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Bi-band quasi Yagi-Uda antenna for worldwide 5G applications

M. Egels¹, A. Venouil¹, P. Pannier¹,

¹Aix-Marseille University, IM2NP (UMR 7334), Marseille, France

Abstract— In this paper a bi-band quasi Yagi Uda antenna is presented. The antenna prototype is designed for the 24.25 GHz -28.5 GHz frequency band and 47.2 GHz - 48.2 GHz frequency band. The second frequency band of operation is obtained by two slots added in the radiator, a patterned ground plane and 3 sets of radiators. Simulations show a 8 dB maximum in the lower band and 8.5 dB in the higher band. A prototype has been realized on 250 μm thick Taconic RF35 ($\tan \delta = 0.0019$ and $\epsilon_r = 3.5$) substrate with 17 μm two thick copper layers. The size of the prototype is 15 x 20 mm^2 . Measurements show a bi-band behavior with 8.5 dB in the gain and 8.2 dB gain in the lower band and 8.5 dB in the highest band. A mismatch of 2 GHz is observed between measurements and simulations in the highest band.

1. INTRODUCTION

With the grows of 5G standard in the world ultra wide band antennas with operating frequencies from 24 GHz up to 70 GHz are proposed in the literature. Having high gain in a such wide frequency band imposes to use antennas such as Vivaldi [1] or log periodic antennas arrays [2]. Analysis of the literature shows that covering 24.25 GHz to 28.5 GHz frequency band and 47.2 GHz to 48.2 GHz allows to address the majority of frequencies for 5G in Europe, South Asia and North America.

In this communication a solution based on bi-band Yagi-Uda antenna is proposed. Some multi-band Yagi-Uda designs have already been proposed. [3] and [4] propose antennas in the Giga hertz frequencies range. [5] proposes a three band millimeter wave antenna with a 6 to 8 dB gain at 25 - 37 and 60 GHz but it seems very complicate to design due to multi-functions of several parts of the antenna. In the bi-band antenna, that is proposed in this communication, each part of the antenna plays a unique function which allows to reduce complexity of the proposed design. Indeed each frequencies band can be designed independently. The proposed design uses a slotted dipole as radiator with addition of a patterned ground plane. The Yagi effect is obtained by the use two sets of directors to have directive antenna in the two frequency bands of interest. The paper is divided in three sections. The first part presents the antenna, its description and some design aspects. The second presents the measurement results and the third part conclude the paper.

2. ANTENNA DESCRIPTION AND ANALYSIS

The proposed antenna is composed of a bi-band radiator with its patterned ground plane and three sets of four radiators to improve its gain in the two desired frequency band (see fig.1). The antenna is designed to be fully planar without via in order to be realized with low cost process. It is realized on a low cost TACONIC RF 35 ($\tan(\delta) = 0.0019$ and $\epsilon_r = 3.5$) 252 μm thick substrate. The two layers (top and bottom) of metal are made of 17 μm of copper in order to minimize the roughness of the metallic layers. All simulations are performed with full 3D finite elements commercial software Ansys HFSS 2020 R2. Figure 1 gives a full description of the proposed antenna.

As standard planar Quasi Yagi-Uda antenna [5] [2], the radiator is splitted in two parts. The first one is on the top layer and connected to a 50 Ω micro-strip line. The second one is placed on the bottom layer and connected to the ground plane of the micro-strip. In order to have bi-band operations, the radiator and the ground plane have to be modified to introduce a second resonance frequency. The technique proposed in [6] for low frequency multi band dipole and in [7] for a low frequency multi band quasi Yagi Uda antenna have been used. It consist of two slots, one on each arm of the radiator, in order to create the second frequency resonance. To confirm the effects of the modified structure parameter sweeps of length of the slots (L_{slot}) and of the parameter L of the modified ground plane have been performed without any director. Simulation results shows that L mainly affects the matching (see fig. 2 (a)) and the length of the slot (L_{slot}) as major effects on the frequency of the second band (see fig. 2). As the length of the slot affects the surface of the radiator, it also impact in a minor proportion the center frequency of the lowest band. The center frequency of the band can be set by the length of the radiator L_{rad} , the matching in this band is controlled by the distance between main ground plane and the radiator (L_1 in fig 1).

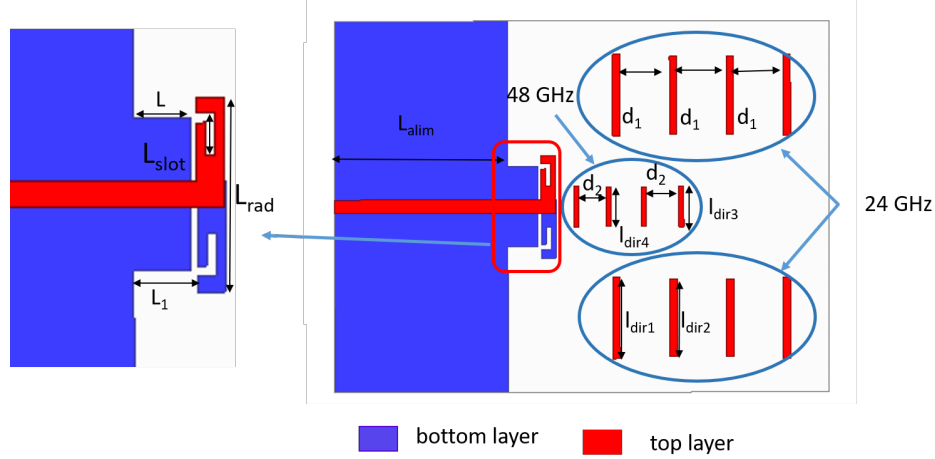


Figure 1: Full description of the bi-band Yagi antenna.

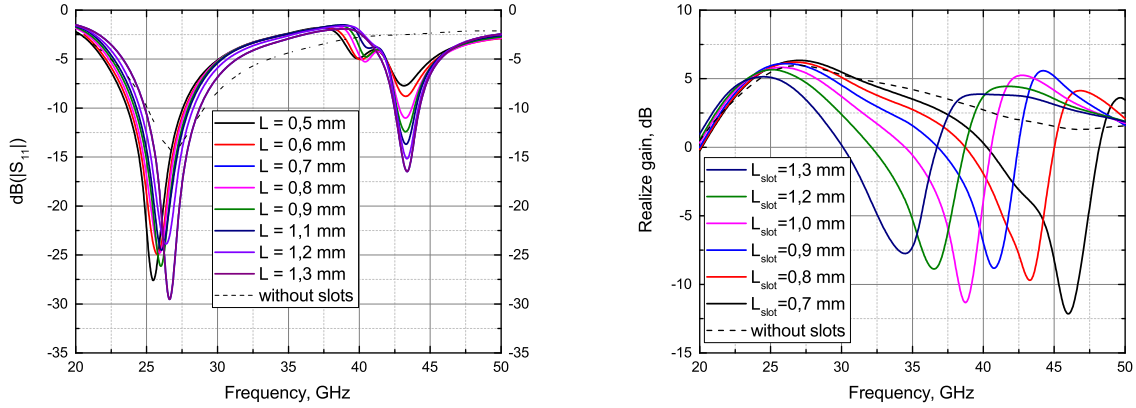


Figure 2: S_{11} (a) as function of frequency for different length of the ground pattern (L) and realized gain (b) as function of frequency for different slot length of the radiator.

From this analysis the following design considerations can be deduced. The center frequency of the lowest band can be set by the length of the radiator L_{rad} , the matching in this band can be controlled by the distance between main ground plane and the radiator (L_1 in fig 1). The center frequency of the highest band is set by the length of the slots L_{slot} and the matching by the length L of the ground pattern. To achieve Yagi Uda effect in a desired frequency the induced currents on each director must be approximately $\lambda/2$ and must be placed in order to have constructive interference waves for the global system. In this way, if coupling effects are neglected, the length of each director must be equal $\lambda/2$ and distances between each radiator must be set to a proper value which is dependent on the number of directors. [8] gives optimal dimensions for Yagi-Uda antennas with set of directors up to 10 elements. A careful attention to the table given in [8] shows that more than 4 directors induce a small increase in gain for a large increase in area. With those design rules, four directors are used for each sets of directors.

With computed values, the second radiator of the 48 GHz set is very close to the second one of the 24 GHz set (see fig. 1). With such geometrical aspects and known current density in a $\lambda/2$ resonator, the best way to minimize coupling between radiator sets is to place it as depicted on fig. 1. To have the same gain in the two bands, two sets of directors sized for 24 GHz hare placed on the both sides of the radiator set designed for 48 GHz frequency band (see fig. 1). Initials values of all dimensions of the radiator sets have been determined thanks to rules found in [8]. Then the antenna design is optimized in order to have the highest and the flattest gain as possible and good matching in the two frequency bands of interest. Table 1 summarizes the values of the different geometrical parameters.

The full optimized antenna is simulated including a 67 GHz end-launch connector used to feed

Table 1: Optimized geometrical parameters of the proposed bi-band quasi Yagi Uda antenna.

parameter (24 GHz part)	value	parameter (48 GHz part)	value
L_{rad}	3.6 mm	L_{slot}	0.9 mm
L_{dir1}	3.3 mm	L_{dir3}	1.65 mm
L_{dir2}	3.15 mm	L_{dir4}	1.60 mm
d_1	2.3 mm	d_2	1.12 mm
L_1	1.95 mm	L	1.20 mm
L_{pcb}	20 mm	W_{pcb}	15 mm

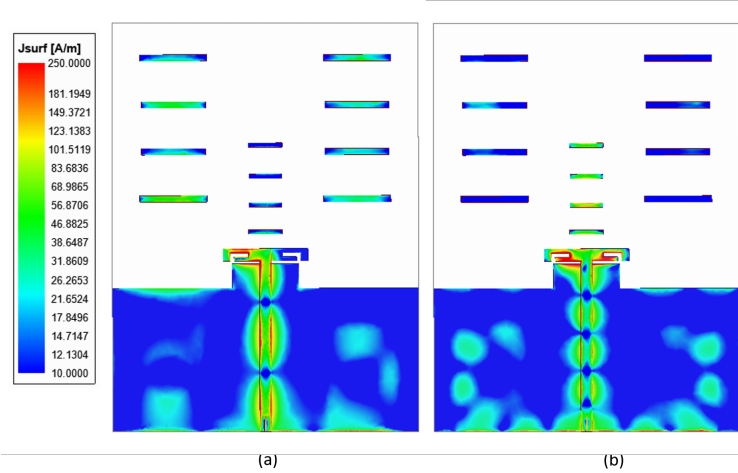


Figure 3: Surface current distribution at a) 24 GHz and (b) 48 GHz.

the antenna during the measurement process. The surface current density plotted on fig.3 (a) shows that, as expected, the longest part of the radiator and the side sets of radiators have the highest current density at 24 GHz and the smallest part of the radiator and the inner set of radiators have the highest current density at 48 GHz (see fig. 3 (b)).

3. MEASUREMENTS

A prototype has been realized with a laser etching machine. A photography of the realized antenna prototype with its end-launch 1.81 mm southwest connector is given on fig. 4.

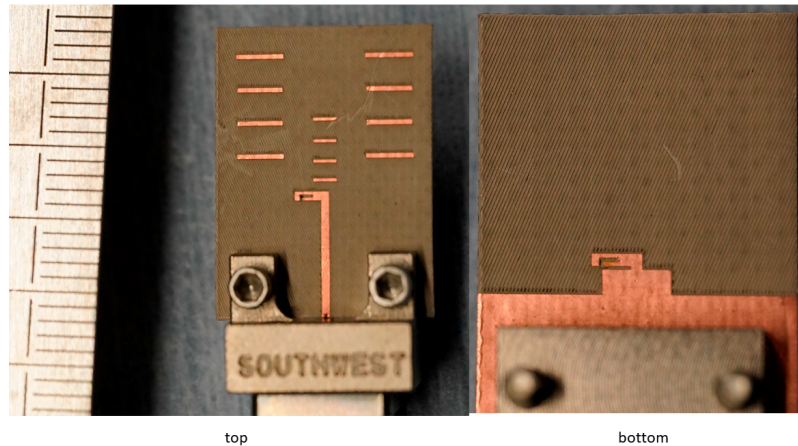


Figure 4: Photography of the realized antenna.

Measurements have been performed with a free space millimeter antenna test bench. Measurement and simulation results of matching and realized gain as a function of frequency are plotted on fig. 5. Antenna presents a 8.2 dB maximum gain in the first band and 8.0 dB in the second frequency band. Good matching is measured between 24.5 GHz - 28.5 GHz and between 48.5 GHz and 51.5 GHz. Simulations and measurements are in good agreement in the first frequency band but a mismatch of 2 GHz which represents a shift of 4.1% in frequencies operation is observed between measurements and simulations in the higher band. It should be due to the inaccuracy during the process of realization.

Measured radiation patterns in E plane at 25 GHz and 27 GHz are also in good agreement with simulations.

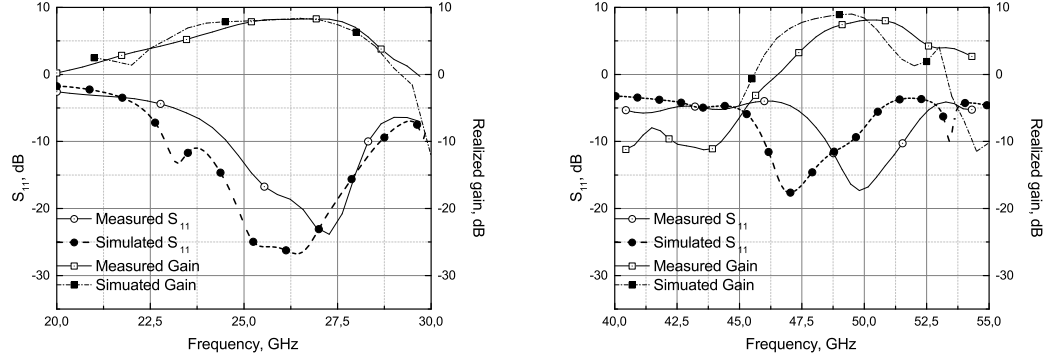


Figure 5: Comparison between measured and simulated realized gain and matching

Table 2: Measured performances of the dual band quasi Yagi Uda antenna.

parameter	simulated	measured	simulated	measured
bandwidth ($ S_{11} < 10$ dB)	23.5 GHz - 28.5 GHz	24.5 GHz - 28.3 GHz	46.0 GHz - 49.4 GHz	48.2 GHz - 51.5 GHz
maximum gain	8.0 dB	8.2 dB	8.5 dB	8.0 dB
3 dB beam-width (E plan)	44° (1) 34° (2)	42° (1) 32° (2)		30° (3) 32° (4)

Measured results show a front to back ratio higher than 16 dB at all measured frequencies and a 3 dB beam-width of 42° at 25 GHz, 32° at 27 GHz, 30° at 48.5 GHz and 32° at 50 GHz. Because of the mismatch between simulations and measurement, the simulated radiation patterns in E plane at 48.5 GHz and 50 GHz are not presented. All measured data are summarized in table 2.

4. CONCLUSION

In this paper a bi-band quasi Yagi-Uda antenna is proposed. It could be an alternative solution to ultra wide band antenna to address multi-frequencies 5G millimeter waves applications. Measurements shows 8.2 dB of gain in the lowest band and 8.0 dB in the highest frequency band. Good matching is measured between 24.5 GHz – 28.5 GHz and between 48.2 GHz and 51.5 GHz. The total surface of the antenna is 20x15 mm². This surface can be reduced if end-launch connector is not necessary. An important mismatch of 2 GHz frequencies operation is observed in measurement, in the higher band but the bi-band operation is obtained. A frequency mismatch of 1.5 GHz (6 %) is observed between simulations and measurements for the highest band.

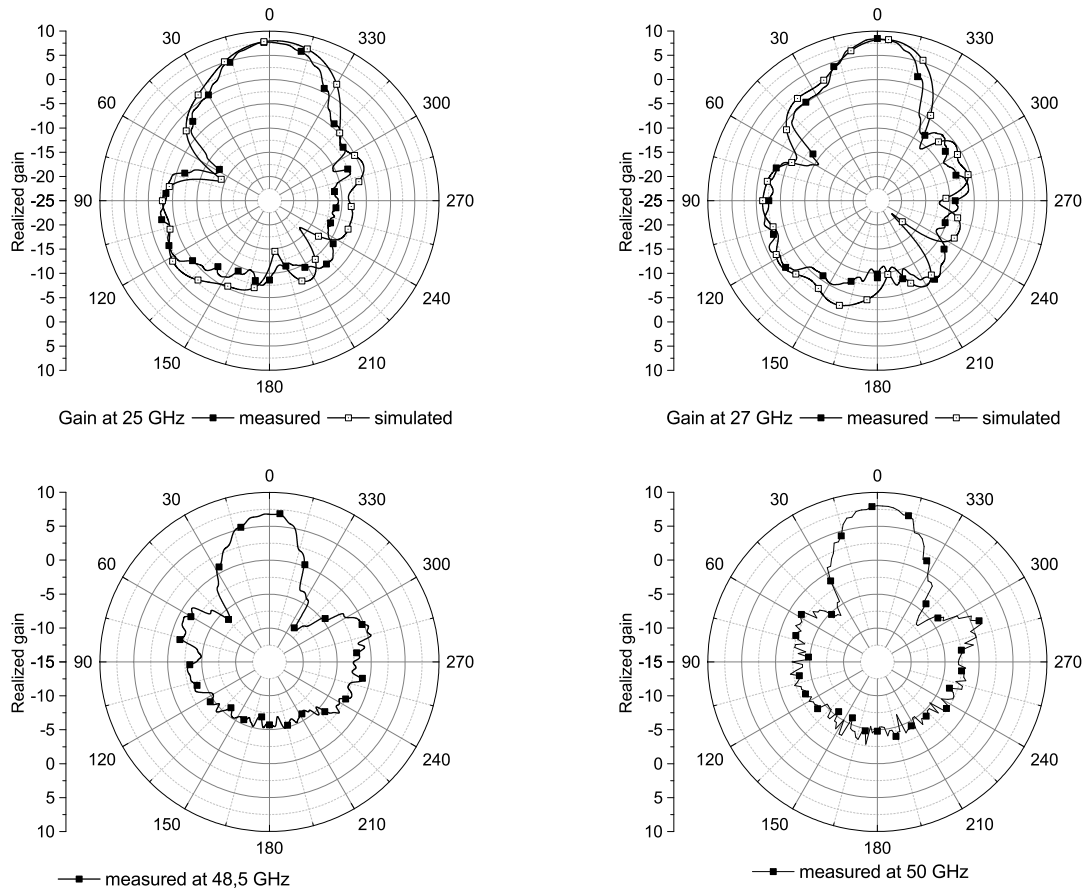


Figure 6: Radiation pattern (E plane) at 25 GHz, 27 GHz, 48.5 GHz and 50 GHz.

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