A Simplified Design Methodology for Hybrid Antenna for S-band Application

Ivaylo Nachev, Ilia Iliev

Abstract – **In this article is presented a simplified design methodology for hybrid antenna, a combination between the simple patch and Yagi-Uda antennas. These antennas are easy to design and manufacture, they come with sufficient bandwidth and high gain and adopt the benefits of both proceeding antenna types. They work with linear and/or circular polarization while also allowing integration of microwave devices into them. The proposed methodology has been tested and results from the process synthesis of a hybrid antenna for WiFi 2.4GHz are going to be further examined later in the article.**

Keywords – **Hybrid antenna, Patch antenna, Yagi-Uda antenna, Circular polarization, Suspended substrate, S-band, WiFi.**

I. Introduction

Classic Yagi-Uda antennas have a broad application in practice for their high gain, wide bandwidth (BW) and low cost, yet they are inefficient and difficultly implemented in frequencies higher than S-band (part of SHF band). The realization of circular polarization (CP) is difficult because it is associated with a change in the spatial distribution of the antenna elements and with the necessary of additional microwave devices. There are published different types Yagi-Uda antennas, allowing their use for higher frequencies - disks for antenna elements [1,2]. However, Yagi's feed network realization remains complex. In contrast, feed network design of patch antennas is easier to implement with linear or circular polarization than Yagi antennas [3]. They are widely used in systems working in S band or higher frequency band. The main disadvantage of patch antennas is their narrow BW and relatively low gain.

This article discusses a design methodology that combines the advantages of patch antennas and Yagi-Uda antennas. The synthesized antennas are easy to simulate and manufacture, have a reduced size and satisfactory characteristics. The methodology was checked. At the end of the paper simulated and measured result of simulation and fabrication of a hybrid antenna with application for 2.4GHz of WiFi standards is shown.

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Ivaylo Nachev, PhD student at the Faculty of Telecommunications at the Technical University of Sofia, 8 Kl. Ohridski Blvd, Sofia 1000, Bulgaria, E-mail: ivaylonachev@yahoo.com

Ilia Iliev, professor at the Faculty of Telecommunications at the Technical University of Sofia, 8 Kl. Ohridski Blvd, Sofia 1000, Bulgaria, E-mail: igiliev@tu-sofia.com

II. The Design Methodology

Patch and Yagi-Uda antennas are widely studied and have numerous designing methods [3-5]. The discussed methodology in this article combines elements of the design methods of both antenna types.

The hybrid antenna to be designed consists of patch antenna which is used as the antenna reflector and vibrator. Directors are borrowed from Yagi structures – Fig. 1.

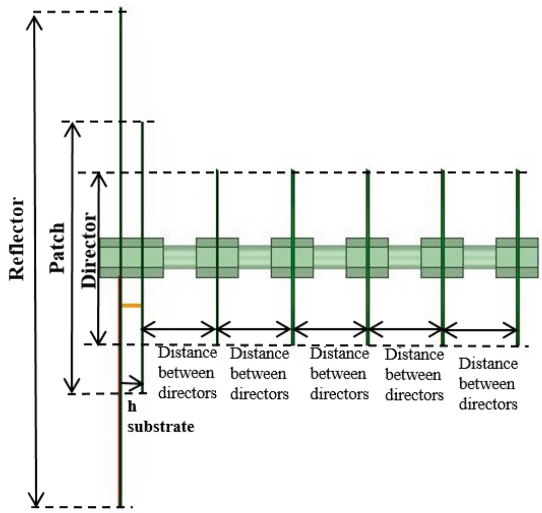

Fig. 1. Structure of the hybrid antenna with a suspended substrate

A patch antenna consists of three important elements: the ground plane, the radiating element and the dielectric substrate between them. Dielectric substrate is characterized by many electrical parameters (such as permeability and conductivity), but in this case the critical parameters are: height of the substrate h, relative dielectric constant ε_r and dielectric losses tanδ [4]. The simplified method for designing a hybrid antenna follows these formulas:

1. The wavelength in the dielectric substrate is:

$$\lambda_g = \frac{\lambda}{\sqrt{\varepsilon_r}} = \frac{c}{f_c\sqrt{\varepsilon_r}}, \quad (1)$$

where λ is the wavelength in free space;

2. The size of the radiating element is calculated as [6]:

$$L = W = \frac{\lambda_g}{2}. \quad (2)$$

For a circular shaped radiating element, the diameter of the patch is calculated by:

$$D_{Patch} = \frac{\lambda_g}{2}. \quad (3)$$

3. In case of need to improve the bandwidth and efficiency of the antennas, a design method called "suspended substrate" can be used. This method introduces equivalent dielectric constant ε_{req} , for which the required parameters are Δ - an air gap between the dielectric substrate and ground plane, h - a substrate height, and ε_r - dielectric constant of material [7]:

$$\varepsilon_{req} = \frac{\varepsilon_r \cdot (h + \Delta)}{\varepsilon_r + h \cdot \Delta}. \quad (4)$$

4. The patch form determines the ground plane (reflector) and the directors' forms. The length of the reflector is dependent on the specific case where the antenna is designed.

5. According Yagi-Uda design methods, size of directors should to be smaller than λ/4 [4,5]. For best antennas characteristics, the practice shows that length of the directors is in the interval [0.40λ(or λg)÷0.45λ(or λg)]. Using this, by optimizing the simulation and measurement of the model, it was found that the diameter of a directors can be reduced to the interval [0.35λ (or λg)÷0.45λ (or λg)].

6. At classical Yagi antennas distance between the directors is [0.3λ(or λg)÷0.4λ(or λg)] [2,8]. The engineering and research practice show that the antenna's frequency performance is not affected negatively and its radiation pattern is optimized when distance between the directors is 0.25λ [3,9,10]. In this methodology, the distances between directors are [0.25λ(or λg)÷0.4λ(or λg)]. It is not necessarily distance between all directors to be equal for optimum designs.

7. The centre of the radiating element is assumed to be the antenna's zero point. At this point the current distribution is zero. Therefore, the place is suitable for mounting elements (the mounting element may be conductive) that makes a galvanic connection between the antenna and the directors. From patch antenna theory, to obtain impedance 50Ω the feed point of the antenna should be approximately the half distance between an edge of radiation element and a zero point (coaxial feed probe method) [11]. The same principle is applied in this methodology. This make $0.25D_{Patch}$ or 0.25L (consistent with equation 2 and 3) from the antenna's centre.

The patch antenna feed point is easily designed for either linear or circular polarization (CP). To make CP it is necessary to add a second feed point to 90^O electric length towards the first feed point. Depending on which of the two feed points is given a direct 90^O phase shift signal the circular polarization can be either right hand circular polarization (RHCP) or left hand circular polarization (LHCP). For circular polarization a 3dB branch line coupler (BLC) is a suitable device for obtaining phase shift of 90^O [12]. Another suitable scheme is microwave circuit using phase shift circuits [13] and others. In Fig. 1, it is shown the configuration of the elements of such hybrid antenna and in Fig. 2 - the location of the feed points, capable of achieving circular polarization.

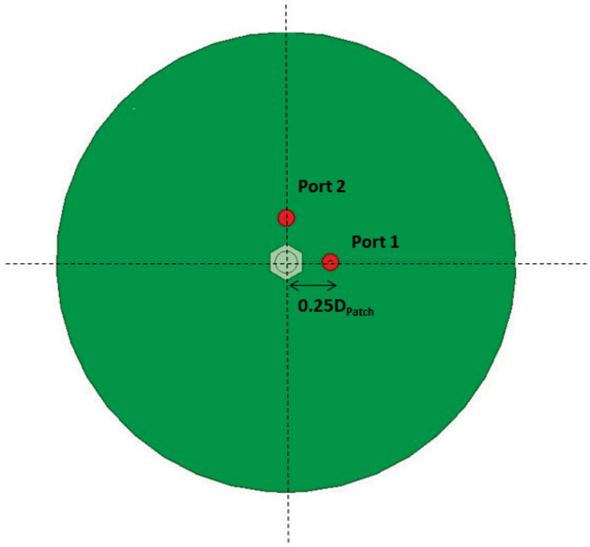

Fig. 2. The location of the feed points of the hybrid antenna for CP

III. Result of the Design and Measurement of Hybrid Antenna

According to the presented methodology, a seven element hybrid antenna was designed for central frequency f_C=2.4GHz and input impedance R_L=50Ω. The patch resonator can be implemented with a dielectric substrate of different type. For the designed antenna an air dielectric is chosen. Therefore the wavelength in dielectric substrate is equal of wavelength in free space. The radiation element is classic circular patch with suspended substrate, synthesized according to this methodology. The radius of the elements and the distance between them are given in Table 1. They are calculated with the given equals and considerations according to the previous point of the article. The dimensions thus calculated were used as a starting point for simulation research and tuning of the antenna characteristics using OpenEMS software.

In Table 1 also is given the dimensions of the antenna after simulation testing and tuning and those applied in its fabrication.

The design antenna can be used for obtaining linear or circular polarization. In order to obtain CP, it was additionally designed and constructed 3dB BLC for the operate antenna frequency. The type of circular polarization is determined by the shoulder of the bridge being used for antenna feed point. The second port of the bridge has a matched load – Fig. 3.

TABLE 1
GEOMETRIC DIMENSION OF THE ANTENNA ELEMENTS

Parameters	Calculate [mm]	Simulation optimized[mm]	Fabricated [mm]
Reflector radius	62.5	62.5	63
Patch radius	31.25	33.78	33.7
Dielectric substrate height	5	5	5
1st Director radius	21.875	21.875	22.8
Distance between patch and 1st director	31.25	31.25	31.2
Distance between directors	31.25	31.25	31.2
Distance between centre of patch and feed points	15	14	14
Reflector radius	62.5	62.5	63
Patch radius	31.25	33.78	33.7

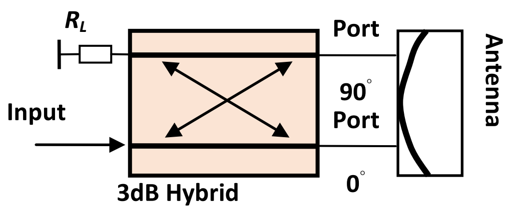

Fig. 3. The antenna feed network using 3dB BLC for circular polarization

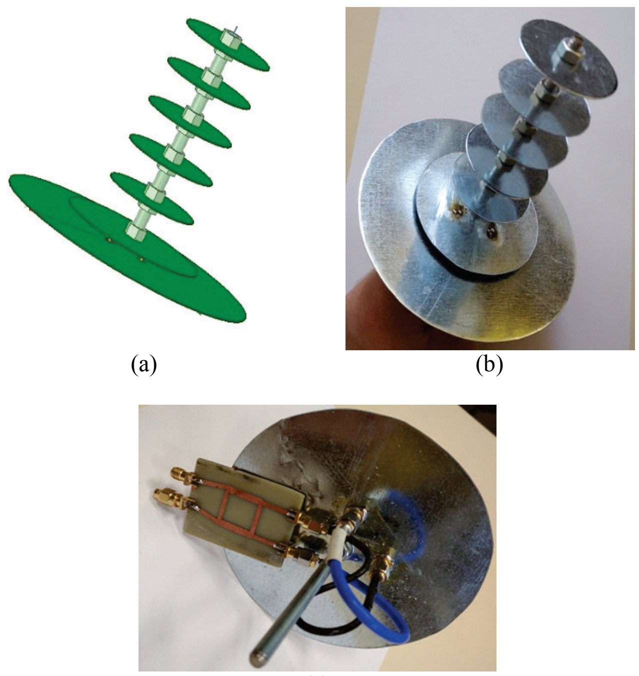
(a) (b) (c)
Fig. 4. (a) Simulation model of hybrid antenna, (b) Fabricated model of hybrid antenna, and (c) Feed network realization

Fig. 5 shows the S parameters of the simulated and realized antenna for the two feed points and the coupling coefficient between them.

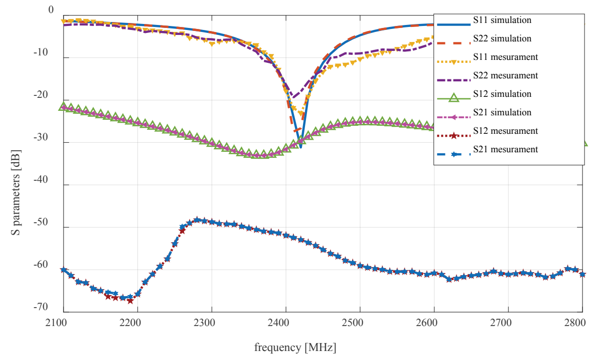

Fig. 5. S parameters of simulated and realized antenna

Using the idea from Fig. 3, BLC is integrated for feed network in the hybrid antenna. In this way the same antenna can work with circular polarization. Fig. 6 gives the measured S11 and S22 parameters for LHCP and RHCP.

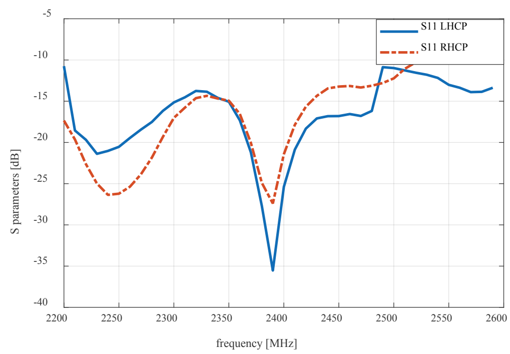

Fig. 6. Measured S11 parameters of the antenna with BLC feed network for CP

The simulation result gives that a seven-element hybrid antenna achieves a gain of 13dBi. This gain is comparatively greater than the gain of the seven-element classic Yagi-Uda antenna.

The manufactured antenna has possibility to work only with linear polarization. In this case one feed point is used. Normalized radiation pattern (RP) for linear polarization in H and E plane is given in Figs. 7-10. The measurement, presented in this article, was made for operating frequency 2.4GHz, performed by an automatic RP antenna measurement system [14].

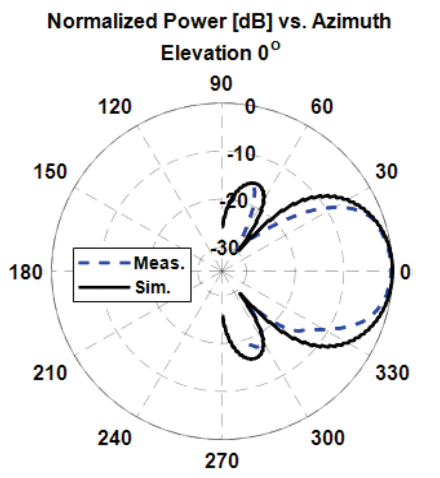

Fig. 7. Simulated and measured RP results in H-plane (azimuth) for linear polarization

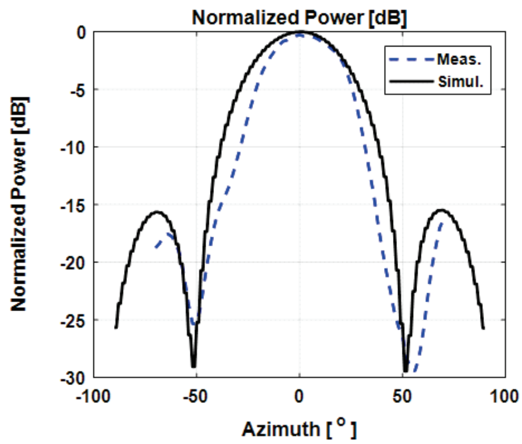

Fig. 8. Simulated and measured RP results in H-plane (azimuth) for linear polarization

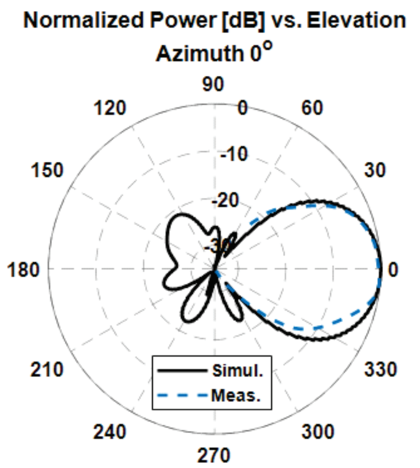

Fig. 9. Simulated and measured RP results in E-plane (elevation) for linear polarization

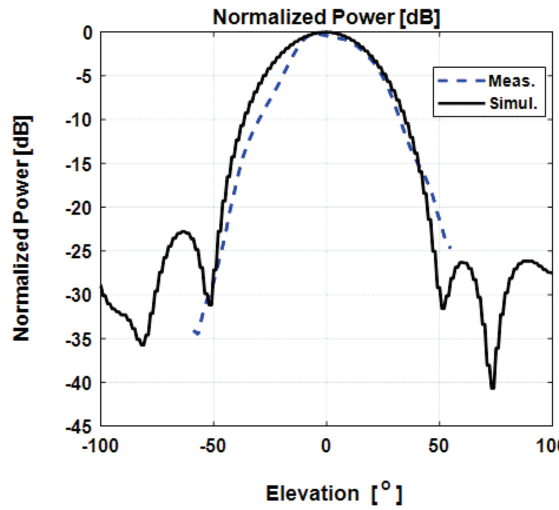

Fig. 10. Simulated and measured RP results in E-plane (elevation) for linear polarization

Figs. 11 and 12 present a comparison between simulated and measured results of a normalized radiation pattern for left hand circular polarization in H and E planes.

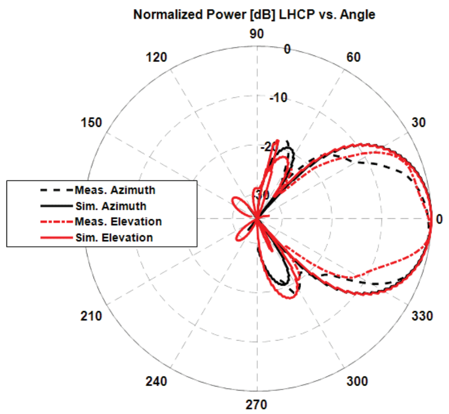

Fig. 11. Simulated and measured RP results in H and E planes for LHCP

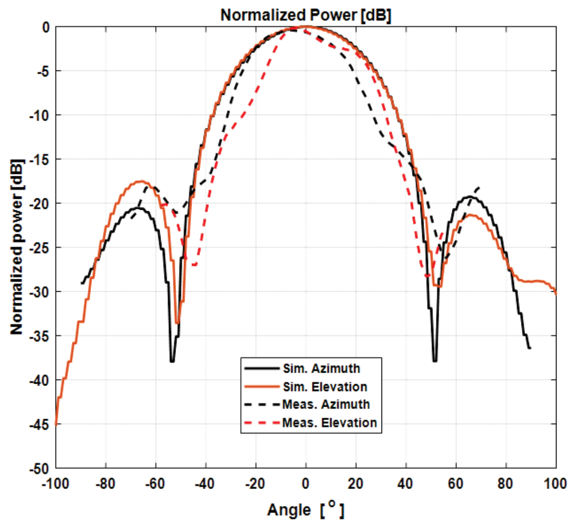

Fig. 12. Simulated and measured RP results in H and E planes for LHCP

In Figs. 13 and 14 are illustrated 3D measured RP.

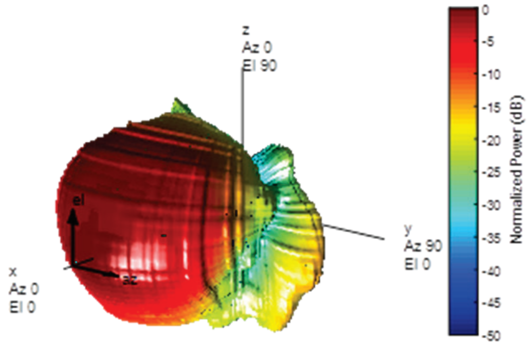

Fig. 13. Measured 3D linear polarized RP

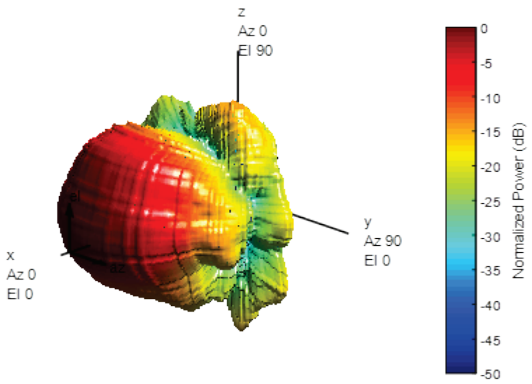

Fig. 14 Measured 3D RP for LHCP

IV. CONCLUSION

The proposed methodology allows the design of hybrid antennas, applicable not only for S-band, but also part of SHF band due to the combination of printed patch and Uda Yagi structures. The practical realization and the measured results prove that the designed hybrid antenna is of reduced dimensions, with sufficient bandwidth and amplification comparable to those of Yagi antennas. The hybrid antennas are easy and cheap for design and manufacturing with easy realization of linear or circular polarization and allow integration of other microwave devices into them. These type antennas can find wide application on different radio communications systems: WiFi, base station for mobile communications – 3G and 4G. The antennas can be integrated also in wireless cyber-physics M2M communication systems or can be used for coverage increasing of the UAV control systems and others.

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