Multi-beam and High Gain Antenna Array for Radio Frequency Energy Harvesting Applications in 5G Network

Chemseddine Benkalfate
Electrical and Electronics Engineering Department
Quartz laboratory, ENSEA
Cergy, France
e-mail: benkalfate.chemseddine@ensea.fr

Achour Ouslimani
Electrical and Electronics Engineering Department
Quartz laboratory, ENSEA
Cergy, France
e-mail: achour.ouslimani@ensea.fr

Abeb-Elhak kasbari
Electrical and Electronics Engineering Department
Quartz laboratory, ENSEA
Cergy, France
e-mail: abed-elhak.kasbari@ensea.fr

Mohammed Feham
Telecommunications Department
STIC laboratory, university of Tlemcen
Tlemcen, Algeria
e-mail: mohammed.feham@univ-tlemcen.dz

***Abstract*—In this paper, a new multi-beam high gain antenna array for Radio Frequency Energy Harvesting (RF-EH) applications in 5G network is presented which consists of 4 sub-antenna arrays (2 x 2) in order to increase the gain and directivity. The sub-antenna array covers the two 5G network bands (3.5 GHz and 26/28 GHz) with gains of 3 dB and 6 dB respectively. The proposed antenna array is studied and simulated for the 26/28 GHz band. The gain reaches 12 dB at 26 GHz and 15 dB at 27.5 GHz. The simulated efficiency of this antenna is of 78%. The antenna is designed on Teflon glass substrate with a relative permittivity of 2.1 and 0.67 mm of thickness. It total dimension is of 65 x 55 mm². These gain values satisfy the beam forming technology adopted by 5G network.**

Keywords—Antenna array, 5G network, High gain, Beam forming.

I. INTRODUCTION

In 5G network, the communication consists in focusing the transmitted power in the direction of the receiver to ensure a high quality of data transmission. This technique is known as beam forming. The transmission power for the 26/28 GHz band must be low to ensure a safe communication on human health. To increase the received power, it is mandatory to improve the gain of the antennas (in transmission and reception). The received power is given by the following Friis formula.

$$P_r = G_r G_t \left(\frac{\lambda}{4\pi d}\right)^2 \cdot P_t \qquad (1)$$

where $G_r G_t$ antenna gains, $P_r P_t$ transmission and reception powers, λ the wave length and d the distance between transmitter and receiver.

The efficiency of RF-EH systems depends on the received power. By adopting the multi-beam forming technique, the RF_EH system stays operational for several orientation.

There are several techniques to increase the antenna gain, including increasing the size of the antenna [1] and using reflectors to concentrate the maximum electromagnetic power in a given direction which increases the gain [2]. The best technique remains the use of an array antenna which allows to considerably improve the gain of the antenna. The main challenge for this technique is the miniaturization. Designing an antenna array with high gain and optimal size facilitates it implementation.

Our work consists in the design and simulation of a multi-beam antenna array for the 26/28 GHz band of 5G network with high gain (12 dB and 15 dB, respectively) and an optimal size of 65 x 55 mm² designed on Teflon glass substrate with 0.67 mm of thickness. Table I presents a comparison between the proposed array antenna and other antennas proposed in references for the same order of gain and frequency band values.

TABLE I: COMPARISON BETWEEN THE PROPOSED ANTENNA AND OTHER PUBLISHED ANTENNAS

Ref.	**Antenna size** (mm³)	**F (GHz)**	**Gain (dBi)**	**Substrate**
[3]	80x20x0.25	28-35	14-15	Hybrid
[4]	150x110x0.1	28	10	RO5880
[5]	150x70x0.2	28	11.16	Alron 430
[6]	150x75x0.75	28	14	RO4450B
Proposed Antenna	**65x55x0.67**	**26/28**	**12/15**	**Teflon glass**

For 26 GHz, the proposed antenna presents six beams located at θ (+,-) = 80°, 90° and 100° with a maximum directivity of 12.1 dBi for both. For 27.5 GHz, the antenna presents 14 beams located at θ(+,-) = 40°, 50°, 70°, 90°, 110°, 130° and 140°, with a maximum directivity of 15.1 dBi. The simulation and optimization have been carried out using CST (Computer Simulation Technology) microwave software.

In Section II, the antenna array structures are given with all dimensions and details. In Section III, simulations of S_{11} parameter and radiation pattern are performed and discussed. We conclude the paper in Section IV.

II. ANTENNA DESIGN

The proposed elementary antenna model consists of a horizontal dipole antenna with a length of 30 mm and six vertical elementary wires forming a sub-antenna array. This antenna has been designed on Teflon glass substrate with a

 ISBN: 978-1-61208-940-9

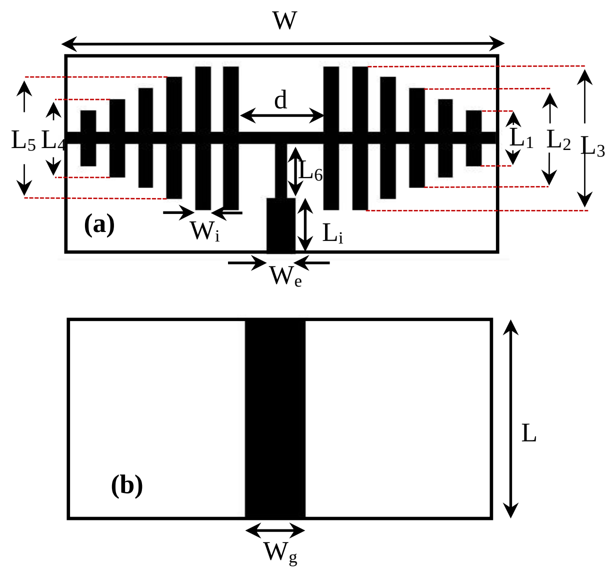

Figure 1. Proposed elementary antenna model, (a): the top side, (b): the bottom side

relative permittivity of 2.1 and a thickness of 0.67 mm. A microstrip line has been used to feed this antenna with an input impedance of 50 Ω. Figure 1 shows the proposed antenna model and its dimensions are given in Table II.

TABLE II: ALL ANTENNA DIMENSION IN (mm)

L_1	L_2	L_3	L_4	L_5	L_6	L_i	L	d	W_i	W_e	W_g	W
5	9	13	7	11	5	5	15	6	1	2	4	30

The first step of the proposed antenna array design is to stack two elementary antennas (of Figure 1) to form a two-antenna (2 x 1) array, as shown in Figure 2. Table III gives the (2 x 1) antenna array dimensions.

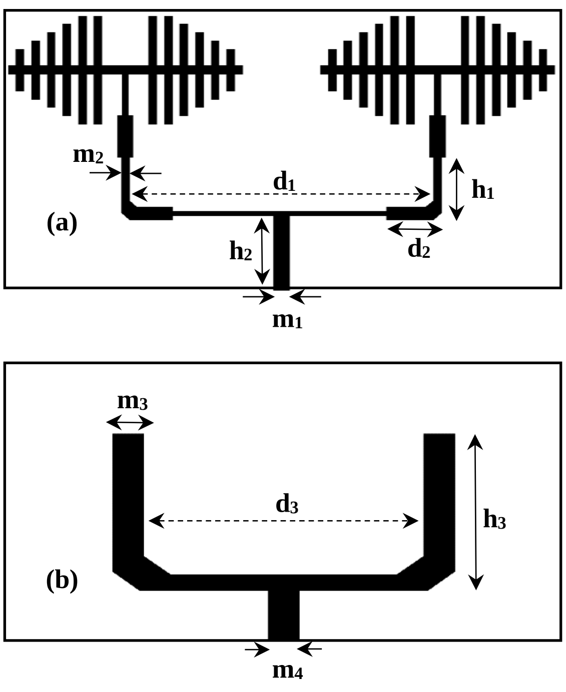

Figure 2. (2 x 1) antenna array model, (a): the top side, (b): the bottom side

TABLE III: (2 x 1) ANTENNA ARRAY DIMENSION IN (mm)

m1	m2	m3	m4	h1	h2	h3	d1	d2	d3
2	1	4	4	7.5	9	9	39	7	36

The second step is to design the (2 x 2) antenna array. In this part, two elementary antennas are added with the goal to increase the gain and directivity of the antenna. The challenge of this part is the impedance matching. Each antenna has to be matched to the equivalent impedance of the other three elementary antennas. For this purpose, a quarter-wave lines and an open stub are used, as shown in Figure 3. Table IV gives the complementary dimensions.

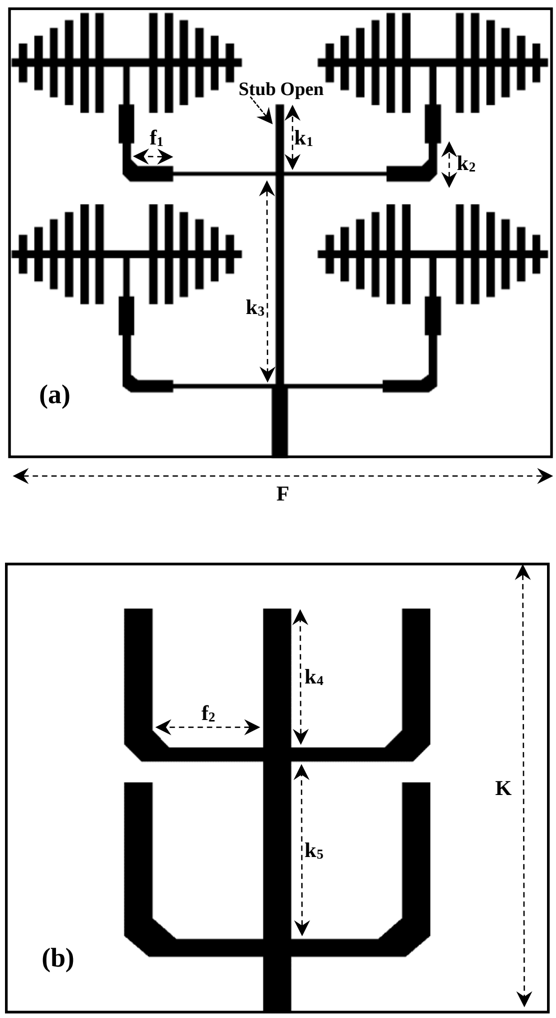

Figure 3. (2 x 2) antenna array model, (a): the top side, (b): the bottom side

TABLE IV: (2 x 2) ANTENNA ARRAY DIMENSION IN (mm)

k1	k2	k3	k4	k5	f1	f2	F	K
8.75	5	27.25	20	25.5	5.5	16	65	55

 ISBN: 978-1-61208-940-9

III. Simulation and Discussion

A. Elementary antenna

Figure 4 presents the simulated coefficient reflection of the elementary antenna (see Figure 1).

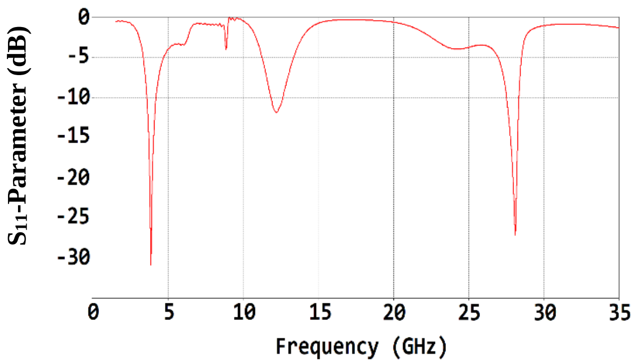

Figure 4. S_{11} parameter of elementary antenna

The elementary antenna is well adapted to the two 5G bands (3.5 GHz and 28 GHz) with an S_{11} parameter of -30 dB and -27 dB, respectively.

Figure 5 depicts the simulated 3D radiation pattern of the elementary antenna for 3.5 GHz and 28 GHz.

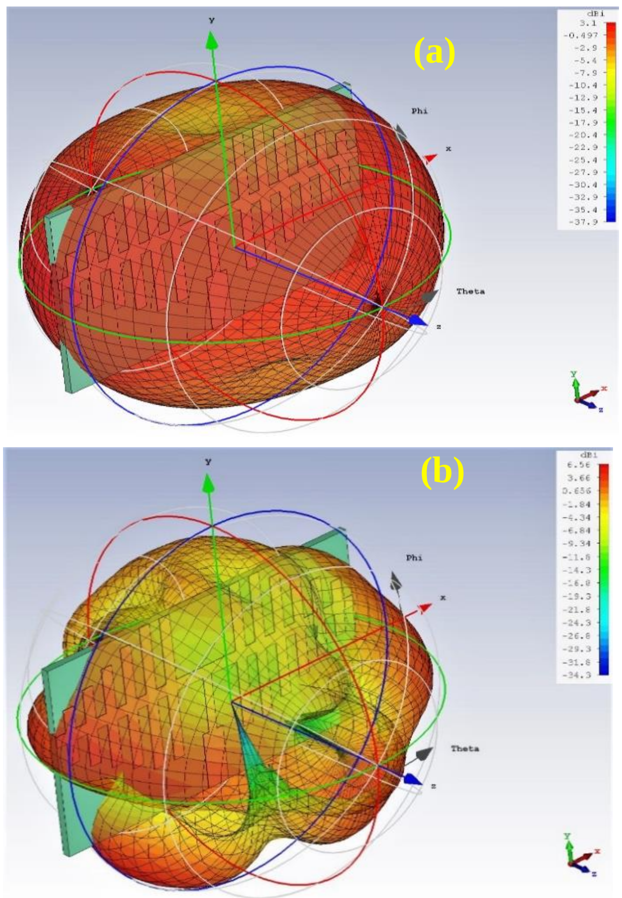

Figure 5. Simulated radiation pattern of elementary antenna. (a) : 3.5 GHz, (b) : 28 GHz.

The maximum directivity obtained by the proposed elementary antenna is 6.5 dBi at 28 GHz and 3 dBi at 3.5 GHz. The beam forming technology is adopted by 5G in the 24/26/28 GHz bands, etc. For this reason, we focus our study of the antenna array in the two 26/28 GHz 5G bands.

B. (2 x 1) proposed antenna array

Figure 6 shows the simulated coefficient reflection of the (2 x 1) antenna array (see Figure 2).

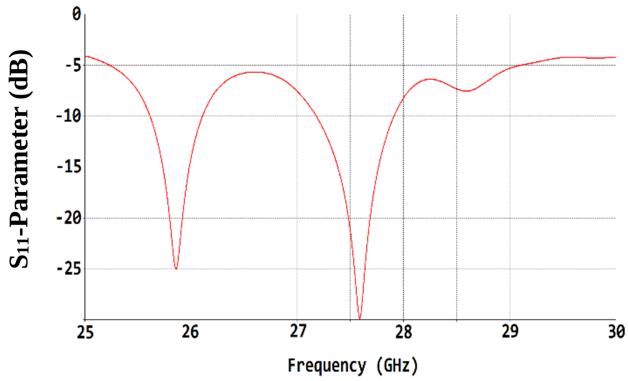

Figure 6. S_{11} parameter of the proposed (2 x 1) antenna array.

It can be seen that the proposed (2 x 1) antenna array is well adapted to both 26/28 GHz 5G bands, with a S_{11} of -25 dB and -30 dB respectively.

Figures 7 and 8 present the simulated radiation pattern of (2 x 1) antenna array (E and H) plans, respectively.

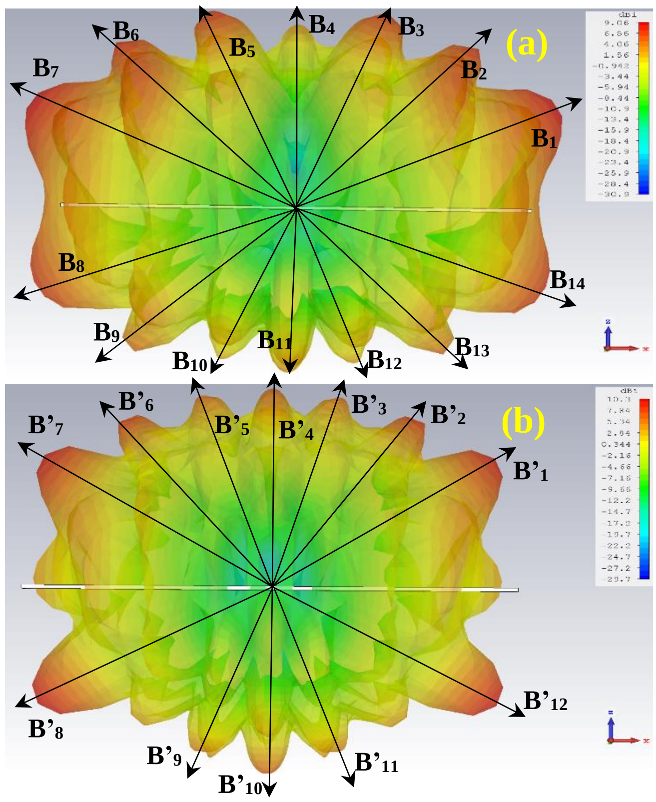

Figure 7. E_Plan simulated radiation pattern of (2 x 1) antenna array. (a) : 26 GHz, (b) : 28 GHz.

 ISBN: 978-1-61208-940-9

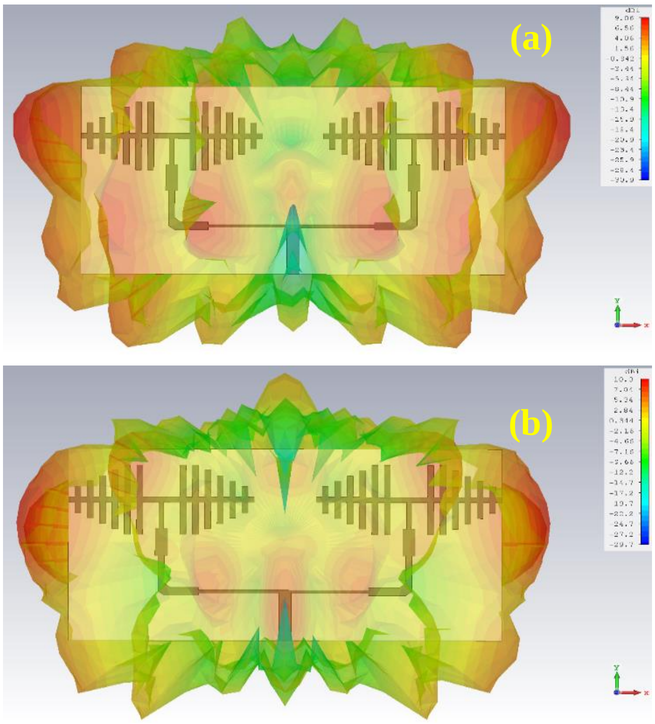

Figure 8. H_Plan simulated radiation pattern of (2 x 1) antenna array. (a) : 26 GHz, (b) : 28 GHz.

It can be noted that the array antenna (2 x 1) is a multi-beam with a high gain for both bands (26/28 GHz). For 26 GHz, the antenna has 14 lobes and 12 powerful lobes for 28 GHz. The maximum gain is of 9.6 dBi and 10.3 dBi, respectively for 26 GHz and 28 GHz 5G bands. Table V gives all directivity values for each beam.

TABLE V: DIRECTIVITY VALUES FOR EACH BEAM IN (dBi)

B1	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**
9	8.8	9	4	7.8	8.1	9	8.8	5.2	4.1
B11	**B12**	**B13**	**B14**	**B'1**	**B'2**	**B'3**	**B'4**	**B'5**	**B'6**
5	4.6	5.6	8.6	9.8	8.4	7.8	7.2	7.1	8.5
B'7	**B'8**	**B'9**	**B'10**	**B'11**	**B'12**				
9.7	10.2	4	8.1	4.8	10.1				

C. *(2 x 2) proposed antenna array*

Figure 9 depicts the simulated S_{11} parameter of the proposed (2 x 2) antenna array (see Figure 3).

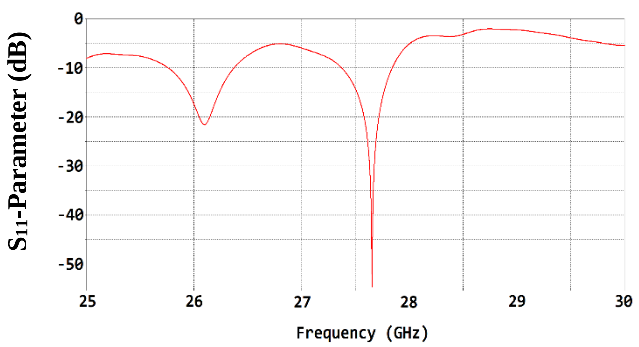

Figure 9. Simulated S_{11} parameter of (2 x 2) antenna array.

It can be noted that the proposed (2 x 2) antenna array is more adapted to 27.6 GHz band with a S_{11} of -55 dB, and adapted to 26 GHz band with a S_{11} of -23 dB.

Figures 10 and 11 depict the simulated radiation pattern of (2 x 2) antenna array (E and H) plans, respectively.

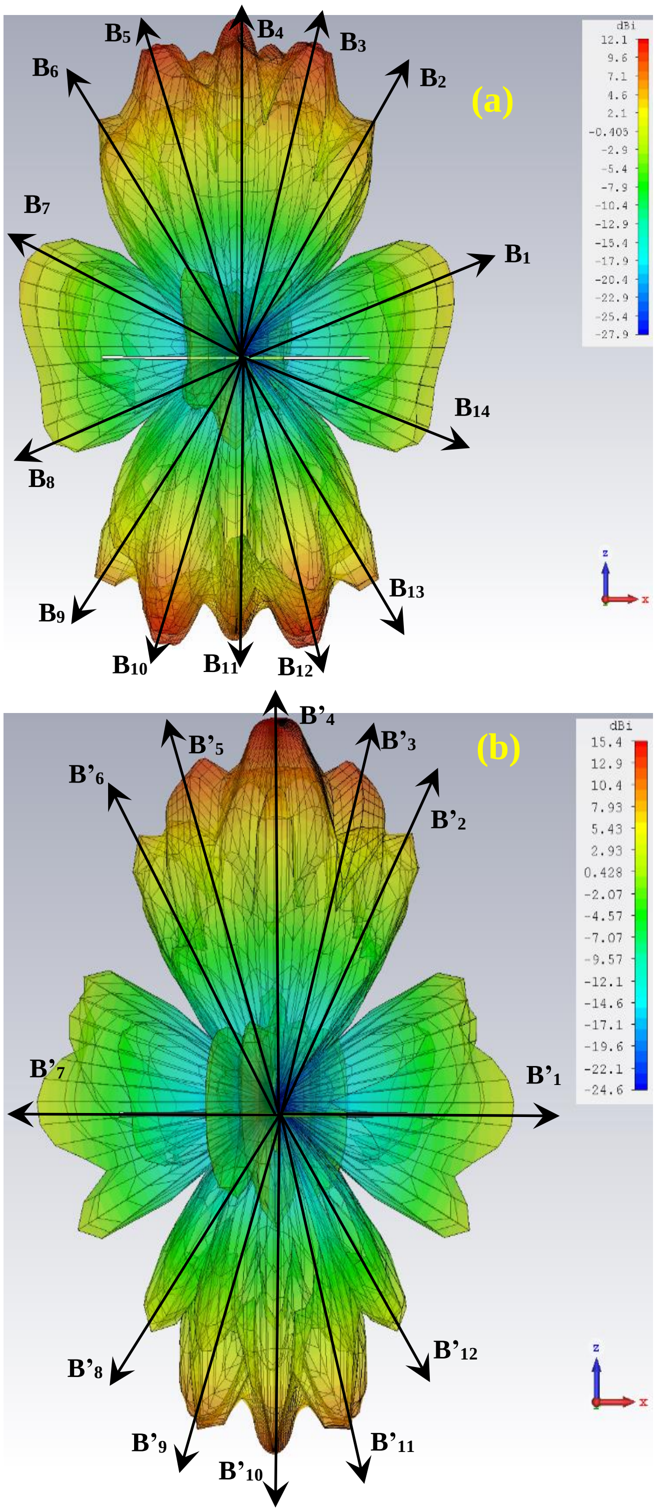

Figure 10. E_Plan simulated radiation pattern of (2 x 2) antenna array. (a) : 26 GHz, (b) : 27.6 GHz.

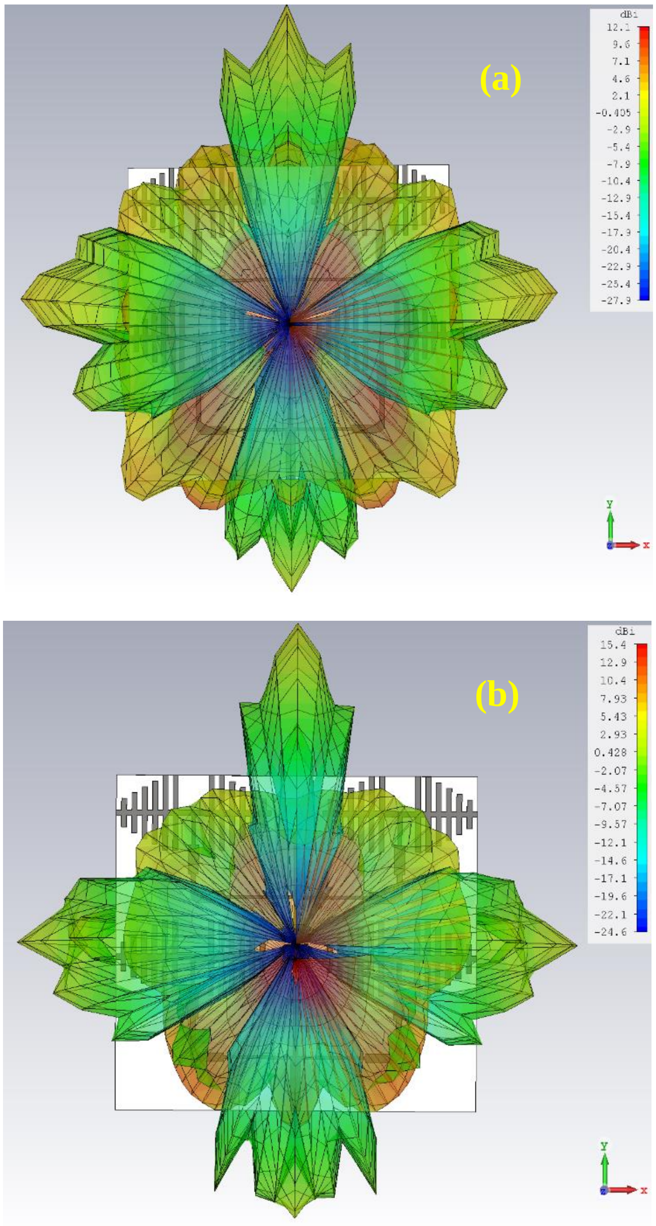

Figure 11. H_Plan simulated radiation pattern of (2 x 2) antenna array. (a) : 26 GHz, (b) : 27.6 GHz.

14 beams with high directivity are visualized by the radiation pattern of the antenna in E_Plan. The directivity values for each beam are given in Table VI.

TABLE VI: DIRECTIVITY VALUES FOR EACH BEAM IN (dBi)

B1	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**
5	7	10.1	12.1	10	7	5	4	7.1	11.1
B11	**B12**	**B13**	**B14**	**B'1**	**B'2**	**B'3**	**B'4**	**B'5**	**B'6**
9.2	11	7.2	4	3	7.3	12	15.4	12	7.3
B'7	**B'8**	**B'9**	**B'10**	**B'11**	**B'12**				
5	5.7	12.5	14.5	12.5	5.7				

For the 26 GHz and 27.6 GHz frequencies, 6 powerful beams are located, 3 in front and 3 in the back of the antenna. This allows the antenna to be operational at both sides. Figures 12 and 13 present the variation of directivity as a function of the direction angles for both frequencies in E and H plans, respectively.

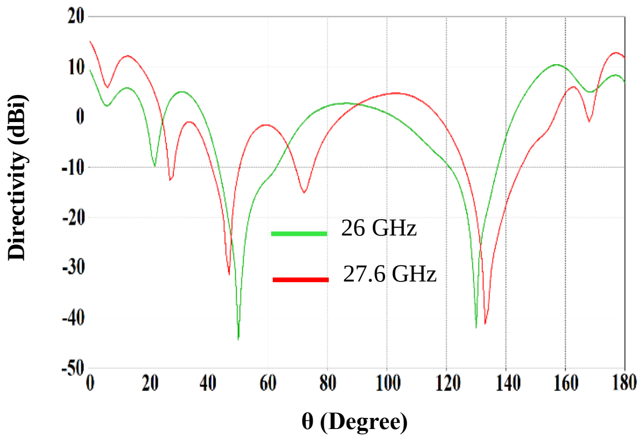

Figure 12. Directivity variation as a function of the direction direction angle in E_Plan

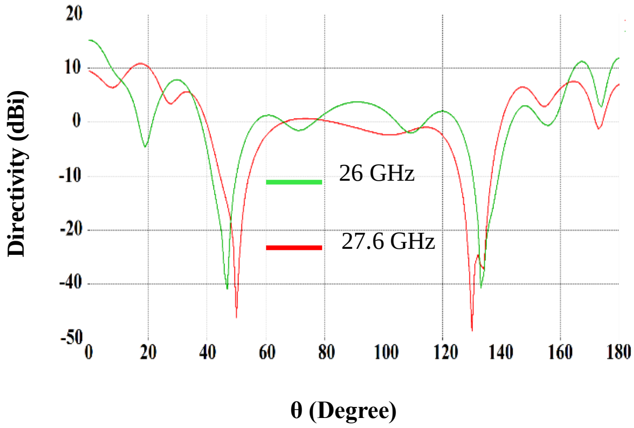

Figure 13. Directivity variation as a function of the direction angle in H_Plan

It can be noted that the maximum directivities are located at 160° for 26 GHz and 180° for 27.6 GHz. The maximum directivity values at the previous angles are 12 dBi and 15.4 dBi respectively.

IV CONCLUSION

In this paper, a high directivity multi-beam antenna for Radio Frequency Energy harvesting in 5G network is presented. This antenna has a size of 65 x 55 mm² designed on Teflon glass substrate with a relative permittivity of 2.1 and a thickness of 0.67mm. The maximum directivity obtained is 12.1 dBi for the 26 GHz frequency and 15.4 dBi for 27.5 GHz. The multibeam property makes this antenna capable of picking up waves at both frequencies (26 and 27.5) GHz in several directions with high directivity, which largely increases the received power.

References

[1] A. J. Compston, J. D. Fluhler and H. G. Schantz, "A Fundamental Limit on Antenna Gain for Electrically Small Antennas," 2008 IEEE Sarnoff Symposium, 2008, pp. 1-5, doi: 10.1109/SARNOF.2008.4520113.

[2] J. Wu, C. Wang and Y. X. Guo, "A Compact Reflector Antenna Fed by a Composite S/Ka-Band Feed for 5G Wireless Communications," in IEEE Transactions on Antennas and Propagation, vol. 68, no. 12, pp. 7813-7821, Dec. 2020, doi: 10.1109/TAP.2020.3000858.

[3] M. Mirzaee and N. Tavassolian, "Low-Profile Wearable Wideband Antenna with High Gain Based on Franklin Array for Future 5G Wireless Body Area Networks," 2020 IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting, 2020, pp. 449-450, doi: 10.1109/IEEECONF35879.2020 9329727.

[4] M. Heino, C. Icheln, J. Haarla and K. Haneda, "PCB-Based Design of a Beamsteerable Array With High-Gain Antennas and a Rotman Lens at 28 GHz," in IEEE Antennas and Wireless Propagation Letters, vol. 19, no. 10, pp. 1754-1758, Oct. 2020, doi : 10.1109/LAWP.2020.3017 129.

[5] S. Kim and J. Choi, "1×8 Slotted Array Antenna with Fan-Beam Characteristics for 28 GHz 5G Mobile Applications , " 2020 International Symposium on Antennas and Propagation (ISAP), 2021, pp. 13-14, doi: 10.23919/ISAP47053.2021.9391404.

[6] L. Vähä-Savo et al., "Empirical Evaluation of a 28 GHz Antenna Array on a 5G Mobile Phone Using a Body Phantom, " in IEEE Transactions on Antennas and Propagation, doi: 10.1109/TAP.2021.3076535.

 ISBN: 978-1-61208-940-9