

3D Printed Large Bandwidth New Yagi-Uda Antenna

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Abstract—A new design of a printed Yagi-Uda antenna is presented. The main idea to be directive and large bandwidth is to replace the driver element associated with its reflector by a directional curved disk monopole and the directors by flat disks monopole. It requires the use of a ground plane to simplify feeding. The study of configuration of the dimensions, the number and dispositions of the directors elements allows a return loss less than -10 dB over 20% bandwidth centered at 5 GHz. Also, a high gain of 13 dBi is obtained with a maximum radiation direction at 26° elevation from the azimuth due to a limitation of the ground plane. This gain remains superior to 10 dBi over the bandwidth. The simulation results are in good agreement with the measurements for return losses, radiation patterns, and gain.

1. INTRODUCTION

Several studies have been conducted for the design of printed Yagi-Uda antennas. All these structures are linear polarization, with single band and offer a narrow bandwidth. They are based on dipoles, monopoles, patches or Archimedean spirals [1–6]. An ultra-wideband capped bow-tie multilayered-stacked Yagi-Uda antenna recently developed attains a small footprint, compact size, customizable gain, and simple geometry [7]. Other research presents Yagi-Uda antennas operating with dual bands [8] and triple bands [9]. However, these antennas are limited in terms of gain, bandwidth, and half-power beamwidth.

This letter presents a new design of 3D printed Yagi-Uda antenna. The driver element and reflector are replaced by a single directional curved disk monopole (Fig. 1(a)) that produces a wide bandwidth and five directors formed by flat disks monopoles [8]. The structure is printed in a flexible, low dielectric permittivity substrate RT/Duroid 5880 laminates with dielectric constant 2.2, $T_s = 0.254$ mm as thickness, $T_m = 18$ μ m as copper metal thickness, and dissipation factor $\tan \delta = 0.001$. It is mounted above a metallic square ground plane (30×30 cm) that allows better electrical contact and excited by a 50Ω SMA connector fixed with the ground plane (Fig. 1). Fig. 1(b) and Fig. 1(c) present its E -plane and H -plane radiation patterns. This structure is more directive and has very large bandwidth compared to the classical monopole antenna [10].

2. ANTENNA CONFIGURATION

The proposed Yagi-Uda (Fig. 2) was designed to be operational in the N79 (4.5 GHz–6 GHz) frequency band for Japanese and Chinese 5G applications. Several parameters have been optimized using the commercial CST Microwave Studio[®] software, to increase the gain of the Yagi-Uda antenna, namely, the number and dimensions of the directors as well as the distances d_1 (between the driven element and the director) and d_2 (between the directors). This structure is composed of:

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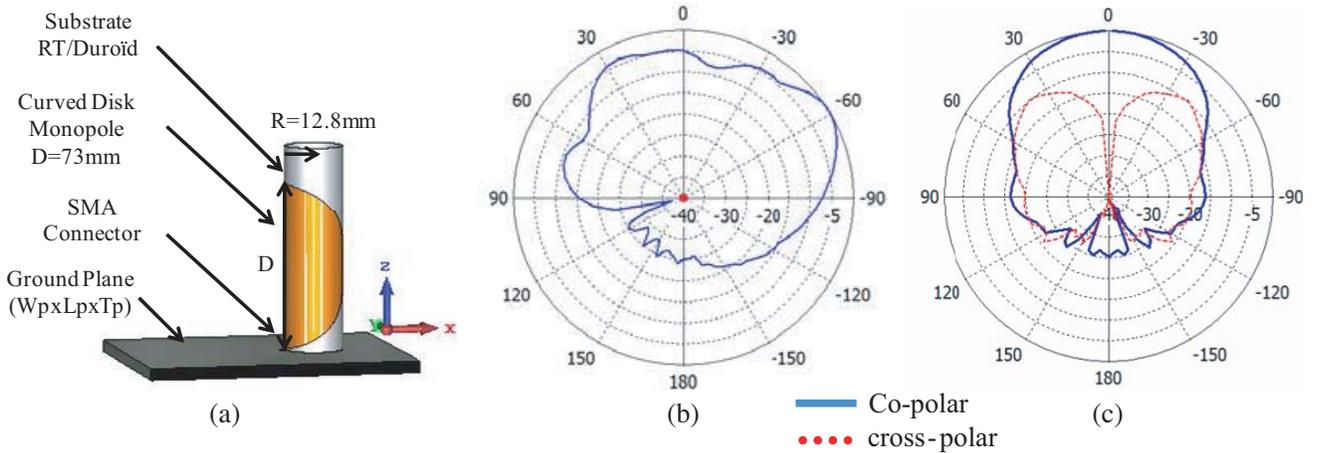


Figure 1. (a) Directive curved monopole antenna structure used as driver [10]. (b) Simulated co and cross polarization in E -plane radiation patterns versus θ for $\phi = 0^\circ$, at 5.3 GHz. (c) Simulated co and cross polarization in H -plane radiation patterns versus θ for $\phi = 90^\circ$, and the plot is aligned to the maximum radiation elevation angle at 5.3 GHz.

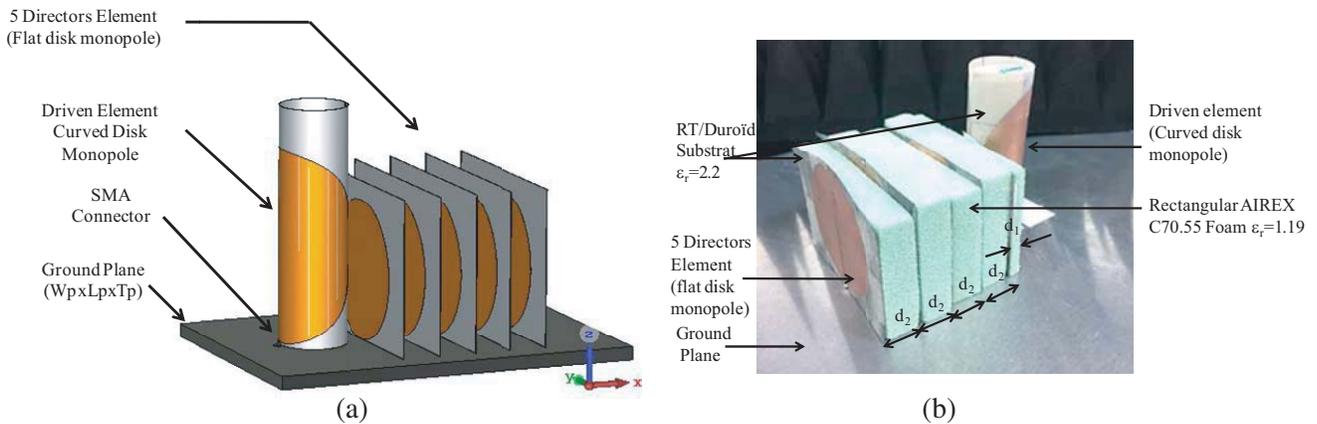


Figure 2. (a) Illustration of new proposed 3D printed Yagi-Uda antenna. (b) Photograph of mount antenna on $30 \times 30 \times 5 \text{ cm}^3$ metallic ground plane.

- A flat disk monopole with 72 mm diameter curved on a 25.6 mm diameter AIREX foam cylinder, powered by a 50Ω SMA connector and placed above a $30 \times 30 \text{ cm}^2$ square metal reflector plane. The flat disk is used for its large bandwidth.
- Five monopole flat disks are as directors with identical diameter of 53 mm (smaller than the driven element) placed at a distance $d_1 = 6.9 \text{ mm}$ (0.122λ at 5.3 GHz) from the radiating element, short-circuited in the metallic reflector plane and excited by electromagnetic coupling ($d_2 = 14.25 \text{ mm} = 0.25\lambda$ at 5.3 GHz). This number is optimized to reach the maximum known gain of Yagi-Uda antenna (13 dBi) and wide bandwidth (38%).

Figure 2(b) shows the prototype of the new Yagi-Uda antenna. Rectangular AIREX C70.55 foam pieces of dielectric constant 1.19 reinforce the five directors in order to perform accurate measurements.

3. PARAMETRIC ANALYSIS

To understand the effects of different parameters on the antenna bandwidth, a series of parametric analyses are performed. Among the parameters considered to have a significant influence on its overall

performance are the diameter of the directors, distances d_1 (between the driven element and the director) and d_2 (between the directors).

3.1 Effect of the Diameter of Directors: The effects of the diameter of the directors on the reflection coefficient of the proposed antenna is shown in Fig. 3(a). It can be observed that the antenna bandwidth is affected by changes in diameter D . For the value of $D = 53$ mm, the reflection coefficient remains stable around the entire frequency band.

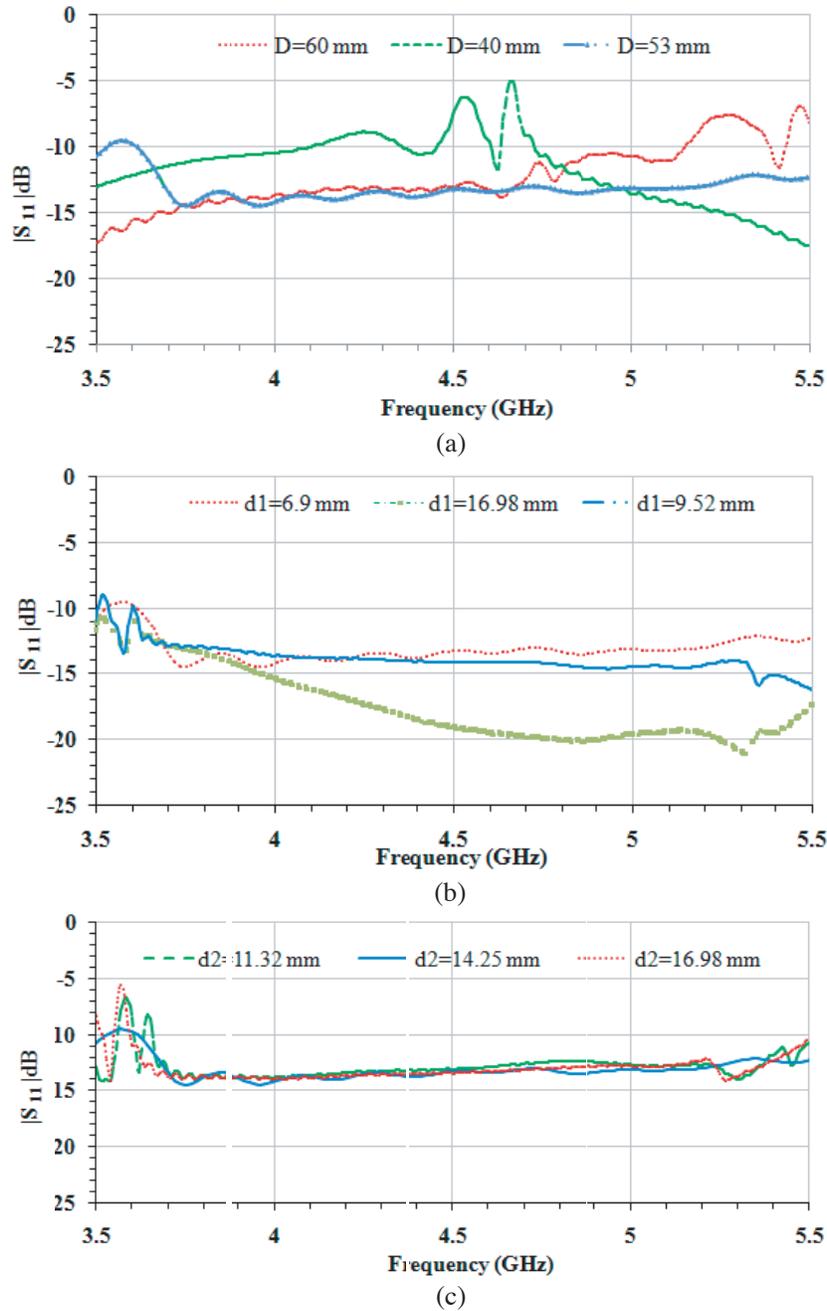


Figure 3. (a) Effect of the diameter D of director on reflection coefficient where $d_1 = 6.9$ mm, $d_2 = 14.25$ mm. (b) Effect of the distance d_1 on reflection coefficient where $d_2 = 14.25$ mm. (c) Effect of the distance d_2 on reflection coefficient where $d_1 = 6.9$ mm.

- 3.2 Distance d_1 (between the Driven Element and the Director):** The variation of the distance d_1 shows a good adaptation for all the values of d_1 especially $d_1 = 16.98$ mm. But for the compactness of the antenna, the value $d_1 = 6.9$ mm is chosen (Fig. 3(b)).
- 3.3 Distance d_2 (between the directors):** The changes in terms of reflection coefficient due to the variations of distance d_2 is illustrated in Fig. 3(c). It is shown that these parameter has a poor influence on impedance matching.

4. SIMULATED AND MEASURED RESULTS

Figure 4 shows the comparison of the simulated and measured S_{11} parameters of the optimized Yagi-Uda antenna. It has been measured by means of an Agilent PNA-X N5242A network analyzer. The measurement results are in good agreement with those of simulation. A matching impedance for measured $|S_{11}| < -10$ dB in the 3.7–5.5 GHz frequency band (39% of bandwidth) is found. The discrepancies between the simulation and measurement in both S_{11} parameters and the gain are probably due to the losses caused by the glue used to fix the rectangular AIREX C70.55 foam used as a support between directors. These losses cause better measured matching at 5.5 GHz than simulation, but it is observable that the gain is lower than 1 dB at this frequency. It confirms that the glue losses must be taken into account in the design. However, it is difficult to have all their RF characteristics.

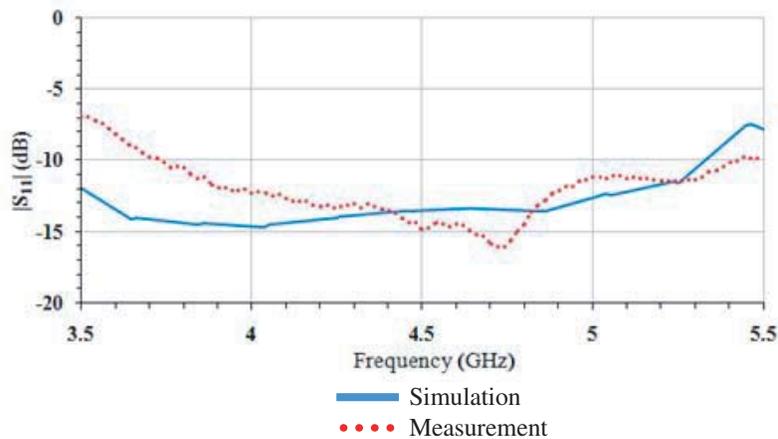


Figure 4. Simulated and measured S_{11} parameter of the Yagi-Uda antenna versus frequency.

The Yagi-Uda antenna variation of the gain as a function of frequency is shown in Fig. 5. It is measured in an IETR anechoic chamber, and the gain is using classical calibration and compared with a known horn antenna. A gain greater than 10 dBi is obtained in the 4.5–5.5 GHz frequency band corresponding to 20% bandwidth. In addition, the gain reaches a maximum value of 13 dBi at a frequency of 5.3 GHz. Experimental results are in good agreement with simulated ones.

The simulated and measured co-polar patterns in the E -plane (xz -plane) of the Yagi-Uda antenna in-band frequencies are shown in Fig. 6. It should be noted that the maximum direction of radiation is at 26° elevation from the azimuth and stable over the entire frequency band. A pointed lobe appears at the maximum gain (at $f = 5.3$ GHz) with a narrow half-power beamwidth about 14.8° for the E -plane. The SLL (Sidelobe Level) is lower than -8.2 dB in the E -plane. The measurements of the radiation patterns are made in the anechoic chamber; they show a good agreement with the simulation results. The only co-polar component is plotted because the cross-polar is very low due to the null at the maximum direction of radiation as plotted in Fig. 7. This last figure shows the H -plane at the maximum radiation elevation. The half-power beamwidth is about 31° ; the side lobes levels are lower than -10 dB; and the cross-polarization is also lower than -10 dB.

Table 1 compares this work with other recent works of Yagi-Uda antennas in terms of bandwidth (FBW), gain, and half-power beamwidth. It can be seen that the proposed antenna features improved performances.

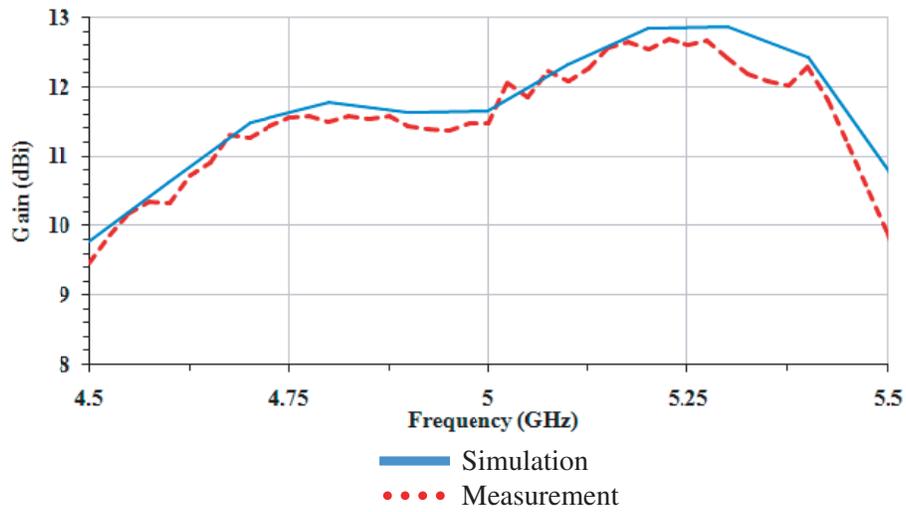


Figure 5. Maximum measured and simulated Gain variation of new Yagi-Uda antenna versus frequency.

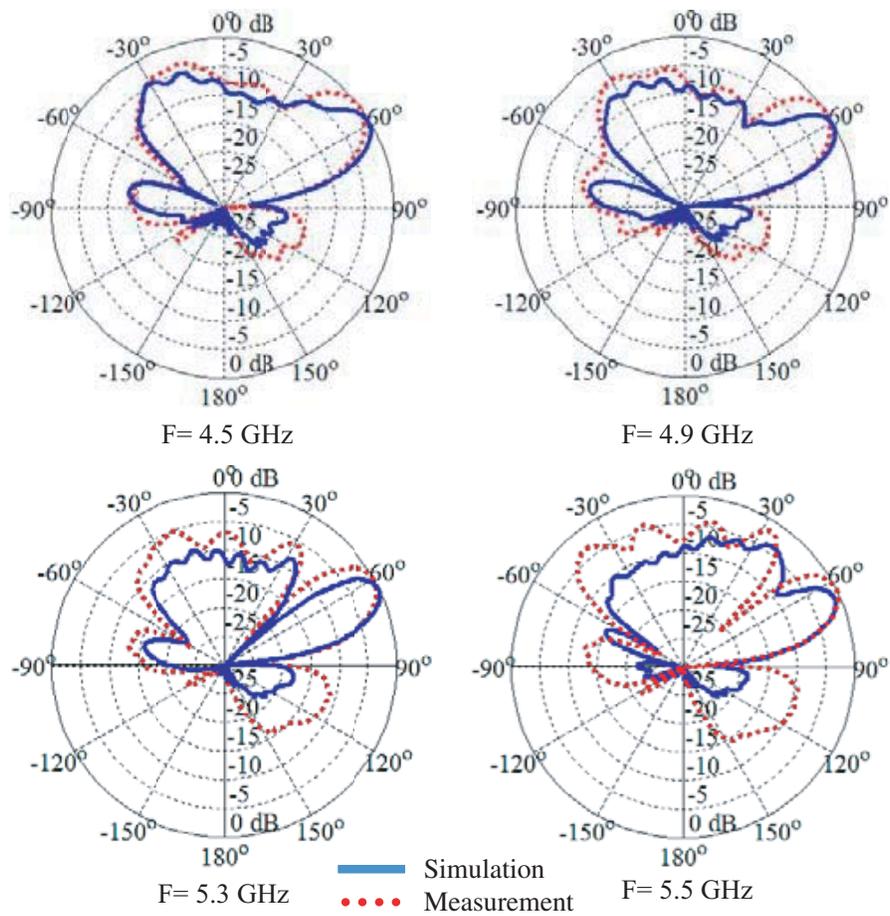


Figure 6. Simulated and measured co-polar radiation patterns of the new Yagi-Uda antenna in E -plane versus θ for $\phi = 0^\circ$, at different frequencies.

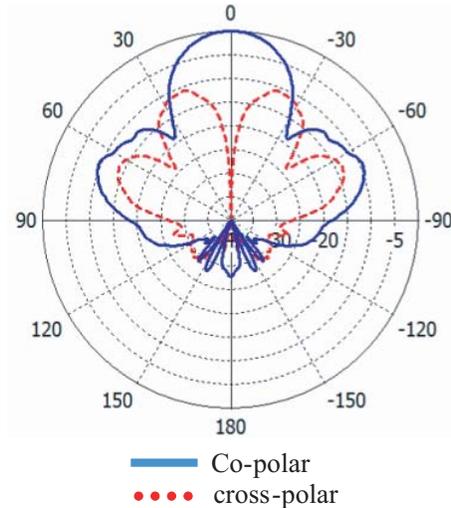


Figure 7. H -plane for the new Yagi-Uda antenna versus θ for $\phi = 90^\circ$, and the plot is aligned to the maximum radiation elevation angle at 5.3 GHz.

Table 1. Comparison of the proposed antenna with other Yagi-Uda antenna available in literature.

Ref.	FBW (%)	Gain (dBi) in the bandwidth	half-power beamwidth ($^\circ$)
[11]	14.4	8	40
[12]	12	8.2	N/A
This work	39	13	14.8

5. CONCLUSION

An original Yagi-Uda antenna structure based on a curved disk monopole as a driven element associated with its reflector and five flat disks monopoles as directors is designed and measured. This structure provides good performances in terms of gain and bandwidth. The structure size is about $7.3 \times 0.9 \times 5$ cm, corresponding to $1.3l_0 \times 0.1l_0 \times 0.8l_0$ at 5.3 GHz. This solution could be useful for 5G N79 (4.5 GHz–6 GHz) frequency band using TDD duplex mode.

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