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High Gain K-Band Patch Antenna for Low Earth Orbit Interlink between Nanosatellites

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Abstract—This paper presents a wideband or high gain 4x4 array operating in k-band. The unit cell of this array is a rectangular patch antenna in a stacked configuration. Four rectangular patches are passively excited by an additional rectangular patch located underneath. The latter is excited by a substrate integrated waveguide (SIW) through an aperture etched on the ground plane. By moving the relative position, and therefore the overlapped area, between the passive patches and the active one, a wideband or a high gain behavior can be obtained, maintaining the same layout. The proposed array achieves the impedance bandwidth of 12.55% with a gain of 22 dBi for the wideband case. In the high gain case, the impedance bandwidth is 5.5% with a gain of 24 dBi.

Index Terms—antenna, array, wideband, high gain.

I. INTRODUCTION

The number of space missions involving nanosatellites is today growing fast. The modern advance in miniaturization technology enable this class of satellites to complex mission such us: 1) earth observation [1], 2) remote sensing, 3) communications [2], 4) weather forecasting, 5) scientific and educational [3], 6) beyond Low Earth Orbit (LEO) [4]. It is also possible, for some applications, to form distributed satellites constellations or swarm. In this configuration, the satellites maintain a fixed or a relative position. Moreover, the low cost of this class of satellites, in contrast with the conventional class satellites, provide easy access to universities and small company who want to the improve experience in the space sector. Among the nanosatellites, the CubeSat platform is one of the most used and popular. It is a cubic-shaped nanosatellite where the basic unit has a fixed size of 10 cm^3 , which can be composed to obtain bigger systems. Despite all the advantage of this new technology, there are also some challenges to face mainly related to the small dimensions, like the limited area and the limited amount of power available on board.

Due to the great flexibility, a wide range of different kind of antennas could be employed. In [5] an integrated transmitter module with a horn antenna in ka-band has been used. For the MarCO mission, the deployable reflectarray in [6] was employed. Despite both solutions can achieve high gain, they are rather bulky and in some cases, due to the restricted space on board, they need deployable mechanisms which make the design complex and more prone to faults. In [1] a circular polarized patch antenna with a gain of 8.22 dBi has been used

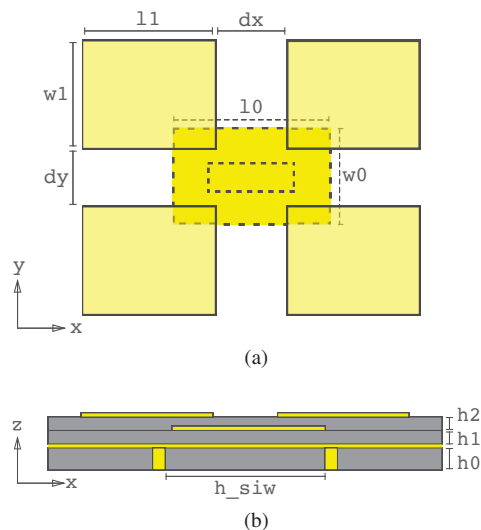


Fig. 1: (a) Top view and (b) side view of the proposed unit cell patch antenna.

for the TIGRIsat project. Another patch antenna for CubeSat has been presented in [7] with a gain of 9.6 dBi but with a narrow bandwidth. In [8] a circular patch antenna with a gain of 15 dBi and sidelobe suppression is presented. It can work wideband or dual band and it could be used on an array configuration in order to keep small the number of elements thanks to high gain.

In this paper, a rectangular patch antenna array for an inter-satellites link in k-band is presented. For this 4x4 array, the single element proposed in [9] has been used. It consists of four rectangular passive patches excited by an underneath rectangular patch. The latter is aperture coupled with a substrate integrated waveguide (SIW) feeding network. By acting on the relative position between the four passive patch, it is possible to achieve up to 24 dBi of gain or up to 12.55% of bandwidth depending on the needs.

II. UNIT CELL

On a nanosatellite lightweight and thin antenna are often desirable. In this sense a printed antenna is the best choice. In Fig.1 the unit cell presented in this section is showed. It exploits the same stacked layout proposed in [9] where four

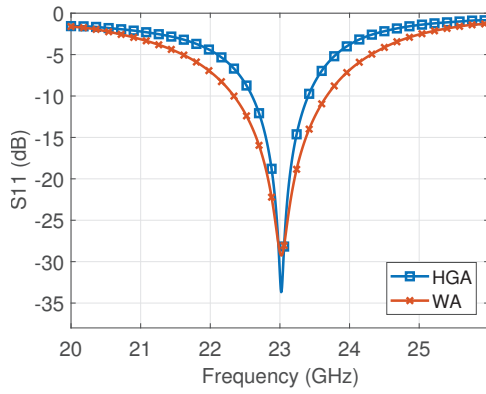


Fig. 2: Simulated $|S_{11}|$ for the HGA and the WA

TABLE I: Unit cell design parameters

	w_0	l_0	w_1	l_1	dx	dy	h_2
HGA	3.4 mm	5.45 mm	3.9 mm	4.8 mm	6.5 mm	6.5 mm	0.254 mm
WA	3.4 mm	5.45 mm	3.9 mm	4.8 mm	0.5 mm	0.5 mm	0.508 mm

passive patches are placed on top of an active patch. This active patch is coupled to the feeding network through an aperture etched on the ground plane. A matching stub at the position of the aperture is used to match the antenna with the feeding network. In this way the antenna is slightly thicker but, from the radiation point of view, it is decoupled from the feeding network.

This configuration is particularly interesting because, maintaining the same layout, a wideband or a high gain antenna can be obtained. The coupling is related to the amount of area overlapped between the passive patches and the active one. This means that increasing the overlapped area the coupling increase, increasing the impedance bandwidth as well. On the other side the effective area of the antenna decrease leading to a decrease of the gain. The opposite effect is obtained decreasing the overlapped area which leads to a higher gain but to a slightly narrow bandwidth.

Two version of the same layout as been simulated before being used in an array configuration. The dimensions used for both layouts are showed in Table I. The four upper patches are placed on a substrate with a dielectric constant $\epsilon_r = 2.33$, as well as the lower patch. Fig.2 shows the scattering parameter of the unit cell in both versions. In Fig.3 the maximum gain of the two versions are presented. For the high gain antenna (HGA) the bandwidth is 3.4% and the gain is about 12 dBi. The wideband antenna (WA) instead shows a bandwidth of 6% and a gain of 10 dBi.

III. FEEDING NETWORK

A crucial part of designing an array is the choice of the feeding network. A common and straightforward solution, which keeps the design process simple, is a corporate feeding network realized in microstrip technology like in [10]. Despite

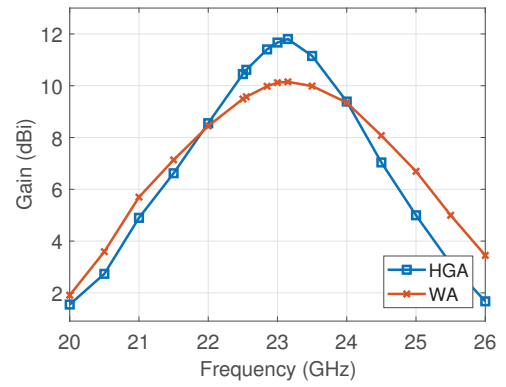


Fig. 3: Simulated realized gain for the HGA and the WA

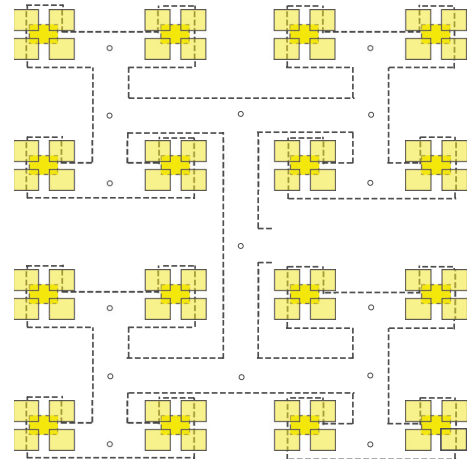


Fig. 4: Top view of the proposed 4x4 array with the feeding network

its simplicity, a microstrip feeding network is rather lossy and cannot be used for some kind of applications. Moreover, the array is supposed to be allocated on the face of the nanosatellite, which actually acts as an additional ground plane. This lead to an additional source of losses because of the open circuit at the end of the stub, used to match the antenna with the transmission line through the aperture, acts as a transition from microstrip transmission line to parallel plate transmission line.

In order to keep small the total thickness of the antenna and at the same time minimize the losses in the feeding network, a substrate integrated waveguide (SIW) has been chosen. The steps and empirical equation in [11] have been used to design the SIW parameters showed in Table II. Compared with a microstrip transmission line an SIW is much wider. This implies that the distance between the elements of the array could be more than $\lambda/2$ which means high sidelobes. In Fig.4 the feeding network realized in SIW technology is showed. In order to minimize the reflection at the T-junction and at the L-bend a metallic post is used [12]. By changing the position and the radius of this matching post, a better impedance matching could be achieved.

TABLE II: SIW design parameters

$vias_radius$	$vias_distance$	siw_width	h_0
0.3 mm	1 mm	6.5 mm	0.787 mm

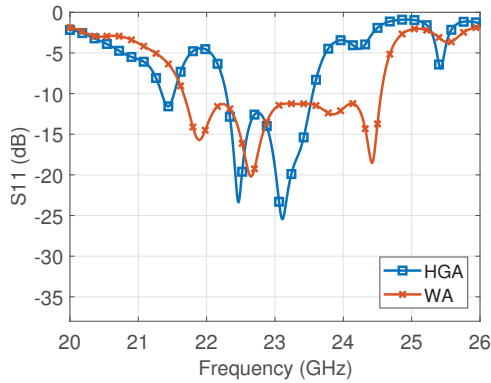


Fig. 5: Simulated $|S_{11}|$ for the HGA and the WA in a 4x4 array configuration

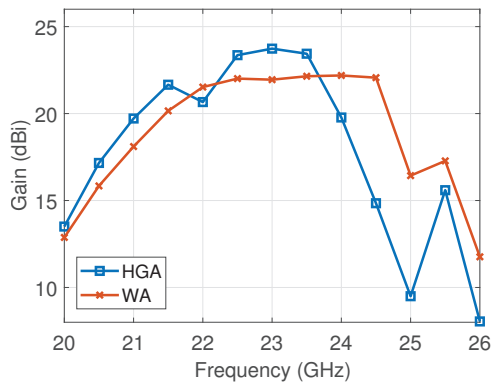


Fig. 6: Simulated realized gain for the HGA and the WA in a 4x4 array configuration

IV. ARRAY

The unit cell patch antenna and the SIW feeding network presented in the previous sections have been used for the proposed 4x4 array. In Fig.5 the simulated $|S_{11}|$ for both the WA and HGA are presented. The WA case shows an impedance bandwidth of 12.55%, while the HGA case shows an impedance bandwidth of 5.5%. Fig.6 shows the realized gain for both cases. The HGA case shows a gain of 24 dBi almost along the whole impedance bandwidth. A realized gain of 21.8 dBi is showed for the WA case which is pretty stable along the whole impedance bandwidth. In Fig.7 the radiation pattern at 23 GHz is presented for both the (a) E-plane and (b) H-plane. Because of the symmetry of the single element both plane are quite similar. The side lobe level (SLL) is -6 dB for the HGA configuration and -5 dB for the WA configuration. The reason behind these high sidelobes is mainly because of the distance between the elements of the array which is mainly fixed by the width of the SIW and the length of the stub.

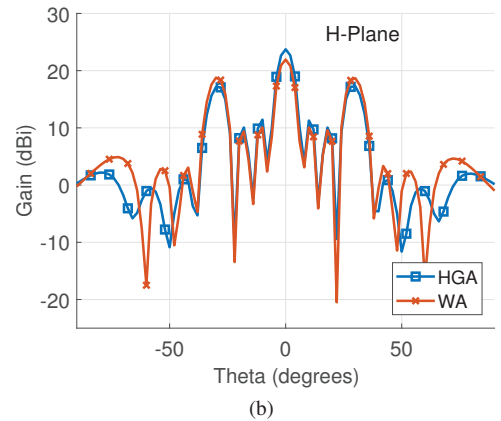
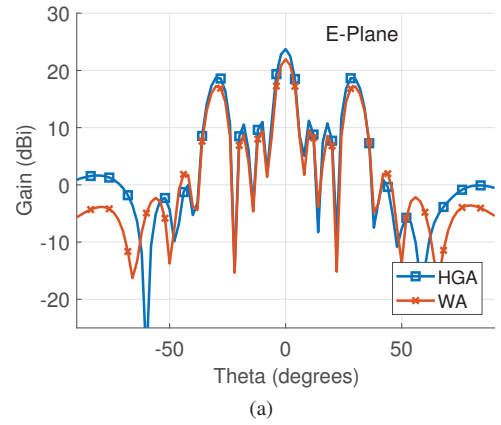


Fig. 7: (a) E-plane and (b) H-plane at 23 GHz for the HGA and the WA in a 4x4 array configuration.

TABLE III: Performance comparison of the presented antenna

	realized gain	bandwidth
HGA	24 dBi	12.55%
WA	21.8 dBi	5.5%

V. CONCLUSION

In this paper, a wideband or high gain stacked rectangular patch array has been presented. This antenna can achieve the wideband or the high gain, maintaining the same layout, by moving the relative position, and therefore the overlapped area, between the passive patch and the active one placed underneath. Increasing the overlapped area lead to an increase of the coupling between the patches thus to an increase of the bandwidth. Decreasing the overlapped area lead to an increase of the gain because the effective area of the antenna is bigger. To feed the 16 elements of the array a feeding network in substrate integrated waveguide technology (SIW) has been used. A comparison between the simulated results for both configurations is presented in Table III

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