Design and Characterization of Wideband Horn Antenna in Quasi TEM Mode

Jéssica A. P. Ribeiro, Karine L. M. Costa, Evandro C. V. Boas, José A. J. Ribeiro, Bárbara R. X. R. Faria and Lucas A. Esteves

***Abstract*— This paper describes the design of a wideband horn antenna operating in quasi TEM mode. The antenna consists of a triangular conductive plate with an inclination angle above a ground plane and directly feed by a coaxial cable. Broadband characteristics, radiation pattern, high gain and small reflection coefficient were achieved. Its performance analysis and main parameters effects were obtained by using ANSYS HFSS® software. In the numerical analysis, an optimized model was obtained in 2.52 to 16.3 GHz band with a 10 to 12 dBi gain. The reflection coefficient was measured and the results were consistent with simulations.**

Keywords—Horn antenna, Quasi TEM mode, Wideband.

I. INTRODUCTION

Wideband structures have been employed in different radio communication systems. As example, there is the UWB (Ultra-wideband) frequency range between 3.1 and 10.6 GHz, with applications in ground penetration radars systems, wall imaging systems, surveillance systems, among others [1]. There are also demands for wideband spectral sensing systems, in predictions for radio cognitive, fifth generation (5G) radio communications, etc. [2][3]. Such systems require components with some specifications throughout the operation frequency range. They must co-work with other systems and the design must ensures minimal interference one on other transmission channel.

Some antennas present similar behavior to a transmission line and a radiation electromagnetic field simultaneously [4]. According to their geometry and design procedure, they prevent reflections and, for that, they exhibit wideband operation [5]. The reason is that the radiated energy may be interpreted as a load effect close to its characteristic impedance. In this paper, a horn antenna with a field distribution close to TEM wave in a transmission line is designed. Their dimensions were chosen to microwave range operation and the development is presented in five sections.

In Section II, the antenna basic models and their operation characteristics are presented. Section III refers to a design procedure by assuming the quasi TEM mode operation, i.e., with field longitudinal components very small compared to the transverse field ones. To obtain its main dimensions, the model proposed by Shlanger *et. al*. [6] is applied. The performance of initial structure is verified by numerical analysis with ANSYS HFSS® software [7]. This step is contemplated in Section IV, where an evaluation of the main constructive parameters effects on the antenna performance is made. An optimized model and its reflection coefficient, input impedance, radiation pattern and gain are obtained. Section V presents the prototype after different development steps. Its frequency response was evaluated by the reflection coefficient measurement. Section VI discusses the project important results and relevant conclusions.

II. STRUCTURE OF THE HORN ANTENNA IN QUASI TEM MODE

The proposed antenna model begins with a balanced composition of two triangular metal plates with an angle separation. This balanced structure demands a feed system adaptation [8], [9]. Its dimensions and separations were gradually modified, in searching the desired performance. As there is no abrupt transition between the guided wave and the external environment, small reflection is envisaged at its end. Therefore, the design depends on three variables: the angular aperture α of the electrodes, the angular separation β between them and the axial length ℓ from the driven point (Fig. 1).

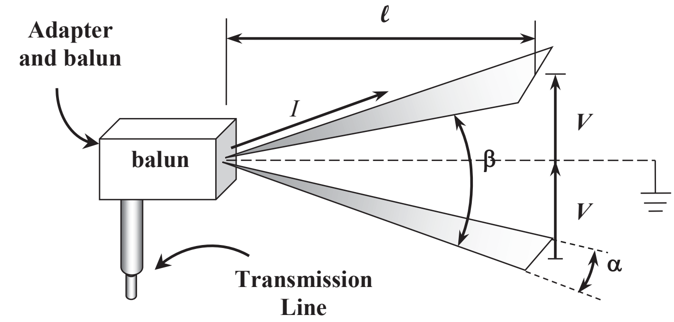

Fig. 1. Structure of the horn antenna operating in quasi TEM mode and fed through a balun.

In the guided wave section, the electric and the magnetic fields are almost perpendicular each other and to the propagation direction, in a similar way of TEM wave. For this reason, the antenna presents input impedance almost equal to its characteristic impedance. In Fig. 1, a hypothetical plane is defined as reference between the conductive plates. There is a voltage V between one of the antenna branches and this reference plane and an identical voltage between this plane and the other branch. The electric current I is the same at both driven points. In this way, the input impedance is [8]:

$$Z_1 = \frac{2V}{I}. \quad (1)$$

Fig. 2 shows an adaptation of this structure, with one of the conductors forming a ground plane, at the position of the reference plane. This new version is an unbalanced structure

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and adaptable to a coaxial cable. The supply voltage is a half the previous value for the same electric current and the input impedance is a half of the obtained in (1):

$$Z_2 = \frac{V}{I}\,. \tag{2}$$

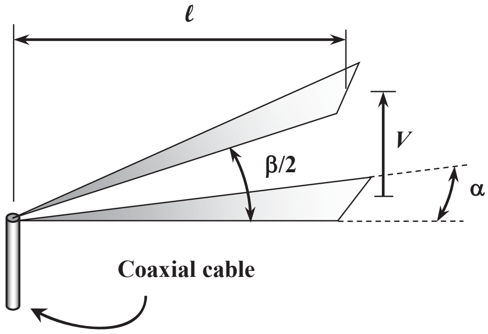


Fig. 2. Structure of the horn antenna operating in quasi-TEM mode with unbalanced fed.

III. ANTENNA DESIGN PROCEDURE

The structures in Fig. 1 and Fig. 2 have the same constructive parameters α, β and ℓ and the same procedure to obtain them. The structure in Fig. 2 is performed considering the characteristic impedance of the structure in Fig. 1 twice the desired value in Fig. 2. Several essays show that the operation of this structure follows the description if the axial length of the antenna is equal to or greater than 1.3 guided wavelength at the lowest operating frequency (f_{min}):

$$\ell \geq 1{,}3\lambda_{máx} = \frac{1.3c}{f_{mín}}\,, \tag{3}$$

with c the speed of electromagnetic wave in vacuum.

To calculate α and β there are some analytical models with very good results [6],[10-12]. The microstrip approximation model, proposed by Shlanger *et. al*. [6], is suitable for values of α and β between 0º and 60º [10]. In this case, the antenna behavior is close to a cascade of microstrip lines segments. In this transmission system the characteristic impedance depends on strip width (w) and the thickness of the dielectric layer to the ground plane (h). In Fig. 3, w represents the extension of the triangular plate base and h is the height at its end respect to the ground plane, ideally assuming infinite and positioned as in Fig. 3(b). The parameter α as a function of β and the ratio w/h is given by

$$\alpha = 2\,atan\left(\frac{w}{2h}\,sin\left(\frac{\beta}{2}\right)\right) \tag{4}$$

As proposed by Shlanger *et. al.*[6], the relationship among geometric parameters and characteristic impedance are:

$$\frac{w}{h} = \frac{8}{e^{A} - 2e^{-A}} \qquad \text{para}\ \frac{w}{h} < 2 \tag{5}$$

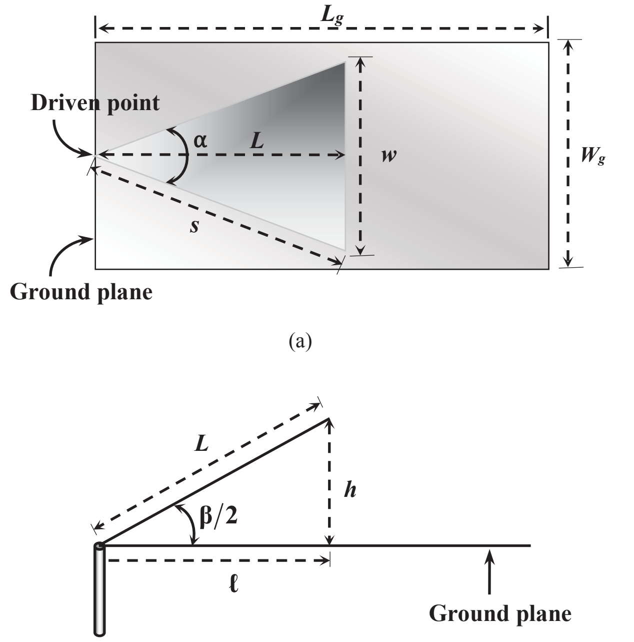
$$\frac{w}{h} = \frac{2}{\pi}\left[\frac{\pi^2}{A} - 1 - \ell n\left(\frac{2\pi^2}{A} - 1\right)\right] \qquad \text{para}\ \frac{w}{h} \geq 2 \tag{6}$$

$$A = \frac{\pi Z_c}{\eta_o} \tag{7}$$

where η_o represents the medium intrinsic impedance in which the electromagnetic wave propagates, in general the air, where $\eta_o = 377\Omega$. In this transmission line model method, there are two free variables: Z_c and one of the angles α or β and it was choose β as free variable. The height (L) and w of the triangular plate are:

$$L = \ell\,sec\left(\frac{\beta}{2}\right), \tag{8}$$

$$w = 2\,\ell\,sec\left(\frac{\beta}{2}\right)tan\left(\frac{\alpha}{2}\right). \tag{9}$$



(a)

(b)

Fig. 3. Dimensions of the proposed antenna (a) upper view and (b) side view.

IV. HORN ANTENNA DIMENSIONS AND RESULTS

The antenna is fed through a 50Ω coaxial cable. Therefore, the antenna was designed with 100Ω characteristic impedance. The minimum frequency is 2.52 GHz and β = 20º, and its value between 16º and 24º does not have appreciable effect on final performance. For $w/h > 2$ and $\ell = 1.3\,\lambda_{max}$, L and w were calculated. The obtained values of Fig. 3 parameters are in Table I.

TABLE I.
DESIGN PARAMETERS TO THE HORN ANTENNA.

Parameter	Value
Z_c	50 Ω
α	46,17º
β	20º
ℓ	154mm
L	156mm
w	133mm
L_g	192mm
W_g	160mm

The antenna bandwidth was evaluated through the reflection coefficient (S_{11}) by using the Finite Element Method (FEM) with ANSYS HFSS® software [7] and is presented in

Fig. 4. The bandwidth was defined for reflection coefficient lower than −10 dB. The numerical results show that the increase of ℓ results in an increase in bandwidth. The final operation frequency band is about 13.7GHz, with limits in 2.52GHz and close to 16.3GHz. To the frequency range of 15.5 and 15.9GHz, the reflection coefficient assumed values between -10 and -9.8dB. The antenna characterization was performed by exploring the reflection coefficient (S_{11}), input impedance, radiation pattern and gain. The S_{11} is in Fig. 4 with ℓ = 154mm and the antenna input impedance is in Fig. 5, with the real part between 25 and 75Ω in frequency range. The imaginary part value changes from of $-j25$ to $j25\Omega$. Table II shows the antenna gain and antenna efficiency obtained in ANSYS HFSS® in frequency operating band. Fig. 6 is 3D radiation pattern in some frequencies and the antenna has similar gain in observed frequencies.

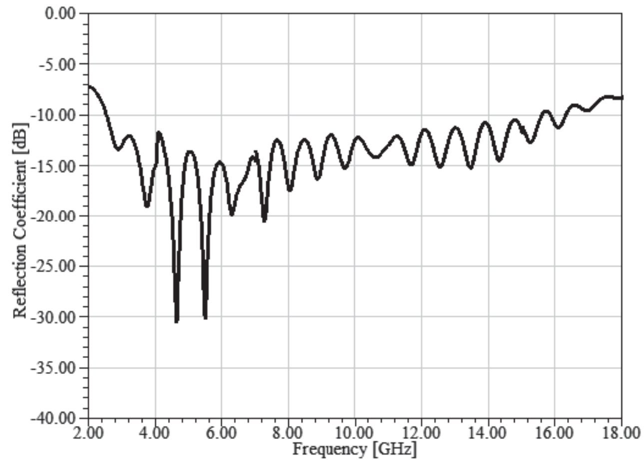


Fig. 4. Reflection coefficient, in dB, for the horn antenna directly fed with dimensions in Table I and ℓ = 154mm.

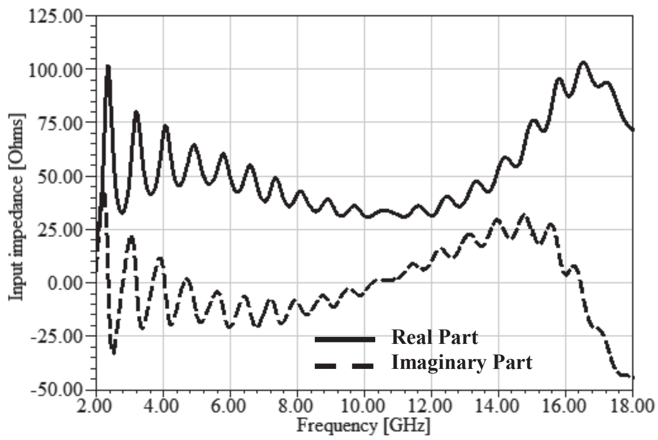


Fig. 5. The horn antenna input impedance, in ohms, with ℓ=154mm. The continuous line represents the real part and the dash line is the imaginary part.

TABLE II.
HORN ANTENNA SIMULATED GAIN AND EFFICIENCY

Frequency [GHz]	Gain [dBi]	Efficiency [%]	Frequency [GHz]	Gain [dBi]	Efficiency [%]
3	10,25	95,04	10	11,59	95,72
4	12,12	96,25	11	11,64	95,92
5	12,67	97,53	12	11,95	94,64
6	12,49	96,79	13	12,19	92,87
7	11,52	95,86	14	12,26	94,20
8	11,69	98,83	15	12,82	93,46
9	11,84	97,50	16	12,10	93,73

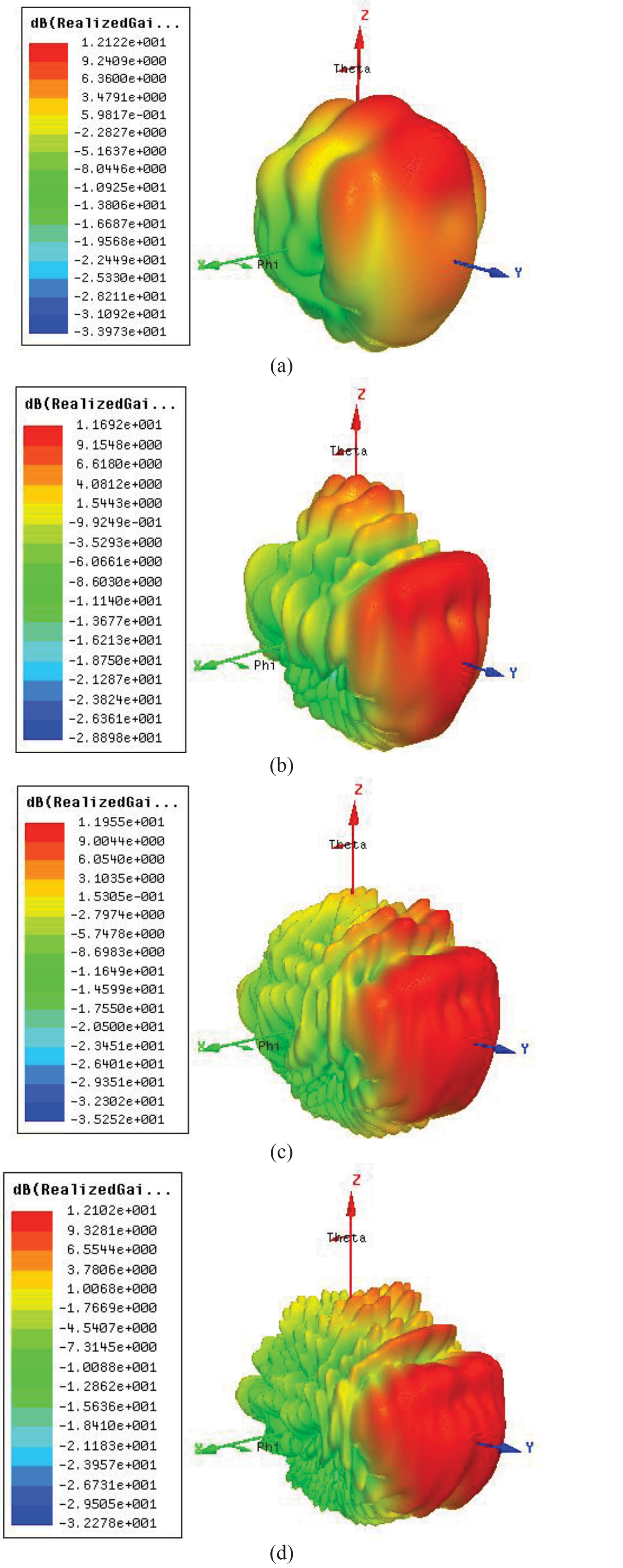


Fig. 6. Simulated 3D radiation pattern in (a) 4GHz (b) 8GHz, (c) 12GHz and (d) 16GHz frequencies.

V. MEASUREMENTS AND DISCUSSIONS

The antenna was constructed with aluminum plates as in Fig. 7, with nylon supports. The prototype performance were evaluated through S_{11} parameter. Fig. 8 is the comparison between the measured and simulated results. The minimum measured operating frequency was 2.35GHz with a 6.7%

reduction compared to simulated results. At frequencies above 15GHz, the measured and simulated curves diverge. In these frequencies, the results are influenced by the SMA fed connector, which can operates up to approximately 18GHz.

(a) (b)

Fig. 7. Prototype horn antennas (a) upper view and (b) front view.

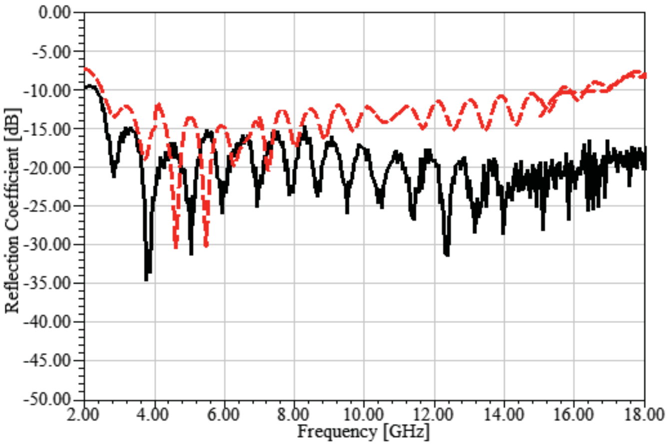


Fig.8. Simulated and measurements comparison of antenna reflection coefficient.

VI. Conclusions

The design of a horn antenna in quasi TEM mode was proposed for applications in wideband frequency operation systems. The antenna is an unbalanced version and suitable to a directly coaxial cable fed. The microstrip approach model was employed to obtain the antenna dimensions. It was observed that to the antenna operates at the minimum frequency defined in the design its axial length has to be close to 1.3 guided wavelength at minimum frequency. Measured results of antenna prototype were similar to the previous obtained with numerical analysis.

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