupled using a second stripline. As a substrate, Rogers 4 (relative permittivity $e_r = 2.2$, $thickness = 1.575$ mm) is used, since its characteristics make it suitable for the frequency bands under consideration. To set the ground plane and complete the design, a partial ground technique is utilized.



(a) top



(b) bottom

Fig. 1. Geometry of the proposed modified printed IF-antenna: (a) top view, (b) bottom view.

The best solution that represents the optimal antenna parameters is presented in Table I. These results were obtained from the utilization of the optimization algorithm, alongside the commercial electromagnetic field simulator HFSS, © 2020 from ANSYS, Inc. AHA, as any evolutionary method, aims to minimize the given objective function. In our case, the goal is to minimize the S_{11} value of the modified IF antenna at the three operating frequencies. Therefore, the objective function can be expressed as

$$\begin{aligned} F(\vec{y}) &= \max(S_{11}^{2.45GHz}(\vec{y}), S_{11}^{5.85GHz}(\vec{y}), S_{11}^{6.5GHz}(\vec{y})) \\ &+ \Psi \times \max(S_{11}^{2.45GHz}(\vec{y}) - L_{dB}) \\ &+ \Psi \times \max(S_{11}^{5.85GHz}(\vec{y}) - L_{dB}) \\ &+ \Psi \times \max(S_{11}^{6.5GHz}(\vec{y}) - L_{dB}) \end{aligned} \tag{1}$$

where $\vec{y}$ is the position vector of the design parameters to be optimized (8 vector arguments), $S_{11}^{2.45GHz}, S_{11}^{5.85GHz}), S_{11}^{6.5GHz}$ are the S_{11} values of the designed modified IF antenna, L_{dB} is the selected S_{11} limit in dB (in this work $L_{dB} = -10$ dB, and Ψ is the penalty factor, equal to 10^8.

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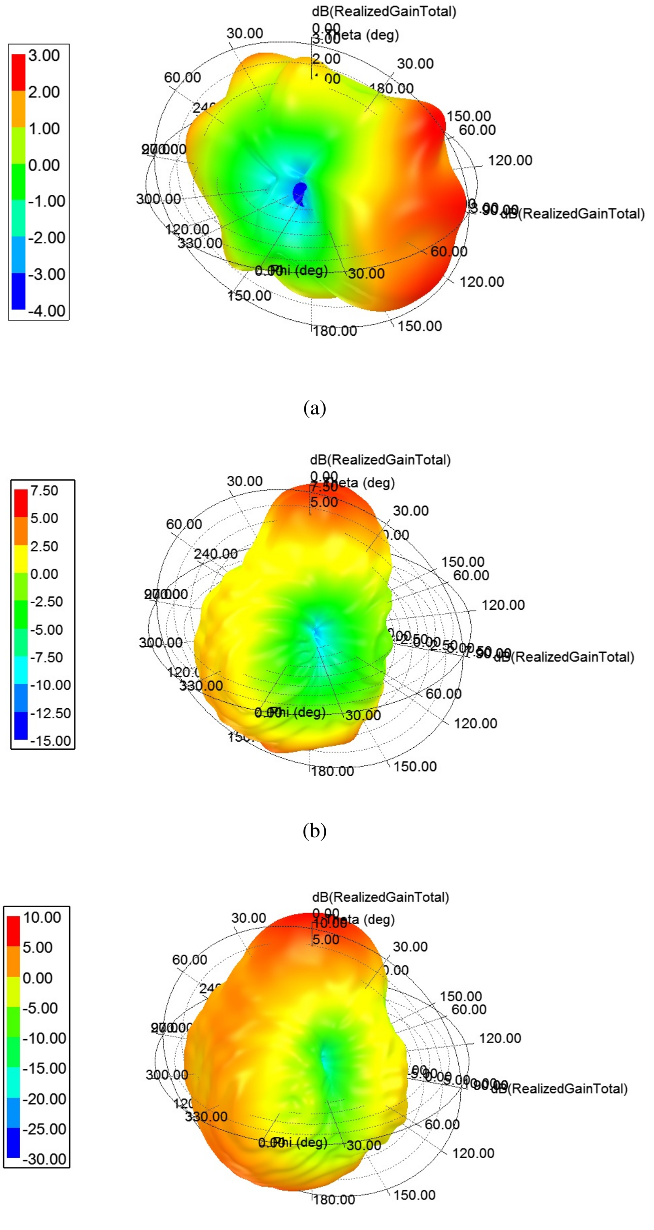


(a)

(b)

(c)

Fig. 3. Realized gain of the best antenna geometry obtained by AHA algorithm: (a) 2.45 GHz, (b) 5.85 GHz, and (c) 6.5 GHz.

TABLE I
MODIFIED PRINTED IF ANTENNA DESIGN PARAMETERS (BEST SOLUTION)OBTAINED BY THE AHA OPTIMIZER.

Parameter	*Value (mm)*	*Parameter*	*Value (mm)*
$L_{stripline1}$	3	W_{arm1}	6.37
$W_{stripline1}$	26.01	$L_{stripline2}$	10.87
$W_{stripline2}$	13.58	W_{arm2}	6.81
offset 1	5.93	$L_{substrate}$	32.21
offset 2	6.34	$W_{substrate}$	52.02

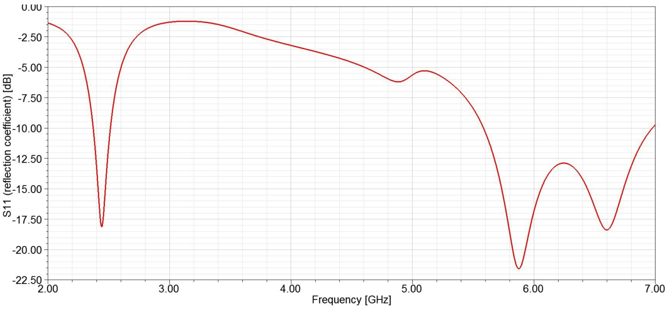
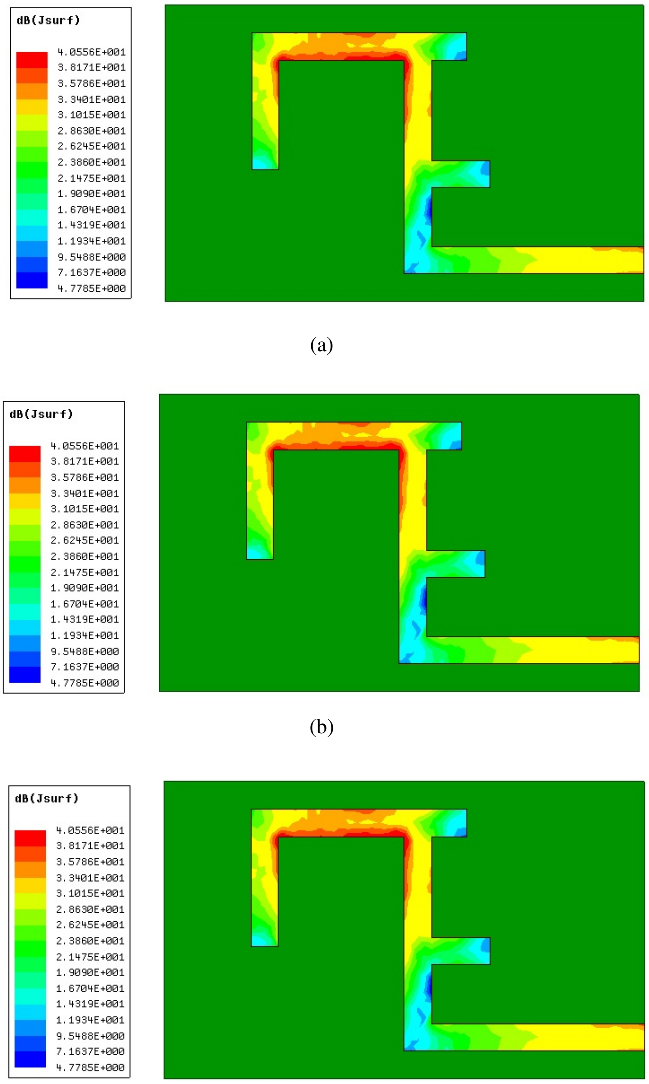


Fig. 2. Reflection coefficient (S_{11}) as a function of frequency for the designed triple-band antenna.

V. RESULTS AND ANALYSIS

The numerical results of the simulated design are presented in this section. The reflection coefficient (S_{11} value) as a



(a)

(b)

(c)

Fig. 4. Surface current distribution of the designed triple-band antenna: (a) 2.45 GHz, (b) 5.85 GHz, and (c) 6.5 GHz

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function of frequency is depicted in Fig. 2. We notice that the proposed modified printed IF antenna achieves reflection coefficient values of $S_{11} = -18.64$ dB, $S_{11} = -21.58$ dB, and $S_{11} = -18.39$ dB at the frequencies of 2.45 GHz, 5.85 GHz, and 6.5 GHz, respectively. In addition, the resulting bandwidth in these frequencies is 140 MHz, 320 MHz, and 440 MHz. The antenna performance can be considered satisfactory for all three frequency bands. The 3D radiation patterns are depicted in Fig. 3 for the frequencies of interest. We notice that the radiated power is delivered in a quite satisfactory way for WI-FI-7 applications. The realized gain is 2.03 dBi at 2.45 GHz, 6.08 dBi at 5.85 GHz, and 6.29 dBi at 6.5 GHz. Additionally, the surface current distribution graphs for the three operating frequencies are shown in Fig. 4. We notice in all three frequencies the maximum value of the surface current magnitude is at the upper part of the antenna. Overall, taking into account all these results, the proposed antenna is considered suitable for mobile devices that operate at WI-FI-7 frequencies.

VI. CONCLUSION

In this work, a modified printed inverted-F antenna for WI-FI-7 applications is designed. The proposed antenna structure operates at three frequency bands; i.e., 2.4 GHz, 6 GHz, and 7 GHz. To achieve satisfactory performance in all frequencies, the AHA optimizer is utilized. Future work includes the further exploration of similar designs, the utilization of other optimization methodologies, and the fabrication of the proposed antenna.

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