Multiband Antenna for Robotic Swarming with Application of Dynamic Boundary Tracking

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Abstract Dynamic swarming of robots requires equally aggressive communication capability even in the event of dynamic network formations. "On-the-fly" communication can pull off real surprises in a matter of microseconds. This motivates a new class of multiband antenna design to accommodate various classes of robotic platforms and to enhance their communication capability. To address this need, we propose an antenna which is designed on FR4 substrate with a thickness of 1.6 mm, $\varepsilon_r = 4.4$, and loss tangent 0.02. The dimension of the antenna is $35 \times 30 \times 1.6\ \text{mm}^3$. Microstrip-line feeding is used in this antenna. It has a structure which is a combination of split ring resonator and meander line resonator. This design is simple, compact, and miniaturized. It seems promising to integrate with the rest of the dynamic boundary tracking robotic circuit.

Keywords Robotics · Multiband antenna · Swarming communication · IoT · White space · ISM

1 Introduction

Ours is the era of distributed robotics. Dynamic boundary tracking has been a hot area of research activity due to affordable communication, sensing, and mobile platform/robotic technologies. While large amount of attention has been paid toward swarming control scheme design, sensors, and communication paradigm at transport and network layers, there are issues to be dealt with at physical layer design in the view of upcoming Internet of Things (IoT) standards and their ubiquitous presence. In this work, we present a novel class of antenna which tries to address this gap and illustrates the design process toward a possible pathway to IoT

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and related class of operations in 2.4 and 5.8 GHz. We believe that a robust and scalable physical layer design will lead to smooth communication process and hence stable performance of swarms participating in the dynamical boundary process as mobility, geographic coordinates, and sensing data overloads increase along with stringent security requirements.

A low-cost planar antenna for a robot has been reported in [1], while report of an interesting antenna design for an untethered microrobot is there in [2]. Multiple antenna-based robotic localization has been designed in [3], and a full-on-communication mechatronic system has been described in [4]. A conformal, structurally integrated antenna for flapping-wing robots has been designed in [5], and hybrid antenna has been reported in [6, 7]. A reconfigurable microstrip patch antenna has been reported in [8], and [9] discusses a localization system based on high-frequency antenna. Millimeter-wave harmonic sensors have been demonstrated in [10], and configurable robotic millimeter-wave antenna facility has been proposed in [11]. Many more interesting versions of antenna-based communication schemes for individual and swarming commutation can be found in [12, 13].

This work is motivated by the lack of multiband antennas for communication systems geared toward robots. To precisely bridge this gap, this work describes a multiband antenna for static and mobile robotic applications. A novel feature of this design is a hybridization of meander line resonator and split ring resonator structures which provide multiband characteristics including ISM, IoT, and white space frequency bands. Simulation results in radiation patterns at different frequencies are presented.

This work is organized as follows: Sect. 2 is the process of basic antenna design. Section 3 contains the details of results and discussion of the proposed antenna, and Sect. 4 presents the conclusive remarks.

2 Antenna Design for Swarming Robots

2.1 *Scenario Under Development*

Multiple defense and academic agencies are working on an effort where technology for cooperative tracking of moving boundaries is being developed using evolvable curves and particular agile hardware is being developed to achieve this mission. There are algorithms proposed where an idea based on hybrid-level set has been used to achieve dynamic perimeter surveillance within a region by constructing an evolving function based on the perceived density of a phenomenon. The utility of this technology is in providing surveillance, security cover, monitoring, tracking, etc., due to its versatile nature. This effective nature of boundary monitoring technology lends itself naturally toward “through-the-door” scene where two robots can be deployed to provide security cover as a part of overall team. While this scenario looks exciting at design table, non-trivial efforts are required to achieve the agile communication capability in the event of changing scenarios and dynamic overlay network.

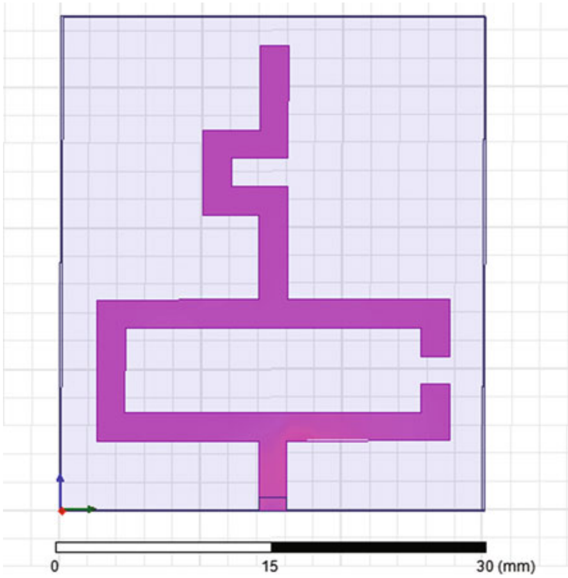

Fig. 1 Geometry of the proposed antenna

2.2 Proposed Antenna Design

The antenna is designed on FR4 substrate with a thickness of 1.6 mm, $\varepsilon_r = 4.4$, and loss tangent 0.02. The top view of the antenna is shown in Fig. 1. The dimension of the antenna is 35 × 30 × 1.6 mm^3. Microstrip-line feeding is used in this antenna. It has a structure which is a combination of split ring resonator and meander line. This design is simple, compact, and miniaturized. It seems promising to integrate with the rest of the dynamic boundary tracking robotic circuit. The antenna is simulated by using HFSS 14 (High-Frequency Simulation Software) by Ansoft.

3 Results and Discussion

The return loss versus frequency plot for the proposed antenna is shown in Fig. 2. Six interesting bands are obtained in this design. The band at 2.015 is quite broad with the impedance bandwidth of 1.52 GHz. It has a return loss of −23.13 dB. This band is of great interest for IoT and high-speed communication. The band at 0.66 GHz is very important, and it covers white space (470–698 MHz) and communication bands such as 860 MHz with the impedance bandwidth of 0.55 GHz and return loss of −20.90 dB. Third band at 4.25 GHz has the small impedance bandwidth of 0.123 GHz and return loss of −11.37 dB. Fourth band at 5.13 GHz has the impedance bandwidth of 0.368 GHz and return loss of −15.25 dB. Fifth band at 6 GHz has the impedance bandwidth of 0.369 GHz with the return loss

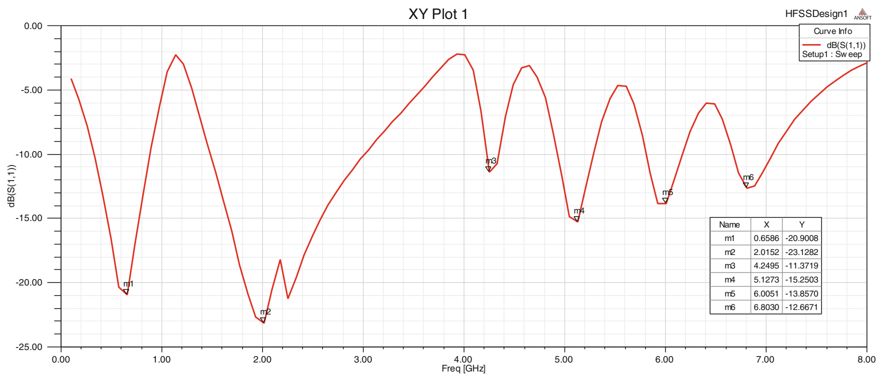

Fig. 2 S11 parameter of the antenna

Table 1 Antenna parameters at different frequency bands

Sl. no.	Frequency (GHz)	Return loss (dB)	Bandwidth (GHz)	VSWR
1	0.66	−20.90	0.55	1.22
2	2.015	−23.13	1.52	1.18
3	4.25	−11.37	0.12	1.78
4	5.13	−15.25	0.37	1.5
5	6.00	−13.86	0.37	1.5
6	6.80	−12.67	0.38	1.65

of −13.86 dB. Finally, there is a sixth band at 6.8 GHz with the impedance bandwidth of 0.384 GHz and return loss of −12.67 dB. The details of these frequency bands are mentioned in Table 1.

Table 1 describes the return loss, impedance bandwidth, and VSWR of the proposed multiband antenna. Six interesting bands are available with this antenna. The maximum impedance bandwidth of 1.52 GHz is seen at 2.015 GHz frequency which is directly relevant to Internet of Things (IoT) kind of robotic and swarming applications.

Figure 3 shows the VSWR versus frequency plot for RFID tag antenna. The bands at 0.66, 2.0152, 4.25, 5.13, 6.00, and 6.8 GHz display VSWR 1.22, 1.18, 1.78, 1.5, 1.5, and 1.65, respectively. This is also mentioned in Table 1.

The simulated *E* plane radiation pattern of the proposed multiband antenna at 738 MHz is shown in Fig. 4a. The pattern for $\Phi = 0$ is seen as omnidirectional, but the pattern at $\Phi = 90$ is fully bidirectional. Figure 4b illustrates H plane radiation pattern at 738 MHz. The radiation pattern at $\theta = 0$ is omnidirectional, and the gain is better than the E plane pattern. The radiation pattern at $\theta = 90$ is bidirectional with improved gain. In both the cases, radiation patterns show similar characteristics.

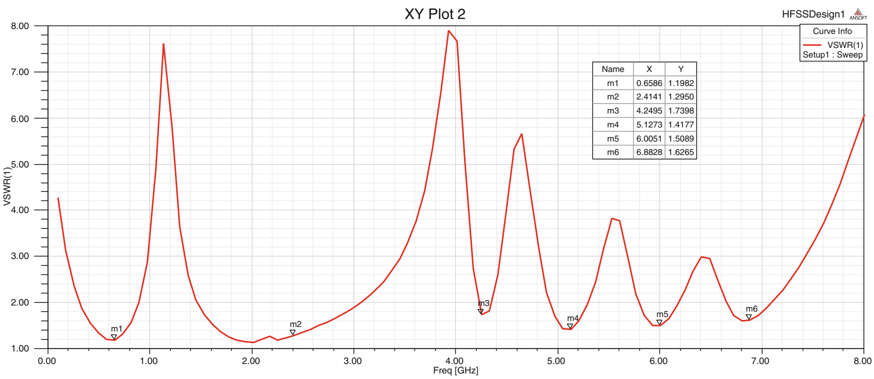

Fig. 3 VSWR versus frequency plot of RFID tag antenna

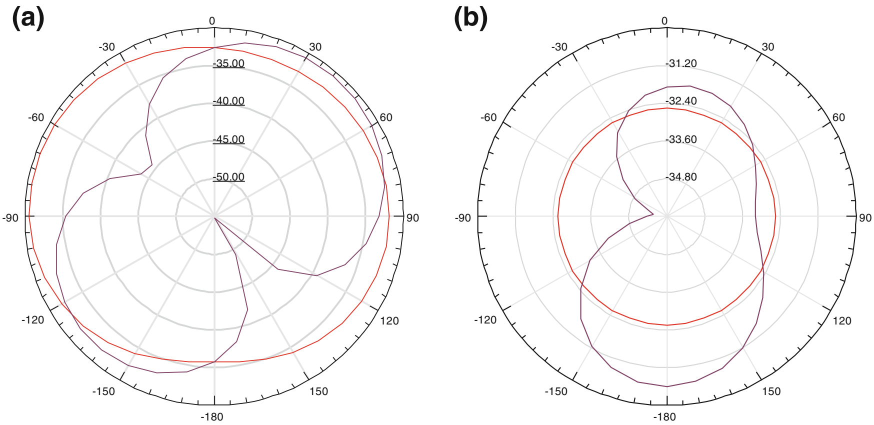

Fig. 4 **a** *E* field radiation pattern at 738 MHz and **b** *H* field radiation pattern at 738 MHz

In Fig. 5a, b, the simulated *E* and *H* plane radiation patterns of the proposed multiband antenna at 2.414 GHz are shown, respectively. The patterns for $\Phi = 0$ and 90 are seen to be nearly omnidirectional. Both the patterns show similar features. The gain in both the cases is better than Fig. 4a, b. In Fig. 5b, it is shown that the radiation pattern for $\theta = 0$ is omnidirectional and for $\theta = 90$, it is directional. But the relative gain is better in comparison with corresponding pattern at 738 MHz.

The simulated *E* and *H* plane radiation patterns of the proposed multiband antenna at 5.845 GHz are shown in Fig. 6a, b, respectively. The patterns for $\Phi = 0$ and 90 are seen to be directional. But the gains in both the cases are better than the patterns shown in Figs. 4a, b and 5a, b, respectively. In Fig. 6b, radiation pattern

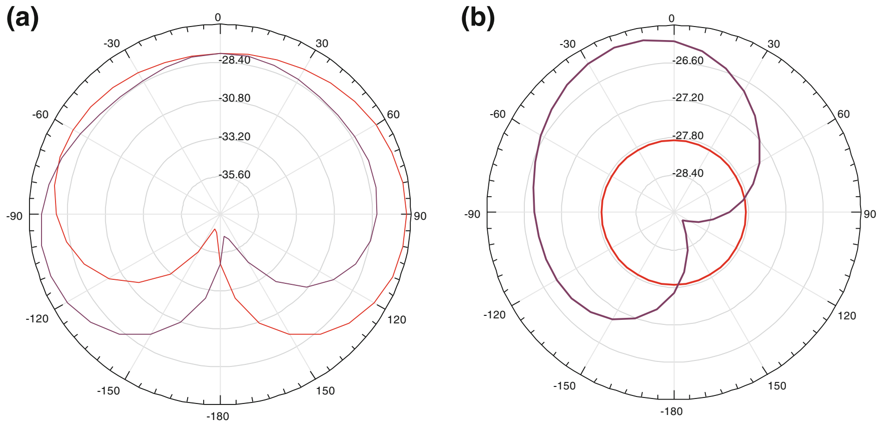

Fig. 5 **a** *E* field radiation pattern at 2.414 GHz and **b** *H* field radiation pattern at 2.414 GHz

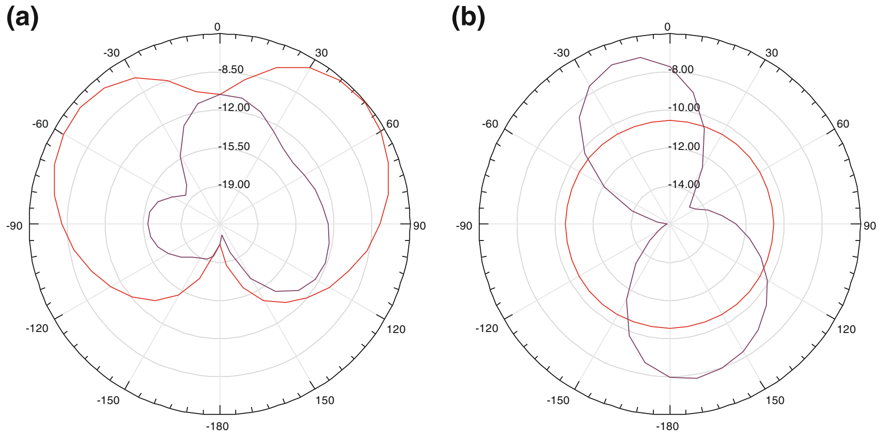

Fig. 6 **a** *E* field radiation pattern at 5.845 GHz and **b** *H* field radiation pattern at 5.845 GHz

for $\theta = 0$ is omnidirectional and for $\theta = 90$, it is bidirectional. But the relative gain is better in comparison with the rest of patterns shown in this paper.

Figure 7 shows the surface current density distribution on radiating patch at 2.4 GHz. It is seen that current density is distributed throughout the radiating patch. The coupling between feedline and rest of the patch is very strong. However, the current distribution is stronger at the lower part of the split ring resonator region of the patch. The gain and other parameters can be improved by adjusting design parameters of antenna and ground plane of the proposed, compact, simple, and miniaturized multiband antenna.

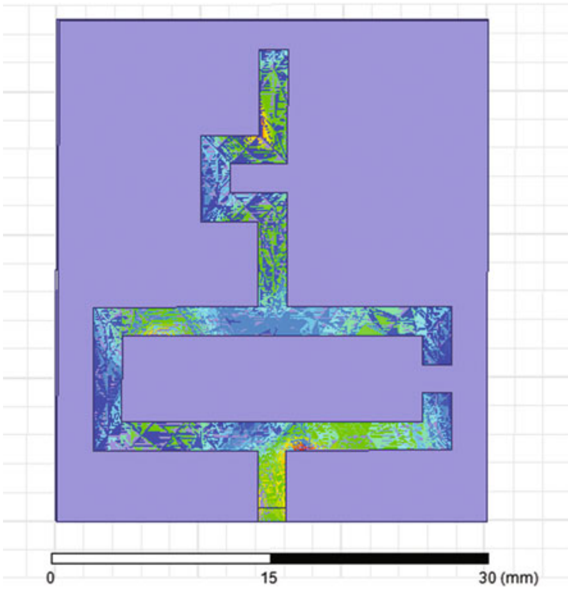

Fig. 7 Current density distribution at 2.4 GHz

4 Conclusions

This paper has addressed the issues of designing simple, compact, miniaturized, and multiband antenna for swarming robotic applications and their integration for multiband operation. It bridges the much needed gap for multiband antennas to support communication for robotic platforms. The antenna is designed on FR4 substrate with a thickness of 1.6 mm, $\varepsilon_r = 4.4$, and loss tangent 0.02. Future work includes real-life demonstration with this antenna integrated with the state-of-the-art robotic/vehicle platforms and next-generation antenna design from lessons learnt from these experiments.

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