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DESIGN AND CONSTRUCTION OF A YAGI-UDA TYPE MICROSTRIP ANTENNA WITH TWO DIRECTORS AT 1 GHZ

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Abstract: Microstrip antennas have currently had a great development in wireless communications, many devices of all kinds are connected to the Internet thanks to these antennas, due to this a wide variety of configurations have been developed from patch type to quasi-Yagi-Uda type. Due to their characteristics, microstrip antennas are made for high frequencies, they are designed with commonly complex methods and, using specialized software, their construction is simpler. This work describes the design and construction of a Yagi-Uda type microstrip antenna with two directors at 1 GHz on an FR4 plate based on the calculation of a patch antenna. The measurements of the antenna parameters were carried out with a nanoVNA and with the nanoVNA software Saver, and the results show that the design coincides with the measured values, a VWSR of 1.29, a return loss of -17.82 dB and the reflection coefficient of 0.126 were obtained at a frequency of 1 GHz.

Keywords: Yagi-Uda antenna, microstrip, antenna parameters, vector network analyzer.

INTRODUCTION

Wireless communication is generated with a radio frequency signal through a transmitter, sending it into free space so that after a while a receiver captures it. The interface between the transmitter and free space, and between the latter and the receiver, is the antenna.

At the transmitter end the antenna converts radio frequency energy into electromagnetic signals capable of propagating over long distances; at the receiver end, the antenna captures the electromagnetic signals, converting them into electrical signals. There is a wide variety of types of antennas used in radio communications and all are based on the same concepts of electromagnetic theory.

The electromagnetic wave is energy radiated by the transmitting antenna and collected by the receiving antenna. It is composed of two fields: one of an electrical nature, which is the electric field **E,** whose intensity is measured in volts/meter and its lines of force are parallel to the conductor. radiator, and the other field of magnetic nature, which is the magnetic field **H,** whose intensity is measured in amperes/meter and its lines of force are perpendicular to the radiator conductor.

The *Institute of Electrical and Electronics Engineers* (IEEE) defines an antenna as that part of a transmission or reception system designed specifically to radiate or receive electromagnetic waves. Although their shapes are very varied, all antennas have in common that they are a transition region between an area where there is a guided electromagnetic wave and a wave in free space, to which a directional character can also be assigned. The representation of guided waves is done by voltages and currents or in free space by fields.

On the other hand, microstrip is probably the most successful and revolutionary antenna technology in history. Its success comes from well-known advantages, to name a few: compact, easy to build and low cost. However, it also has some limitations, the most well-known of which are narrow bandwidth, narrow impedance, low axial ratio (AR), small gain, power handling capacity and low efficiency; For this reason, different techniques have been developed to increase bandwidth. The microstrip antenna was conceived by Deschamps in 1953 in the United States. In 1955, Gulton and Bassinot in France patented the “flat” antenna that was used in the UHF region. The construction of the microstrip radiator was not active until the early 1970s [4].

Du Preez et al (2016), comment in a follow-up on microstrip antennas that these dates back to the 1950s, but technical interest began in the 1970s. They are very compact antennas that in arrays of hundreds of them can be grouped into panels with certain applications. Patch antennas are designed to radiate energy over one side in such a way that the main beam or lobe is orthogonal to the patch. It is made up of a substrate on a ground plane, at the top the antenna is usually made of copper with a thickness of 35 μmeters with different configurations and at the bottom the ground plane.

Mohammed et al (2019), assume that taking into consideration, the assumptions of the near future, data hungry devices (smartphones, tablets, sensors, etc.) will lead to a shortage of bandwidth. Therefore, the advancement of wireless networks is essential. 5G technology employs high frequency bands and wide signal bandwidth to increase bit transmission rates, thus providing better coverage with low battery consumption.

In the last fifteen years, microstrip patch antennas (*Microstrip patch Antenna,* MPA) are the fastest developing systems in the antenna field. They have received creative attention from researchers around the world and several patents, articles or books have been published. In addition, multiple symposium sessions and short courses have been held. As a result, MPAs have rapidly evolved from an academic novelty to a commercial reality with applications in a wide variety of microwave systems.

Also Mohammed et al (2019), state that the electrical performance of basic MPAs or arrays thereof suffers from several serious drawbacks, for example, narrow bandwidth, high power network losses, poor cross-polarization and low power handling. Consequently, in recent years, many antenna designers have paid considerable attention to improving various features of MPAs along with specific applications such as millimeter wave, worldwide interoperability for microwave access (WiMAX), wireless local area network (WLAN). and ultra-wideband (Ultra-Wideband, UWB) [4].

Run Nan et al (2012) comment that the quasi-Yagi-Uda antenna was proposed by Quian et al in 1998 and currently continues to be a challenge in antenna research activities. In their work they propose a two-array printed director antenna with compact structure fed by a balanced slotted microstrip transmission line, according to the simulation in CTS Microwave Studio.

The operating bandwidth was 1.8 to 3.5 GHz with a reflection coefficient less than -10 dB, the gain was 4.5 to 6.8 dBi and the full magnitude of the antenna was smaller than.34 λ*.58 λ. They additionally mention that the arrangement allowed a gain of 2 dB greater than a single antenna.

Sun et al (2012) describe that in recent years microstrip antennas can be configured as Yagi-Uda arrays. Furthermore, they mention that John Huang (1991) in his work proposes a new antenna structure that is formed by a combination of the Yagi-Uda array concept and the microstrip radiator technique. The Yagi-Uda antenna consists of a fed patch element, another that serves as a parasitic reflector and two or three patches that serve as directors.

Yagi-Uda antenna design with a cover on the directors, they show the antenna design of three directors with and without a cover, and determine that the length values change, with those with a cover being longer. The results obtained allow them to conclude that this type of antenna can work together with others since its cover does not interfere with the radiation pattern of the others. This proposal was simulated in CTS Microwave Studio.

Gordón et al (2016) designed a 5.8 GHz microstrip Yagi-Uda antenna with four director elements under two calculation approaches: one on tables and two according to mathematical equations. They compare the results of both approaches and show that they are almost similar in terms of the gain of 9.27

dB and the directivity of 9.39 dBi, where they differ is in the reflection coefficient and the standing wave ratio (*Voltage Standing Wave Ratio,* VSWR). The antenna was simulated with the CTS software and it is assumed that the values obtained for directivity and gain differ from the simulation because the software libraries contain values of dielectric constants different from those existing on the market.

For the analysis of microstrip antennas there are several models that can be used: the transmission line model, cavity, full wave analysis, among others. The transmission lines model is the simplest but with less precise results.

Uribazo et al (2013) mention that the first step to design a microstrip antenna is to choose the correct substrate for its mechanical support. For this support, the substrate must be made of a dielectric material, which can affect the electrical performance of the antenna, circuits and transmission line, therefore, it must simultaneously satisfy the electrical and mechanical requirements, which is sometimes difficult to achieve. find.

The choice of substrate and its evaluation are an essential part of the design process. Many properties must be considered, the dielectric constant, the loss tangent, its variation with frequency, temperature, homogeneity and uniformity of the substrate thickness are some of the most important. There is no ideal substrate, your choice depends on the applications. For example, for low frequencies, high dielectric constants are required that maintain a small size of the antenna.

Balanis (2015) mentions that the effective dielectric constant is a function of frequency, as the operating frequency increases the majority of the electric field lines are concentrated on the substrate. Furthermore, the microstrip line behaves as a homogeneous line of a dielectric only from the substrate and the effective dielectric constant approaches the value of the dielectric of the substrate. The typical variations as a function of frequency of the effective dielectric constant for a microstrip line with three different substrates are shown in Figure 1.

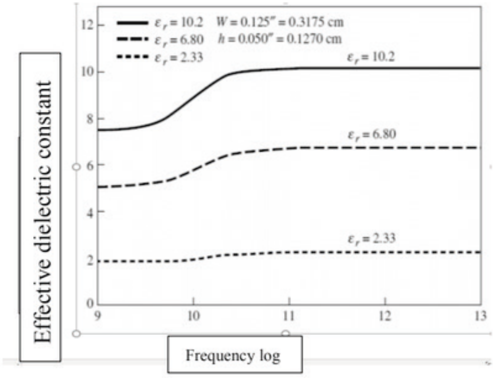
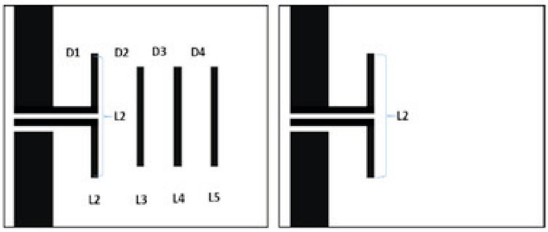


Figure 1. Behavior of the effective dielectric constant against frequency. Source.

Based on Figure 1, for low frequencies the effective dielectric constant is essentially constant, for intermediate frequencies its value is monotonically begins to increase and eventually approaches values of the dielectric constant of the substrate.

Yagi-Uda type microstrip antenna like the one shown in Figure 2, where he suggests that the dipole must be in the center.



Yagi-Uda microstrip antenna proposed by Flores (2017). Source.

Finally, it can be said that microstrip antennas will continue to develop, with the patch antenna being fundamental, which serves as a basis for other configurations such as the Yagi-Uda type as mentioned by Sun et al (2012), therefore, it is interesting to describe a design process that allows obtaining results close to those of construction such as the one presented here using the one proposed by Flores (2017) as the antenna template, although it must be noted that there are more options.

DEVELOPMENT

For the development of the two-director Yagi-Uda antenna, the following methodology was followed:

- Documentary research
- Radiation frequency proposal
- Antenna design
- Materials selection
- Construction of the microstrip antenna
- Characterization of the constructed microstrip antenna
- Testing and analysis of results
- Conclusions

DESCRIPTION OF ANTENNA DESIGN AND CONSTRUCTION

According to Fatthi (2011), the design of a patch antenna begins with the calculation of the wavelength from the transmission frequency. For this case, an FR4 PCB was used with a relative permittivity of =4.6, h=1.2 mm and at a frequency of 1 GHz, with Equation 1 the wavelength was determined, being equal to 300 mm (Fatthi Alsager, 2011) :

$$\lambda = \frac{c}{f} \qquad \text{Ec. 1}$$

Where:

λ: Wavelength in meters

c: Speed of light 3*108 mts / sec

f: Design frequency in Hertz

Next step, the width of the patch was obtained using the relative permittivity of the substrate as indicated in Equation 2, substituting the values, W =.08964 meters.

$$\mathrm{w} = \frac{\mathrm{c}}{2\mathrm{f}_0} * \sqrt{\frac{2}{\epsilon_\mathrm{r} + 1}} \qquad \text{Ec. 2}$$

$$\mathrm{w} = \frac{3 * 10^8}{2(1 * 10^9)} * \sqrt{\frac{2}{4.6 + 1}} = .08964\ mts$$

For the effective permittivity, Equation 3 was used, substituting the values, an effective permittivity of 4.58 was obtained dimensionless:

$$\epsilon_{ef} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} * \frac{1}{\sqrt{1 + 12 * \frac{h}{w}}} \qquad \text{Ec. 3}$$

$$\epsilon_{ef} = \frac{4.6 + 1}{2} + \frac{4.6 - 1}{2} * \frac{1}{\sqrt{1 + 12 * \frac{.125cm}{8.964\ cm}}}$$

The additional length was obtained with Equation 4, substituting the values, the additional length was equal to :

$$\Delta \mathrm{L} = h(.412) \left[\frac{(\epsilon_{ef} + .3)\left(\frac{w}{h} + .264\right)}{(\epsilon_{ef} - .258)\left(\frac{w}{h} + .8\right)} \right] \qquad \text{Ec. 4}$$

$$\Delta \mathrm{L} = (.125)(.412) \left[\frac{(4.58 + .3)(\frac{8.964}{.125} + .264)}{(4.58 - .258)(\frac{8.964}{.125} + .8)} \right]$$

Using Equation 5, the final length of the patch was calculated, substituting the values to obtain 6.88 cm.

$$\mathrm{L} = \frac{\lambda}{2} - 2\Delta\mathrm{L} = \frac{\mathrm{c}}{2\mathrm{f}_0\sqrt{\varepsilon_{ef}}} - 2\Delta\mathrm{L} \qquad \text{Ec. 5}$$

$$\mathrm{L} = .070 - .01154 = .0688\ \mathrm{mts} = 6.88\ \mathrm{cm}$$

This effective length was used as the length of the dipole according to Sreelakshmi (2018) who also proposes the following formulas for calculating the length and space between directors that coincide with Run- Nan (2012) (Run-Nan et al., 2012; Sreelakshmi et al., 2018) :

$$\mathrm{D_L} = .8(\mathrm{L}) \qquad \text{Ec. 6}$$

$$\mathrm{D_L} = .8(6.88\ \mathrm{cm}) = 5.5\ \mathrm{cm}$$

This is the length **D** $_L$ for each of the two directors, in the same way Equation 7 was used to calculate the separation distance between director-dipole and director-director.

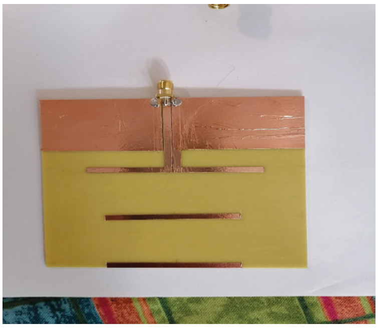
$$D_d = .4(L) \qquad \text{Ec. 7}$$

$$D_d = .4(6.88\ \text{cm}) = 2.75\ \text{cm}$$

The dimension of the reflector was 2.5 cm wide and from it to the dipole there is a distance of 1.5 cm, in addition the separation between the reflector arm and the dipole arm there is a separation of 1 mm, all tracks have a width of 3 mm.

TESTS AND RESULTS

Figures 3 and 4 show the microstrip antenna built with transmission line feed on a 10*10 cm pcb and with an SMA connector (Sub-miniature A) at 50 Ohms on a plate with relative permittivity of 4.6. The measurements were performed with a nanoVNA (*Vector Network Analyzer)* as it can be seen in Figure 5.



Yagi-Uda type microstrip antenna with two directors, transmission line feed and SMA connector. Own source

Figure 4. Antenna ground plane. Source: self made

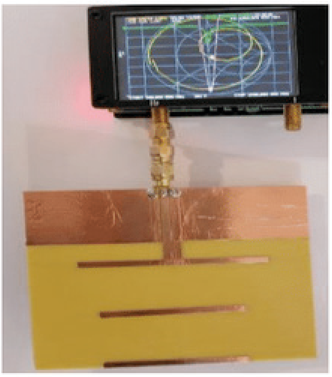


Figure 5. Measurement of antenna parameters with nanoVNA. Source: self made

The measurement of the antenna parameters was carried out with the nanoVNA whose bandwidth is 3 GHz. Before measuring, it was first calibrated from a frequency of 500 MHz to 1500 MHz, the results obtained show that the antenna is tuned to 1 GHz, with return loss of -17.82 dB, with a VSWR of 1.29 and a reflection coefficient of 0.126 as indicated in Figures 6, 7 and 8.

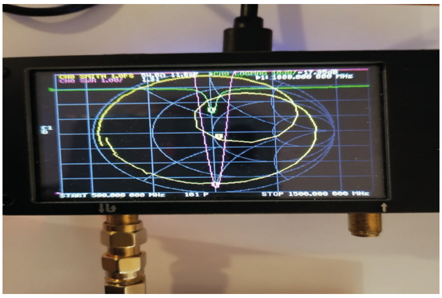


Figure 6. Measurement of VSWR, reflection and return loss coefficient and antenna tuning frequency with nanoVNA. Source: self made

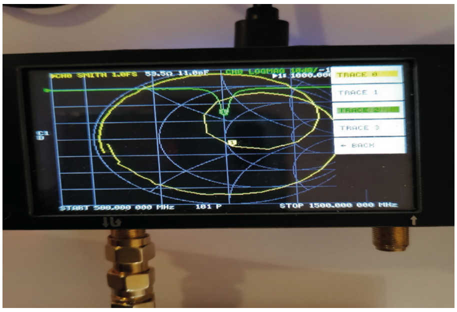


Figure 7. Smith chart showing tuning of the Yagi antenna at 1 GHz with the nanoVNA. Source: self made

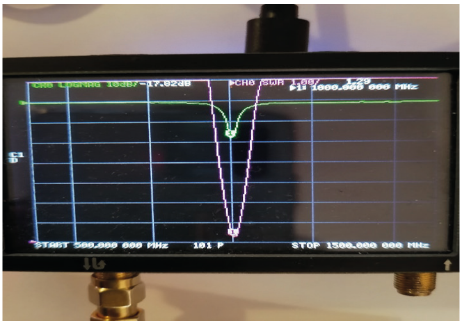


Figure 8. Return loss of -17.82 dB and VSWR of 1.29 at a frequency of 1 GHz of the Yagi-Uda antenna with the nanoVNA. Source: self made

The nanoVNA software was also used Saver on the computer that is attached with the nanoVNA the results were similar and valid as the nanoVNA (see Figure 9), in it, the antenna measurement can be identified with the results in the graphs.

For a better visualization of the results, the graphs in Figure 9 were disaggregated. The values of the measurement parameters of the constructed microstrip antenna are shown separately in Figures 10, 11, 12 and 13.

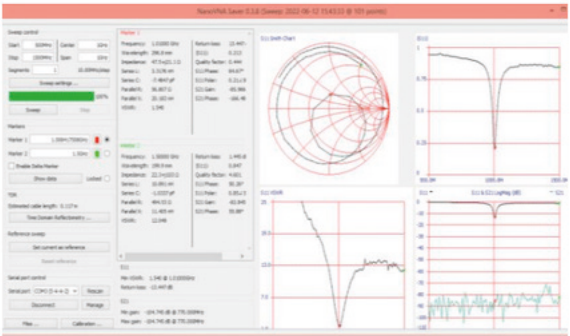
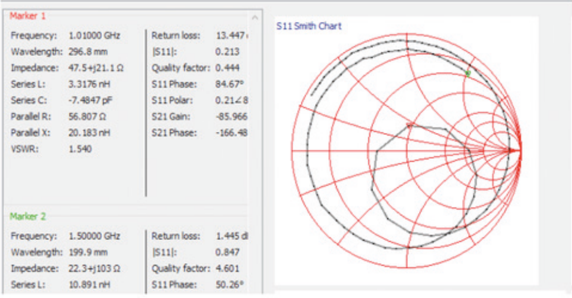


Figure 9. Measurement results of Yagi-Uda type microstrip antenna at 1 GHz with nanoVNA software Saver. Source: self made



Marker 1
Frequency: 1.01000 GHz
Wavelength: 296.8 mm
Impedance: 47.5+j21.1 Ω
Series L: 3.3176 nH
Series C: -7.4847 pF
Parallel R: 56.807 Ω
Parallel X: 20.183 nH
VSWR: 1.540
Return loss: 13.447
|S11|: 0.213
Quality factor: 0.444
S11 Phase: 84.67°
S11 Polar: 0.21∠8
S21 Gain: -85.966
S21 Phase: -166.48

Marker 2
Frequency: 1.50000 GHz
Wavelength: 199.9 mm
Impedance: 22.3+j103 Ω
Series L: 10.891 nH
Return loss: 1.445 d
|S11|: 0.847
Quality factor: 4.601
S11 Phase: 50.26°

Yagi-Uda type microstrip antenna at 1 GHz. Source: Own elaboration

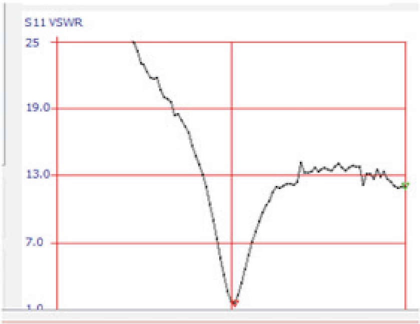
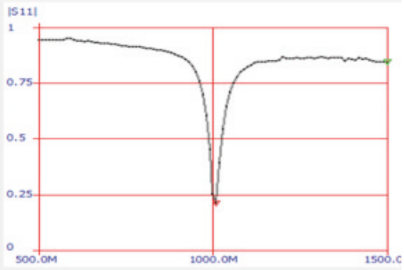
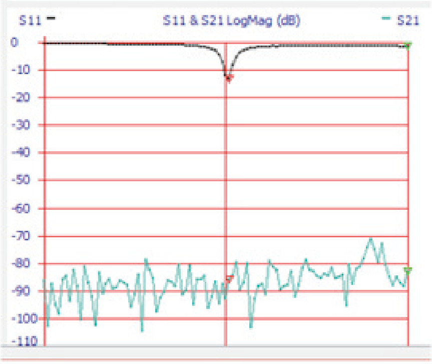


Figure 11. Graph of the VSWR result which is 1.54 for the built microstrip antenna. Source: self made



Yagi-Uda type microstrip antenna at 1 GHz. Source: Own elaboration



Yagi-Uda type microstrip antenna at 1 GHz. Source: Own elaboration

Likewise, it can be seen in Figure 9 that the impedance Z given by the resistance and reactance is 53.5 and -j11.8 Ohms showing the tunability for 50 Ohms. It can be said with respect to the Standing Wave Ratio SWR in English VSWR that the value of 1.54 in the computer and 1.29 with the nanoVNA at the frequency of 1 GHz is acceptable, as suggested by Darimireddy (2015), who mentions a recommended value less than 2. Formula 8 indicates the reflected power, an SWR value less than 2 implies a reflected power less than 10%, that is, 90% of the energy is transferred from the source to the load.

$$P_r = \Gamma^2 P_i \quad \text{Ec. } 8$$

Where:
Pr: Reflected power in watts
Pi: Incident power in watts
Γ: The dimensionless reflection coefficient

CONCLUSIONS

Yagi-Uda type microstrip antenna with two directors at 1GHz was designed and built, based on the calculation of a patch antenna.

The antenna was built and its parameterization was obtained through a nanoVNA and also with the nanoVNA software Saver on the computer, although there is a small difference, the measurements are very close and both valid, this is because when the computer is used the nanoVNA is calibrated again.

The graphs of measured results with respect to the proposed design can be considered good, since considering the PCB board (Printed circuit Board) FR4 the relative permittivity provided by manufacturers ranges from 4.2 to 4.6. Furthermore, this also varies with frequency.

In the tests carried out it was found that the separation of the reflector and dipole affects the tuning result of the antenna, in this project a value of 1.5 cm was used, and the antenna was tuned to 1 GHz. Which suggests taking this into consideration, . distance, as well as the separation of the directors, the length and width of the ground plane.

It can be said that the results are satisfactory since the measurements of the microstrip antenna with the software on the computer show a tuning frequency of 1 GHz with a VSWR of 1.54 and return losses of -13.47 dB and a reflection coefficient of 0.213 and with the nanoVNA a tuning at 1 GHz, VSWR of 1.29 and a return loss of -17.82 dB with a reflection coefficient of 0.126.

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