Design and Optimization of a Yagi-Uda 5G-Rejecting TV Antenna

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Abstract This paper discusses the design and optimization of a Yagi-Uda antenna for television (TV) reception that can reject ultra-high frequency (UHF) 5G mobile communication band signals. The antenna presents a high realized gain of more than 10 dBi between 470 and 694 MHz, which corresponds to the UHF TV band and rejects 5G mobile communications signal in the 700 MHz band. The antenna is designed and optimized using CST Studio Suite and it does not utilize an extra filter, relying only on the filtering properties of the structure, especially of the last few director elements.

Keywords UHF TV band · Yagi-Uda antenna · 5G communications

1 Introduction

5G is a new worldwide wireless standard for telecommunications. It has higher data capacity and transmission speeds than 3G and 4G networks. 5G has certain network parts that are based on older generations of mobile and wireless communications technology; however, it is not a gradual progression of current networks despite including these aspects. It offers global connection with very high bandwidth and minimal latency communication for individual users as well as devices that are linked [1]. Digital television is an essential aspect of today's advanced communications infrastructure, which makes use of ultra-high frequency (UHF) broadcasting frequencies in order to both receive and transmit data [2]. The increasing need for superior television transmissions is facing new challenges due to the emergence of fifth generation (5G) mobile communication technology. The implementation of 5G networks, specifically in the 700 MHz frequency spectrum, presents possible interference issues that may impact the continuous reception of television signals. The search for a resolution of interference involves the implementation of filters or the utilization of directive antennas that are specifically designed for this purpose.

The UHF Yagi-Uda Antennas are widely acknowledged for their outstanding performance in the Ultra High Frequency (UHF) band, encompassing the television broadcast frequency range. The Yagi-Uda antenna demonstrates exceptional directivity and gain, making it a suitable option for reducing interference by relying only on the filtering properties of the structure, especially of the last few director elements.

The Yagi-Uda antenna has gained significant popularity as a home television antenna due to its low cost, simple design, and relatively higher gain [3]. The Yagi-Uda antenna exhibits a relatively narrow bandwidth, which may be enhanced to some extent by utilizing alternative feeds instead of a simple dipole [4].

The Yagi-Uda array, in its conventional form, is comprised of a series of parallel cylindrical conductors that are arranged in a linear fashion. Among these conductors, only a single one is actively driven, while the others are considered parasitic elements. Within the category of parasitic elements, one functions as a reflector located behind the driven element while the remaining elements operate as directors placed in front of the driven element as shown in Fig. 1. The enhancement of directivity in Yagi-Uda arrays has posed a difficult challenge for antenna engineers [5]. The directivity and gain of an antenna are highly dependent on the element spacing. The antenna's radiation pattern may be fine-tuned by altering the lengths and distances of the directors and reflector. In order to attain the end fire configuration, the parasitic elements oriented towards the main beam direction are comparatively shorter in length than the driven element. In general, it is common for the length of the driven elements to be slightly shorter than $\lambda/2$, usually ranging from 0.45λ to 0.49λ. On the other hand, the director lengths typically fall within the range of 0.4λ–0.45λ. Typically, the distance between directors' ranges from 0.2 to 0.4λ, but it is not always essential for achieving optimal designs [6]. Stutzman and Thiele [4] have identified two distinct simple methods for modifying the far field pattern of a Yagi antenna for a specific frequency. One approach is to alter the distance between the directors while maintaining their length and the distance from the reflector. The second approach involves altering the length of the directors while keeping the remaining parameters constant [7].

2 Proposed 23 Element Yagi Uda Antenna Layout

The Yagi-Uda TV antenna is a well-known design for receiving television broadcasts. The proposed antenna double-director Yagi-Uda works within a broad frequency range of 470–694 MHz, essentially rejecting any transmissions outside of this range.

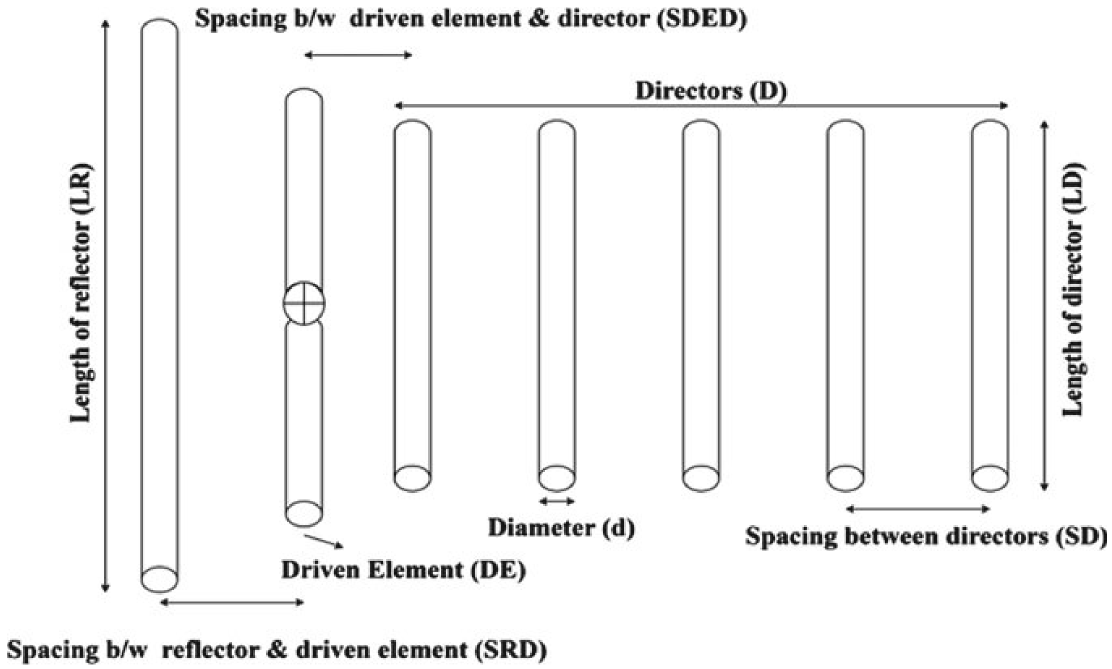

Fig. 1 Yagi-Uda antenna

Multiple parameters were used in the CST design process to create the Yagi-Uda antenna as mentioned in Table 1. The initial Yagi-Uda antenna was designed at 500 MHz and employs a driven element separated by a distance of 0.250 m from the main reflector and 0.055 m from the 1st double director element. The antenna's front-to-back ratio is enhanced, and the energy is directed towards the intended direction by the strategic placement of seven upper and seven lower elements forming a 120° corner reflector. The reflector elements are of same length 0.55 m, and the spacing between the reflectors is 0.054 m. The double directors are arranged in front of the driven element with equal distances 0.160 m between each of them. Each director is of the same length, i.e., 0.2 m. Their function is to improve the antenna's forward gain as well as its directivity. The primary distinction between conventional directors and double directors in a Yagi-Uda television antenna is their respective placement. Double directors provide superior directivity, gain, and front-to-back ratio in comparison to standard directors, therefore double directors are useful for applications that require enhanced performance. After simulating the initial design, a parametric linear sweep was performed of director lengths from 0.2 to 0.155 m. Upon conducting an analysis of the parametric results, it was determined that a director length of 0.16 m exhibited optimal wideband performance. The performance of the Yagi-Uda antenna was further enhanced by an optimization process which was carried out by employing CST's trusted region framework algorithm. The optimization targets are stated in Table 1. The spacing between directors (SD), and the length of each director (LD), were two parameters that were taken into account throughout the optimization process. The allowable range for adjusting these parameters was limited to a variation of ± 10% (Figs. 2, 3; Tables 2, 3).

Table 1 Optimization configurations

Parameters	Frequency (MHz)	Goals (dBi)	Weight
Realized gain	450–700	> 16	3.0
Realized gain	710–1000	< – 15	6.0
S11	450–700	< – 20	1.0

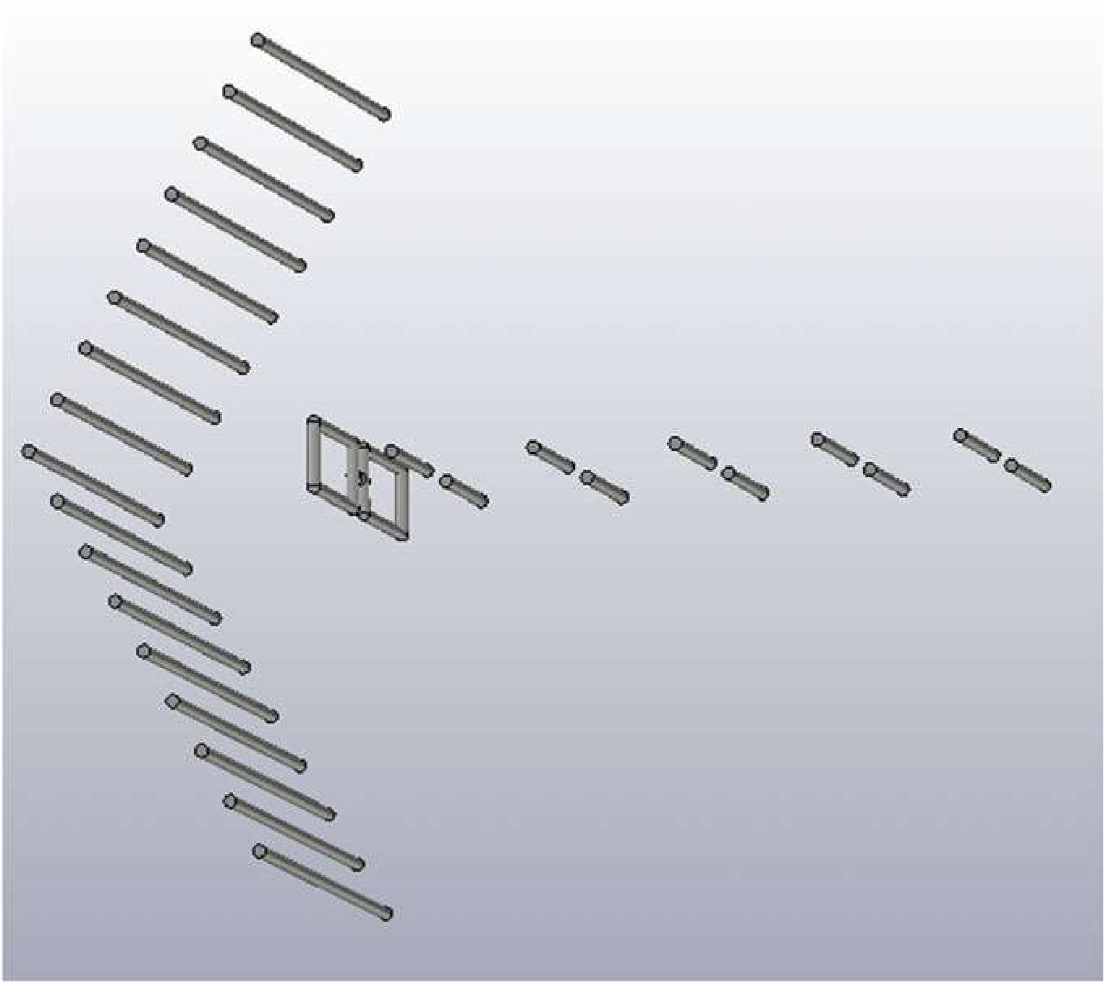

Fig. 2 Isometric view of proposed model of Yagi-Uda 5G rejecting TV antenna in CST software

3 Simulation Results

The CST electromagnetic simulation software was utilised to conduct a time domain simulation, employing a hexahedral meshing approach which comprises a total of 1,374,894 mesh cells. The simulation was carried out with a precision level of – 50 dB. The proposed design was subjected to open boundary conditions with an estimated reflection level of 10^{-4}.

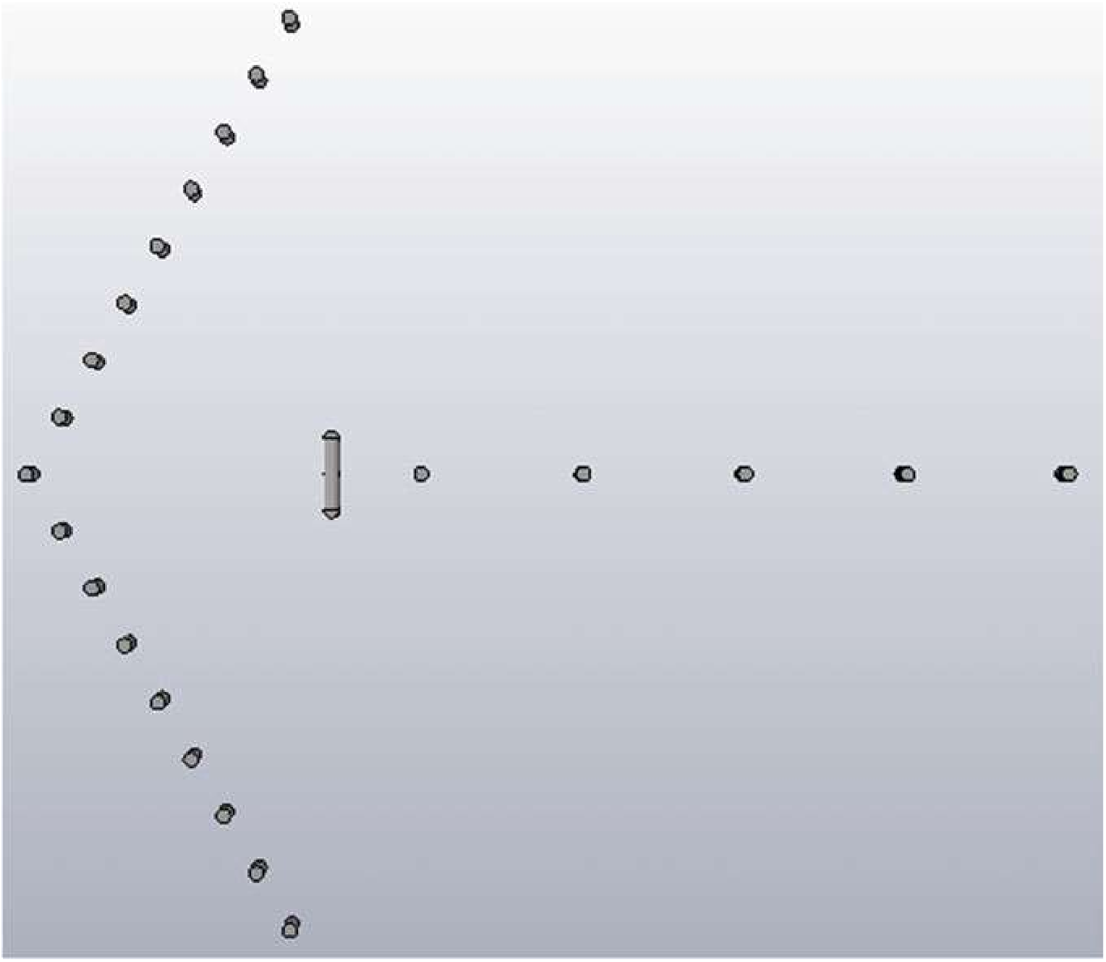

Fig. 3 Front view of proposed model of Yagi-Uda 5G rejecting TV antenna in CST software

Table 2 Optimization parameters

Parameters	Minimum	Maximum
Spacing between directors (SD)	132	162
Length of director element (LD)	144	176

As its evident from Fig. 4, the simulated (optimized) values of return loss exhibit a satisfactory level of acceptance with reduced S11 values observed within the operational frequency range of television broadcasts.

Figure 5 depicts a plot illustrating the initial design, parametric sweep result where d = 0.160 m, and optimized realized gain as a function of frequency ranging from 450 to 1000 MHz. The optimized design exhibits a maximum value of 13.91 dBi at 670 MHz and a minimum value of − 5.5 dBi at 720 MHz. The antenna provides a significant gain within the TV band and good rejection above 694 MHz.

Figure 6 illustrates the front-to-back ratio of the initial design, parametric sweep result where d = 0.160 m, and optimized design within the frequency range of 450–1000 MHz. The optimized result demonstrates that the antenna model possesses excellent directional characteristics.

Table 3 Dimensions of Yagi-Uda antenna

Initial design		Parametric sweep	Optimized design
Parameters	Values (m)	Values (m)	Values (m)
Radius of driven element (RDE)	0.002	0.002	0.002
Radius of reflector (RF)	0.004	0.004	0.004
Spacing between reflector and driven element	0.250	0.250	0.250
Length of reflector element (LR)	0.550	0.550	0.550
Spacing between reflectors (SR)	0.054	0.054	0.054
Radius of director (RD)	0.004	0.004	0.004
Length of director element (LD)	0.200	0.200–0.155	0.160
Side gap between double directors (SDD)	0.085	0.085–0.95	0.95
Spacing between directors (SD)	0.160	0.160	0.147

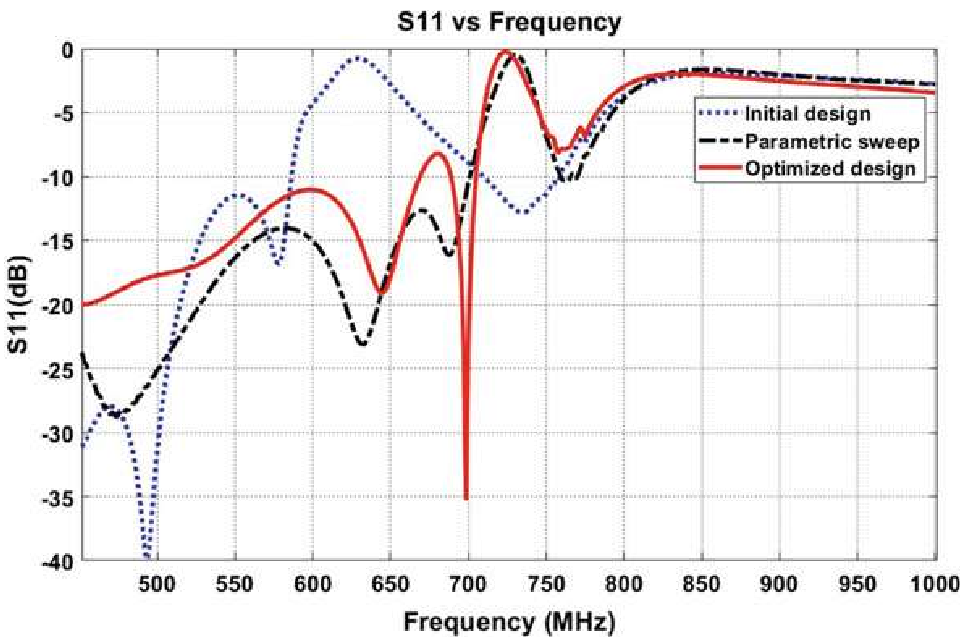

Fig. 4 S11 parameter of Yagi-Uda antenna

Figure 7 represents the 3D radiation pattern of optimized design depicting the realized gain 13.90 dBi at 660 MHz and observed end-fire radiation pattern.

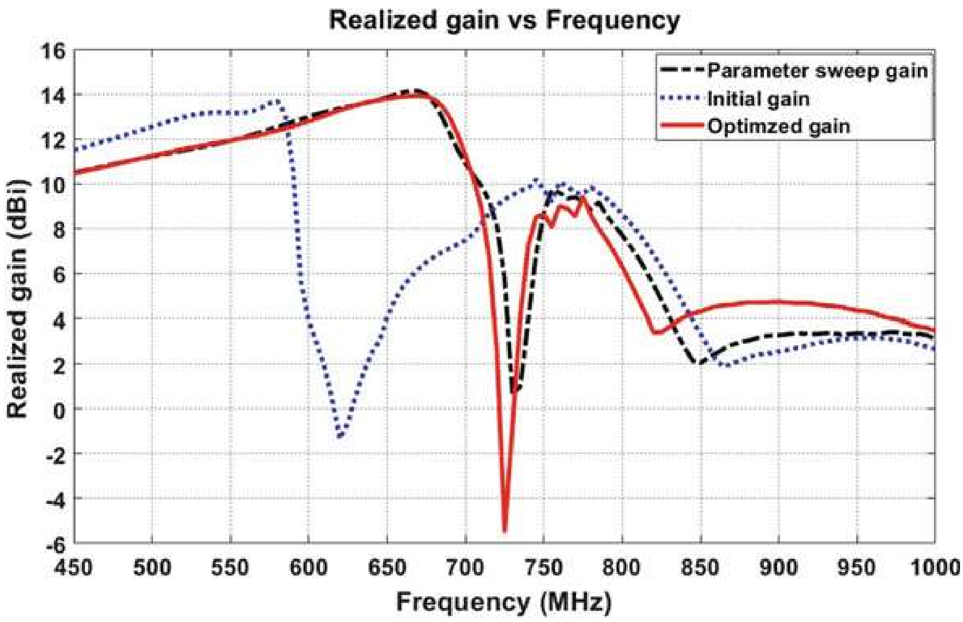

Fig. 5 Realized gain over frequency

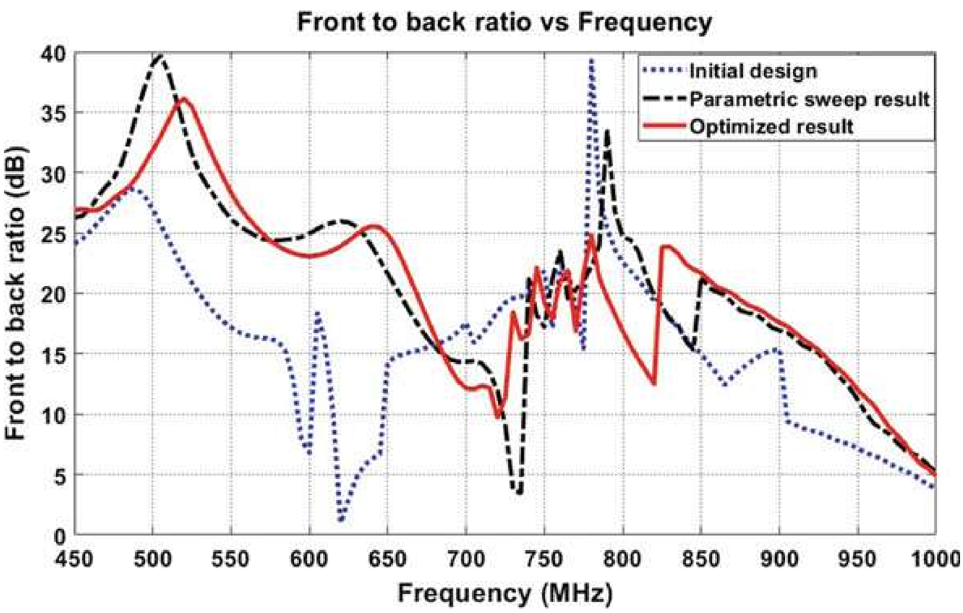

Fig. 6 Front to back ratio over frequency

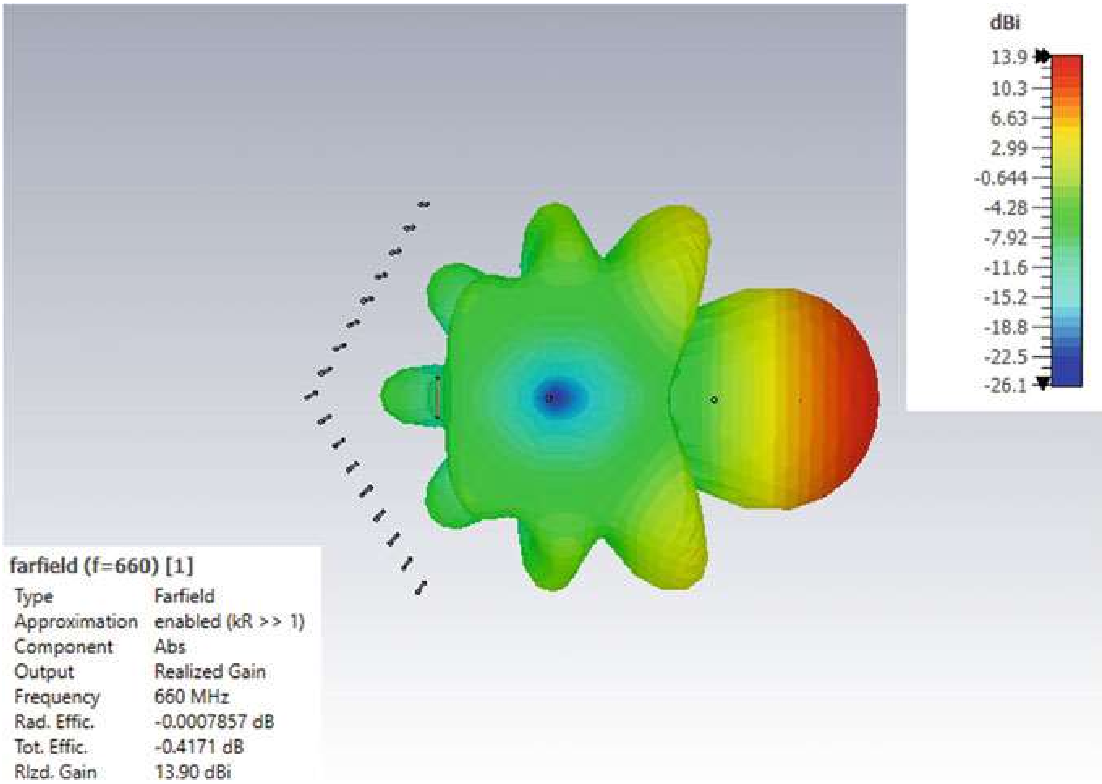

Fig. 7 Radiation pattern in 3D form at 660 MHz

4 Conclusion

The suggested design for a 23-element Yagi-Uda antenna may serve as a cost-efficient solution for UHF television reception, possessing the ability to reject the 700 MHz 5G mobile communication band without the need for expensive filters. This design has the potential to address the issue of interference resulting from the simultaneous operation of TV broadcasting and mobile communications services, leading to an improvement in broadcasting reception performance. The proposed Yagi-Uda antenna design has excellent directional properties, favorable matching, and reasonably high gain. These properties show significant promise for their potential applications.

Acknowledgements This work was partially supported by the European Union through the Horizon 2020 Marie Skłodowska-Curie Research and Innovation Staff Exchange Programme, "Research collaboration and mobility for beyond 5G future wireless networks (RECOMBINE)" under Grant no. 872857.

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