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Experimental Analysis of Quasi-Yagi Antenna Shapes

Abstract. *In this work, a broadband quasi-Yagi antenna is presented and its shape design is changed to analyse new characteristics and properties for wireless communications. This microstrip-fed antenna is designed in five different shape versions: dipole driver, patch driver, meander driver, log-periodic director array, and multi-director array. Details of the proposed designs and measured results of input return loss and radiation pattern are presented and discussed. In addition, a technique using a microwave link to measure the radiation pattern is explored, showing good radiation characteristic of the elements in a real environment.*

Streszczenie. *Przedstawiono analizę i projekt nowej anteny szerokopasmowej typu Yagi przeznaczonej do komunikacji bezprzewodowej. Antenę zaprojektowano w pięciu różnych wersjach kształtu. Przedstawiono wyniki badań tych propozycji. (**Analiza eksperymentalna pięciu szerokopasmowych anten typu Quasi-Yagi**)*

Keywords: Wireless communication, planar antenna, quasi-Yagi antenna, driver, directors.
Słowa kluczowe: Komunikacja bezprzewodowa, anten typu quasi-Yagi.

Introduction

Modern wireless communications permit to live and work differently from the conventional, offering us flexibility and mobility, which is reflected into many aspects involving the world. The current wireless communications consist of a vast amount of technologies, including: Mobile cell system, Mobile personal services, Satellites, Specialized mobile radios (used by the police, fire brigade, army, etc), and WLANs.

In recent years, the need of wireless communications has grown with exponential rate and the antenna design has developed itself, searching wideband and better radiation pattern characteristics. With the rapidly development of 3G and 4G technology and the growth of the market for their equipments, the seeking for antenna technical solutions has increased a lot for these applications. The antennas used in these systems represent a fundamental role in its performance and have been regarded as critical elements. For a viable technical and economical operation, the characteristics of them should have specific requirements such as light weight, low cost, and easy construction. Planar antennas can provide these requirements and they have as main advantage the fact that they are readily integrated with microwave circuit components. However, these elements present serious restrictions due to their narrow operation range [1]. For instance, the microstrip patch antenna [2, 3] is typically narrow-band, although broadband performance can be accomplish by employing multi-layers structures with aperture coupling.

A new class of uniplanar antennas, called quasi-Yagi antennas, was introduced as a class which presents better characteristics than the other ones [4, 5]. These characteristics include both the compactness of resonant-type antennas and broad-band characteristics of travelling-wave radiator. Its design is based on the classic Yagi-Uda dipole antenna, being proposed at the first time by Qian *et al.* [6] and since then explored in several papers [7, 4, 8, 9]. Its bandwidth can satisfy, after optimized, more than 40 % and its radiation pattern shows excellent characteristic over a wide frequency band.

In addition to the dipole driver (QY), a geometry innovation is made seeking other viable shapes [10, 11, 12, 13, 14, 15, 16, 17]. Specifically in this work, two distinct shapes were built and tested for the antenna driver: one of them with two patches (PY) and the other in a meander shape (MEY).

Other tests were also executed in relation to the number and length of the director of the quasi-Yagi antenna, designing an array of directors in a log-periodic configuration (LGY) and the other in a multiple configuration (MY). An analysis to verify the influence of the geometric shape of the driver and the directors was executed by bandwidth and the radiation pattern simulation and measurements.

In this way, many simulations have indicated the design directions and the fabricated prototypes have shown the desired features and properties. The fabrication details, results, and analysis are presented and all antennas follow the same aim, that is, optimized bandwidth for operation from 1.85 to 2.7 GHz.

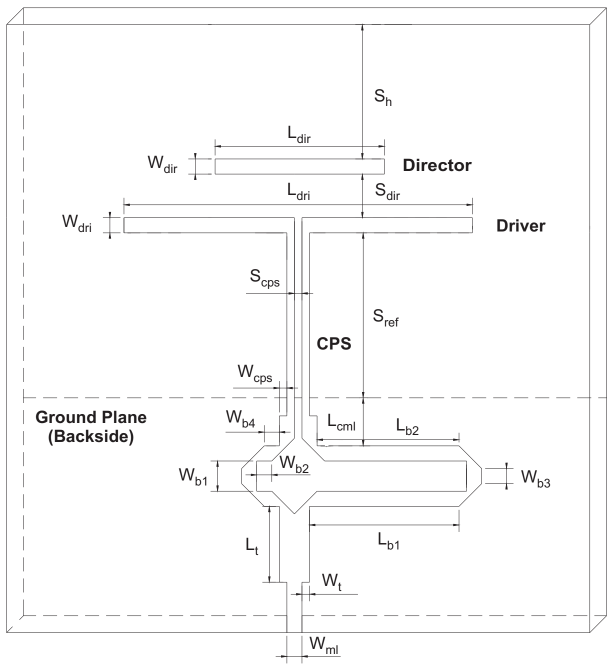


Fig. 1. Schematic of the quasi-Yagi antenna with dipole driver.

This work is organized as follows: In Section 2, the different shapes proposed are shown and designed. In Section 3, their input return loss measured results are compared with simulated and their mainly characteristics are presented. Also, in Section 3, it is described the radiation pattern simulation and measurements at anechoic chamber and at a microwave link. Finally, the section 4 concludes this paper.

Quasi-Yagi Antenna Shapes Design

In this work, the antennas are designed using QFDTD90 method code. The FDTD simulation box dimensions, in terms of wavelength at 2.4 GHz, were approximately 0.573λ x 1.208λ x 0.898λ. The FDTD cell sizes were chosen to be Δx = λ/235 = 0.533 mm, Δy = Δz = λ/262 = 0.476 mm at 2.4 GHz.

The top metallization consists of microstrip feed, two microstrip arms, driver, and director elements (variables), while the bottom metallization is a truncated ground plane used as a reflector element. A half wavelength delay (33 mm at 2.4 GHz) introduced in one of the the two microstrip arms (balun) is required to obtain the odd mode coupling [18]. The total substrate area is 104 x 106 mm. The structures are fabricated on FR-4 substrate with $\varepsilon_r = 4.8$, 1.6 mm-thick, $\delta = 0.018$, and metallization on both sides.

Besides the quasi-Yagi dipole driver, four different shapes are developed and tested as possible candidate to change it on quasi-Yagi antenna. Each shape has a owner characteristic and a different calculate technique. Fig. 2 shows the fabricated prototypes with five different shapes.

To facilitate the design and to establish a more precise comparisons among the characteristics of various shapes, the quasi-Yagi antenna with dipole driver was previously optimized, and then, utilized as reference. After that, happened the substitution of the driver and directors, and then, a new round of optimization for each new shape is made.

0.1 Dipole Driver

It can obtain reasonably good initial dimensions for the length of the dipole driver element being equal λ_g. For the length of the director element, a good initial length is $\lambda_g/2$ [19]. The director element length is shorter than the classical Yagi-Uda antenna design and this contributes to the antenna wideband characteristic.

After many interactions, through trial and error method, the optimized schematic of the quasi-Yagi antenna is shown in Fig. 1, and its dimensions are (unit: mm): $W_{ml} = W_{dri} = W_{dir} = 2.86$, $W_t = 1.27$, $W_{cps} = 1.35$, $W_{b1} = 5.40$, $W_{b2} = W_{cml} = W_{b4} = 2.70$, $L_{dri} = 30.50$, $L_{dir} = 30.30$, $L_{b1} = 26.75$, $L_{b2} = 25.40$, $L_{b3} = 5.35$, $L_t = 13.55$, $S_{dir} = 7.80$, $S_{ref} = 29.50$, $S_{cps} = 1.35$, and $S_h = 24$.

For the other proposed antennas, the dimensions are identical of this, except for the driver and directors, that can be easily found by analyzing the Fig. 2, due to its proportional dimensions. The antenna being tested is shown in Fig. 2(a), where it can be observed the dipole driver structure of the fabricated prototype.

0.2 Patch Driver

The first alternative design is a pair of planar patch elements instead of dipole driver [20]. The name patches is due to the square approach shape at the each monopole, but precisely for patch configuration, a ground plane is required and, in this case, the square patches operate without ground plane under them. In spite of this, the name is keeping due to the easy identification.

Firstly, the patches were designed with length equal to half a dipole driver and the width equal to the length, acquiring a square shape. Many simulations have shown that the length may be larger, about 15%, while the width is kept equal. The antenna being tested is shown in Fig. 2(b), where it can be observed the patch driver structure of the fabricated prototype.

The impedance matching, in theory, could be refined using the inset feed technique for the patch elements, but different from the isolated patch antenna, the use of inset feed does not improve the performance. Simulation with this technique shows a bad impedance matching, thus it maintain the patch structure without inset feed.

0.3 Meander Driver

To facilitate the design and optimization, the linear structure of the driver is folded into many sections with the distances between adjacent lines equals to the width of the lines, except for the meander line adjacent to the CPS line which has a higher value to compensate the smaller CPS line width, in this way, assuring a symmetric structure [21].

If a conventional dipole size is L and a dipole in a meander shape has the size of l, the reduction factor β is designated by $\beta = l/L$ [22]. The driver length of the quasi-Yagi antenna reference is $L_{dri} = 62.43$ mm, but now in the meander configuration is 20.03 mm. This result is due to addition of $3W_{dri} + 2S_{dri1} + S_{dri2}+$ to the width of the CPS line that is 1.43 mm. Thus, the β factor is 0.66, which represents a reduction of $\approx$ 35% into the structure. It is an excellent result, totally coherent for the use of the meander configuration, that generates a reduction of the physical length in the order of 24 to 40% [22]. The antenna being tested is shown in Fig. 2(c), where it can be observed the meander driver structure of the fabricated prototype.

Due to this folding of the element, the capacitance and the inductance per length unit are increased, this way reducing the propagation speed in the driver meander, which is what provides the length reduction in relation to the dipole.

0.4 Log-Periodic Director Array

Another modification made on the structure of the QY antenna is the addition of two more directors. Two configurations were chosen: the first one, presented in this subsection, as a log-periodic director array and a simpler one in the shape of a multi-director, presented on the following subsection.

There are several publications that show how to design and determine the characteristics of the set of radiated log-periodic dipoles in free space [23, 24, 25]. On the other hand, there are few studies on antennas using the printed geometries on microstrip [26].

The log-periodic array has the proportionality formulation [26] shown in Equation 1.

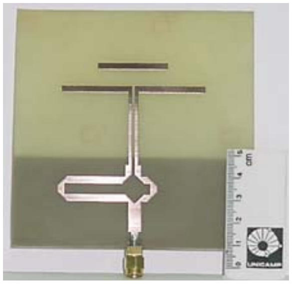
(1)
$$\frac{1}{\tau} = \frac{L_1}{L_2} = \cdots = \frac{L_n}{L_{n+1}} = \frac{S_1}{S_2} = \cdots = \frac{S_n}{S_{n+1}} = \frac{W_1}{W_2} = \cdots = \frac{W_n}{W_{n+1}}$$

Using the Equation 1, it is founded the initial values for the antenna design, later having more appropriate values.

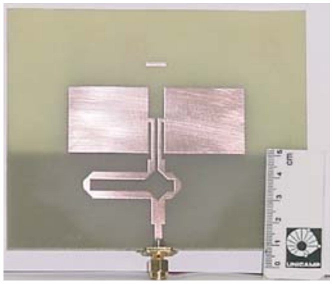
In practice to simplify the construction, the width of the elements are the same of QY antenna, and this does not compromises the performance of the structure. Another simplification that is done to the structure is the use of equal distances between directors, this way, the log-proportionality is only applied to the lengths of the directors.

Having all these values, it can be found all commonly referred antenna parameters in the log-periodic configuration [26]:

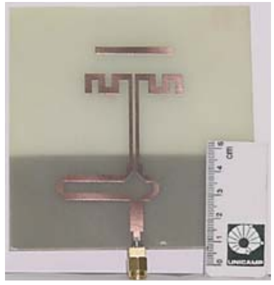
$$\sigma = \frac{S_n}{L_n} \quad ; \quad \alpha = \tan^{-1}\left(\frac{1-\tau}{4\sigma}\right) \tag{2}$$



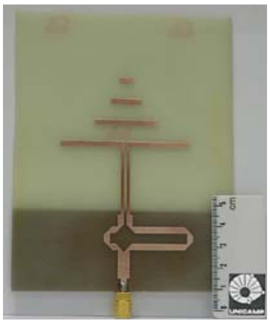
(a) Dipole Driver



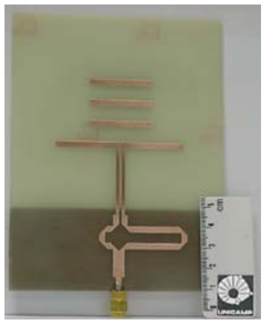
(b) Patch Driver



(c) Meander Driver



(d) Log-Periodic D. Array



(e) Multi-Director Array

Fig. 2. Fabricated antenna prototypes with five different shapes.

Substituting these optimized LGY antenna values, we find the ratio value between distances in relation to the next element and the size of the element $\sigma = 0.125$ and the angle between of the center of the ninth director and the border of the driver $\alpha \approx 45^0$. The antenna being tested is shown in Fig. 2(a), where it can be observed the log-periodic director structure of the fabricated prototype.

0.5 Multi-Director Array

The last designed structure, as mentioned before in the previous, section is the antenna configuration with multiple directors. Maintaining the same dimensions as the QY antenna, two more directors are added on the antenna structure.

The antenna being tested is shown in Fig. 2(e), where it can be observed the fabricated prototype.

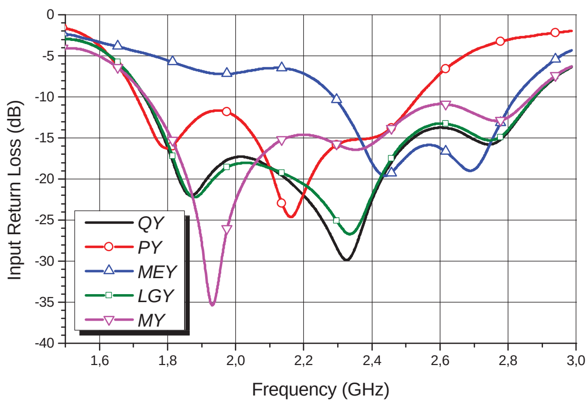
The size of the directors, as well as, the spacing between them, are maintained equal, with the same values presented in QY antenna. No optimization process is utilized, except for two parasite elements that were added to the structure, so that, more precise comparisons could be executed.

Amongst the four design that were presented in this section, this antenna is the simplest one, with only the inclusion of two directors, besides the ones the QY antenna already has.

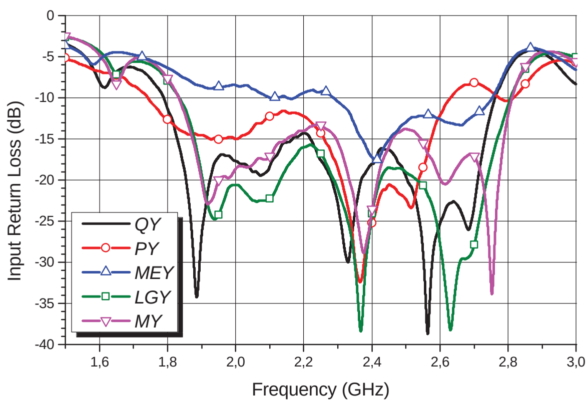
Results and Discussions

The impedance matching can be analyzed by VSWR, which may be less or equal to 2 in the operation band, due to 90% of the antenna input power to be radiated in this case [27]. This situation is represented by input return loss less or equal to -10 dB. The structures were optimized in relation to its bandwidth, the results were found through the FDTD method, and the simulated results are presented in Fig. 3(a), while Fig. 3(b) shows the measured ones.

In Fig. 3, it can be observed that all the measured results of the antennas are in agreement with the simulation. They have, approximately, the same bandwidths, presenting almost the same initial and final frequencies, although small differences are accepted, due to the variations of ε_r value in the substrate and its typical value used by simulations. However, note that the dips inside the band are somewhat shifted due to an insufficiently fine grid of the structure used in simulations.

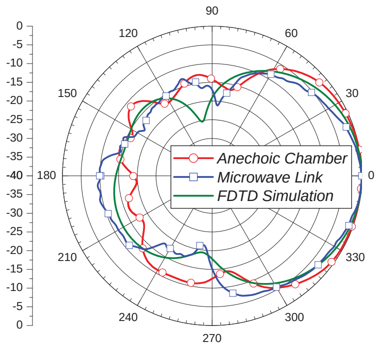


(a) FDTD simulations

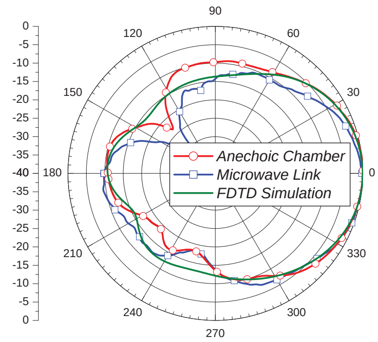


(b) Measurements

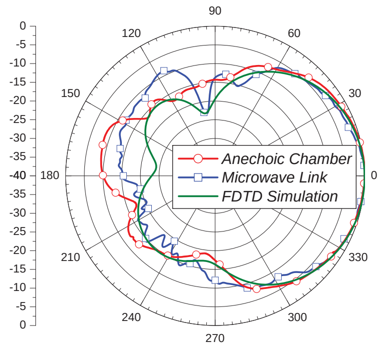
Fig. 3. FDTD simulated and measured input return loss characteristic of the antenna prototypes.



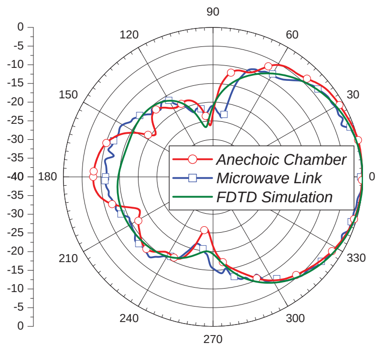
(a) Dipole Driver



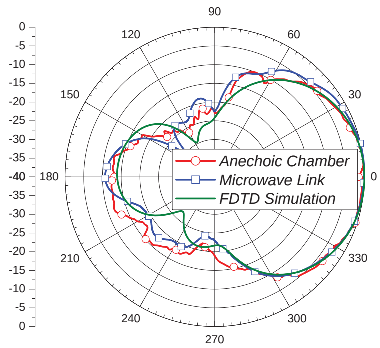
(b) Patch Driver



(c) Meander Driver



(d) Log-Periodic Director Array



(e) Multi-Director Array

Fig. 4. Simulated and measured results of the E-CoPol radiation patterns of the antennas at 2.4 GHz.

Table 1. Summary of the simulated band operation by FDTD for five designed antennas.

Antenna simulated	Lower frequency (*GHz*)	Upper frequency (*GHz*)	Center frequency (*GHz*)	Band width (%)
QY	1.74	2.88	2.31	49.35
PY	1.72	2.54	2.13	38.50
MEY	2.38	2.92	2.65	20.38
LGY	1.74	2.88	2.31	49.35
MY	1.74	2.88	2.31	49.35

Table 2. Summary of measured operation band for five tested antennas.

Antenna measured	Lower frequency (*GHz*)	Upper frequency (*GHz*)	Center frequency (*GHz*)	Band width (%)
QY	1.78	2.76	2.27	43.17
PY	1.74	2.64	2.19	41.20
MEY	2.3	2.76	2.53	18.18
LGY	1.84	2.82	2.33	42.06
MY	1.84	2.82	2.33	42.06

Tables 1 and 2 shows that the antennas which have a variation on the directors maintained the same QY antenna bandwidth, and the ones that have a variation on the driver have a band decreased. Nevertheless, they are all operational, except for the MEY antenna which not operates at GSM-USA standard (for VSWR $\leq$2). It proves that the antennas work perfectly in all band of interest, from 1.85 GHz to 2.7 GHz, operating at 1.9 GHz (GSM-USA standard), 2.4-2.5 GHz, 802.llb/g/n WLAN, Bluetooth, 3G, and 4G (2.5 GHz-WiMAX standard), etc.

To measure the radiation pattern of the prototypes, in addition to the conventional test using anechoic chamber, it was developed a microwave link using an open-field set-up. This link is used to verify the behavior of the antennas at a real environment in contrast to a controlled test like inside an anechoic chamber [28]. At building top-floor, whose vision is shown in Fig. 5, was fitted out a Standard Horn antenna which is used to transmit a carrier at 2.4 GHz. Around 65 m in Line-Of-Sight (LOS), there is a antenna tower, that can be observed in the middle of the Fig. 5, with a robot positioner servomechanism, which is responsible to change the direction in the azimuth plane. The average power value is acquitted by Spectrum Analyzer (in steps of 5^o) and the data acquisition was made by NI LabView.

Fig. 5. Microwave link (building top-floor vision).

Fig. 4 shows FDTD simulation and measured results for E-plane radiation patterns at 2.4 GHz for quasi-Yagi antennas with five different shapes, indicating well-defined endfire radiation patterns in all prototypes. The simulation results reveal that the radiation patterns have the front-to-back ratio around 15 dB for QY, LGY, and MY. For PY and MEY, the radiation patterns have a front-to-back ratio around 10 and 22 dB, respectively.

The radiation pattern measured results indicate a well-defined endfire with a front-to-back ratio around 10 dB for all shapes in both, the anechoic chamber and microwave link. This is contrary to many other broadband planar antenna designs, where increased bandwidth is usually obtained at the expense of degradation in either backside radiation.

The radiation patterns of the PY and MEY antennas are more isotropic than the other ones, due to characteristic of the patch and meander elements added into structure. Observing the characteristics of the radiation patterns, it can be noted that the PY antenna has a broader radiation pattern than the other ones, and that the MY has a larger gain and directivity due to the increase in the number of directors.

Conclusions

This paper proposes an analysis on the influence of driver geometry and director quantity and geometry, applied to quasi-Yagi antennas with optimized operation band. The antenna driver shape was changed to patches and later to a meander. After that, the characteristics related to the number and shape of directors on the structure was verified.

The experimental results confirm the good performances observed by the FDTD simulations. The radiation patterns present good front-to-back ratio and the input return losses show that the antennas are operational in all interested band, from 1.85 to 2.7 GHz, except for the MEY antenna which not operates at 1.9 GHz GSM-USA standard (for VSWR $\leq$2). In addition, it is shown that each new shape presented a particularity, capable of being used, or even optimized in the future, and that the quasi-Yagi antenna has a balanced behavior between all the necessary characteristics for an very good planar antenna.

In this way, all antennas should have wide applications in a great variety of wireless systems, with benefit of easy integration with other circuit components for its planar structure.

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