Simple Superstrate Antenna for Connectivity Improvement in Precision Farming Applications

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***Abstract*—In this paper, a concept of a simple circularly polarized antenna with partially reflecting surface (PRS) has been adopted for precision farming applications. The investigation contains an analysis of the dependence of the antenna performance on the elements number in the PRS structure in X- and Ka-band frequencies. Especially meaningful parameters from point-to-point connectivity perspective are axial ratio less than 3 dB and high gain of the antenna. Simulation results show that all antennas proposed in the paper comply with these requirements providing the gain greater than 13 dBic in any case. All of the presented designs have high efficiency and also are characterized by a compact size and lightweight.**

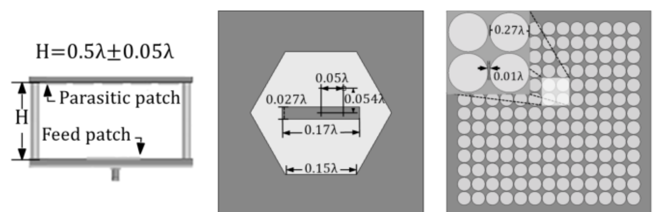
Keywords—partially reflecting surface (PRS); high-gain antenna; circular polarization; microstrip antenna; IoT

I. Introduction

Remote sensing in areal earth observation plays an important role in nowadays farming applications [1]. Dedicated satellite platforms, unmanned aerial vehicles (UAVs) or high altitude pseudo-satellites (HAPS) with mission altitudes around 18 km [2] can provide regular and accurate vegetation and environmental parameters. However, to complement video imaging with the capability of monitoring soil parameters, it is possible to use dedicated internet of things (IoT) sensors [3]. To provide affordable sensors that can seamlessly be read from long distances by different aerial platforms, one has to provide simple and inexpensive high gain circularly polarized antennas that may be a part of low-cost IoT sensors. In this study, a partially reflecting surface (PRS) antenna concept proposed in [4] is adopted to design two antennas operating in X and Ku frequency bands, that can be used in different precision farming applications, including V2X communication with fast moving objects [5]. The purpose of this work is to investigate the influence of the elements number in the PRS on the antenna performance at various frequencies. Simulation results presented in this paper show the optimal superstrate antenna configurations and the main limitations of the designs.

II. Antenna Concept And Design

The design of the antenna based on the PRS array consists of feeding part and dielectric layer placed above it with a periodic array arranged in front of the radiating part which constitute the PRS structure, as shown in Fig. 1(a). Electromagnetic waves radiated from the feeding part are subject to multiple reflections inside the cavity which is formed between the PRS plane and the ground plane. By phase alignment of the rays passing through PRS layer one can obtain directivity improvement compared to the initial antenna without an additional layer. In the proposed X-band antenna structure, a microstrip patch is used as an exciting radiator and is placed on the top side of a 1.52 mm thick RO3003 substrate with relative permittivity and loss tangent equal 3.0 and 0.001, respectively. In order to provide circular polarization, hexagonal shape of the radiator was chosen. Feeding point is off-set from the center of the patch to generate right handed circular polarization (RHCP). The structure has been designed and simulated using FEKO simulator and all dimensions are presented in a Fig. 1(b) and (c).



(a) (b) (c)

Fig. 1. Geometry of the antenna with superstrate layer side view (a), radiating element (b) and exemplary PRS structure (c)

The proposed PRS structure is placed above the radiating part as presented in Fig. 1(a). Between this layer and the patch, there is a gap of height H that allows high efficiency. An FR4 substrate with thickness of 1.5 mm, effective permittivity of 4.47, and loss tangent of 0.017 is chosen for a dielectric layer on which the PRS superstrate is created. On the bottom of this dielectric board, an array consisting of conducting circular parasitic patches (cells) is arranged. A number of boards containing different sets of these elements were designed. The parasitic patches have been arranged as $m \times m$ arrays, where $m \in \{5, 7, 9, 11, 13\}$. In order to simplify the design and analysis in all configurations, the same size of each cell is assumed. The overall size of the largest considered antenna design having 13 x 13 elements in the PRS structure is 170 x 170 x 20.6 mm^3.

The same design framework was used to design a similar antenna structure intended for 27 GHz. In this antenna configuration, a 0.508 mm thick RO3003 substrate and 0.508 mm thick FR4 substrate were used for the radiating and the PRS layers, respectively. As in the case of X-band antenna, a number of PRS boards with a symmetrical periodic grid structure for $m \in \{5, 7, 9, 11, 13\}$ has been designed. The overall size of the

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Ka-band antenna design in the largest configuration with 13 x 13 array PRS structure is 42 x 42 x 7 mm^3.

III. Simulation Results

The simulated S11 parameter of the X-band antenna is below -20 dB at 8.4 GHz in any configuration. The bandwidths amount to over 11.5% for all tested PRS configurations. The maximum gain of the antenna increases with the number of parasitic elements in the PRS structure as shown in Fig. 2(a). The highest value of gain is reached in 13 x 13 arrangement and it is equal to 19.6 dBic. The corresponding values of the axial ratio indicate that the best results shift to lower frequencies for higher number of parasitic patches. The widest 3dB axial ratio bandwidth is achieved for 5 x 5 PRS configuration and it equals to 4%. The main limitation of the presented type of antenna is its high cross-polarization radiation, as shown in Fig. 3(a). The least favorable values are the observed ones for the 7 x 7 PRS configuration, where 11.5 dB co-to-cross-polarized isolation can be observed but, in fact, none of the results obtained in simulations is satisfactory. All detailed characteristics of the antenna are gathered in Table I. The value of maximum gain increases and simultaneously the beam narrows with the number of parasitic patches in PRS structure. Other parameters such as efficiency, side lobe level and front-back ratio remain at an acceptable level.

The simulation results of the PRS antenna for Ka frequency band prove that this type of antenna can be scaled and maintains similar radiation performance. The achieved S11 bandwidth is 8% in the worst case and amounts to 12.6% in the best case. In Fig. 2(b), the simulated plots of axial ratio for five investigated PRS configuration are presented. The best 3dB axial ratio bandwidth is 8% and is observed for 5 x 5 PRS configuration. Again, as shown in Fig. 3(b), cross-polarization level is not satisfactory. In Table I, all important results of the antenna are summarized. Satisfactory efficiency and front-to-back ratio values are obtained for all PRS configurations. One should note, however, that in this case, contrary to the X-band design, maximum gain does not improve for higher than 9 x 9 PRS number of elements.

IV. Conclusion

In this study, the concept of PRS antenna in different configurations for two frequency bands, namely X and Ka, is investigated. The most valuable parameters, i.e. high gain over 13 dBic and circular polarization are met in all presented designs. Satisfactory antenna parameters are achieved for overall size of 1.92λ x 1.92λ x 0.59λ and 1.63λ x 1.63λ x 0.61λ in presented sets of antennas designated to work in the X band and Ka band, respectively. The designed antennas are compact and lightweight, therefore, they can be employed for point-to-point communication in systems of mobile devices or vehicles used in support or optimization of processes under smart/precision farming paradigm. Potential applications may include affordable sensors that can seamlessly be read from long distances by different aerial platforms and V2X communication with fast moving objects or vehicles. In the next development steps of the concept, other PRS structures and types of radiating element of the antenna will be investigated.

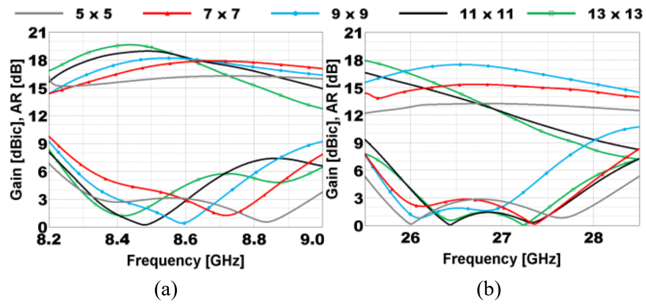

Fig. 2. Simulated maximum gain and axial ratio for five different PRS configuration (a) X-band antenna (b) Ka-band antenna

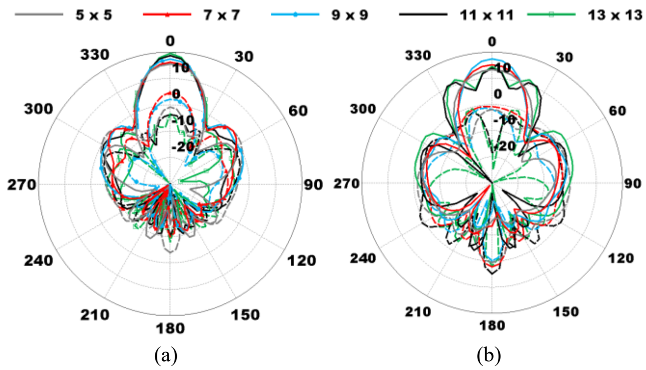

Fig. 3. Simulated radiation patterns for five different PRS configuration Φ = 0° plane (a) at 8.4 GHz (b) at 26.5 GHz

TABLE I. Specification of X-band and Ka-Band antennas

PRS size	5 x 5		7 x 7		9 x 9		11 x 11		13 x 13	
Band	X	Ka	X	Ka	X	Ka	X-	Ka	X	Ka
S11 BW [%]	15	12.6	13.4	10.5	15.6	8.0	15.5	9.6	15.5	9.4
AR 3dB BW [MHz]	355	2441	220	1859	300	1326	264	1704	214	1533
Maximum gain [dBic]	16.3	13.5	17.9	15.3	18.2	17.5	19.0	15.3	19.6	16.2
HPBW	23.6°	30.6°	21.4°	25.4°	19.8°	21.4°	18.7°	13.6°	13.9°	13.2°
Efficiency [%]	>91	>93	>88	>88	>86	>90	>86	>92	>85	>91
SLL [dB]	18.0	17.9	14.9	17.4	17.1	17.0	19.4	6.0	23.2	7.0
front-to-back ratio [dB]	30.2	41.1	32.2	30.6	50.4	45.8	41.4	24.7	48.4	31.7

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