# Experimental Measurements of Radiation Patterns of a Wire-Medium Loaded X-Band Antenna

[1]Antônio Tomaz and , [2]Joaquim J. Barroso, and [2]Pedro J. Castro
[1]Aeronautics Technological Institute (ITA), [2]National Institute for Space Research (INPE)
São José dos Campos, SP, Brazil
attomaz@gmail.com

***Abstract*—This paper reports on the radiation patterns measured on a X-band antenna loaded with a periodic array of metallic wires. Design details of the wire medium to provide low return losses in the range 8 to 12 GHz are given. Using different test setups, the diagram patterns are measured at different frequencies associated with minimal return losses. Radiation characteristics of the loaded antenna are discussed.**

***Keywords* – wire medium; horn antenna; periodic structure; artificial dielectric; antenna measurements.**

## I. INTRODUCTION

Horn antennas loaded with artificial dielectrics made up of periodic arrays of metallic wires have been investigated in recent years [1]-[5] and have shown improved radiation characteristics. In this regard, the wire medium structure provides an interesting approach to improve a desired property or functionality of a given antenna. The metamaterial wire medium can be designed on the basis of the analytical models and full-wave electromagnetic simulations to meet specific requirements. In our study, the wire medium consists of thin metallic wires of diameter $d$ and arranged on a square lattice of a periodic spacing $a$ as shown in Fig. 1.

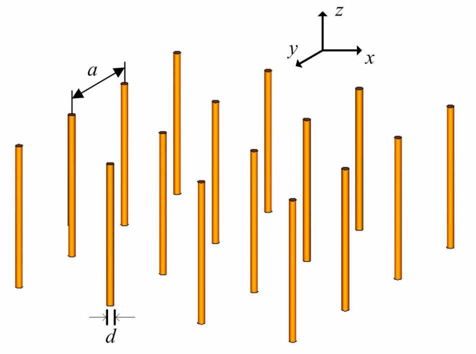


Fig.1. Periodic array of wires.

The cutoff frequency of this structure is estimated by [3]-[5]

$$f_c = c\left[a\sqrt{2\pi\left(\ell n\frac{a}{\pi d}+0.5275\right)}\right]^{-1} \tag{1}$$

where $c$ is the speed of light in vacuum. According to the Drude model [5], [6], in the low-frequency regime (when a quarter of the guided wave length is less than the periodic distance $a$), such artificial dielectric exhibits a permittivity (relative to vacuum) expressed by

$$\varepsilon = \varepsilon_h\left(1-\frac{f_c^2}{\varepsilon_h f^2}\right) \tag{2}$$

where $\varepsilon_h$ is the permittivity of the host medium, $f$ the frequency of the incident wave, and $f_c$ the equivalent cutoff frequency. By taking into account the relaxation time of the free electrons in the wire, Ohmic losses can also be considered in (2). This equation explicitly states that either negative or near-zero permittivity can be achieved at a particular design frequency [6], [7].

The aim of this project is the implementation of the wire medium structure in X-band frequencies, and to investigate how a loaded antenna performs at some specific frequencies. Details about the present design and experimental results on espsilon-near zero (ENZ) refraction effects are described in [8]. Accordingly, the design parameters of the periodic structure are a lattice spacing of 10.0 mm and wires of 0.5 mm in diameter, giving a cutoff frequency of the 7.7 GHz. Electromagnetic simulations confirmed this calculation and the broadband resonance over the entire X-band. The implementation of this structure is made in air, such that in the above calculations the permittivity of the host medium is taken as unity.

Over a specified frequency range the refractive index of a wire-medium slab can be made close to zero, and so rays refracting at the air-slab interface emerge from the ENZ medium nearly perpendicular to the slab surface. In the analytical formulation for a normally incident plane wave with the electric field in the direction of the wire, magnetic effects are not considered, and so the magnetic permeability of the medium is unity. In this condition, the refractive index is calculated as $n=\sqrt{\varepsilon}$. The ENZ effect can be advantageously employed to enhance the functionalities and radiation properties of microwave antennas.

## II. WIRE MEDIUM HORN ANTENNA

The horn antenna is loaded with seven rows of thin copper wires equally spaced on a square lattice, thus forming a rigid structure inside the antenna as displayed in Fig. 2.

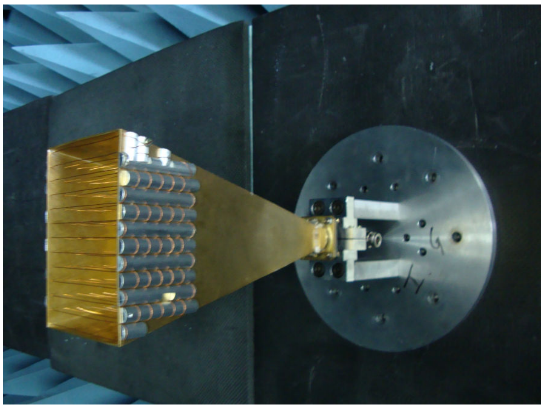


Fig. 2. Wire-medium antenna installed in the anechoic chamber.

In this design the wires are in electrical contact with the metallic faces of the antenna. The original horn antenna is linearly polarized and the presence of the wires barely modifies the original polarization since the electric field inside the source antenna is almost parallel to the wires. Important details about the constructive design and effects arising from the wire medium are discussed in [5], where the host used is a low loss rigid polystyrene foam with dielectric constant of 1.03.

## III. ELECTROMAGNETIC SIMULATION OF THE WIRE-LOADED ANTENNA

Full-wave electromagnetic simulations [10] of the horn antenna have been performed to get further insight into the performance of the antenna when loaded with the designed artificial medium. Figure 3 shows the simulated scattering parameter $S_{11}$ for the horn antenna containing the seven-layer wire medium.

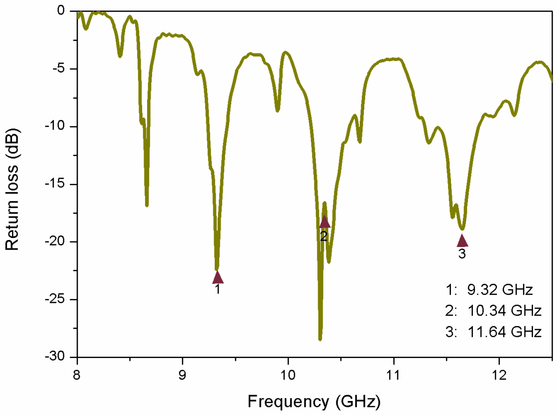


Fig. 3. Simulated $|S_{11}|$ of the wire-loaded horn antenna.

The simulated return loss spectrum shows four strong resonances and two additional weak resonances, which all arise from the periodicity of the structure. Simulated radiation patterns for the three strongest resonance dips (9.32, 10.30, and 11.64 GHz) are displayed in Fig. 4 and Fig. 5.

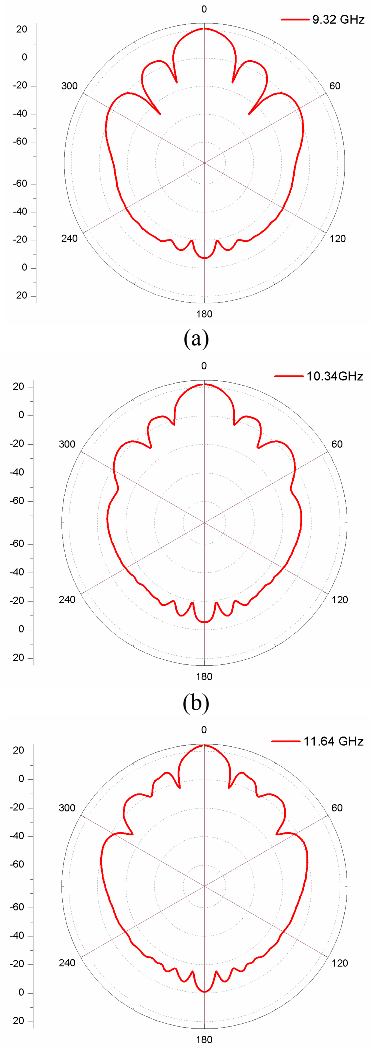
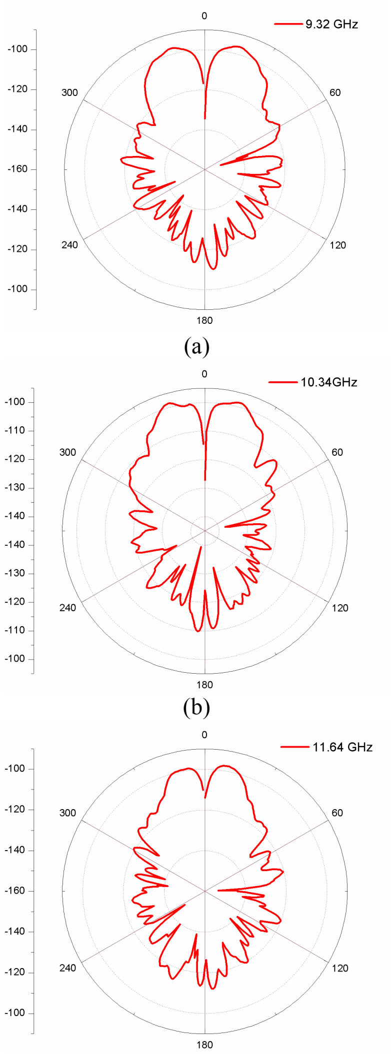


Fig. 4. Simulated E-plane co-polarized radiation patterns (in dB) for the wire medium antenna at three different frequencies.



(a)

(b)

(c)

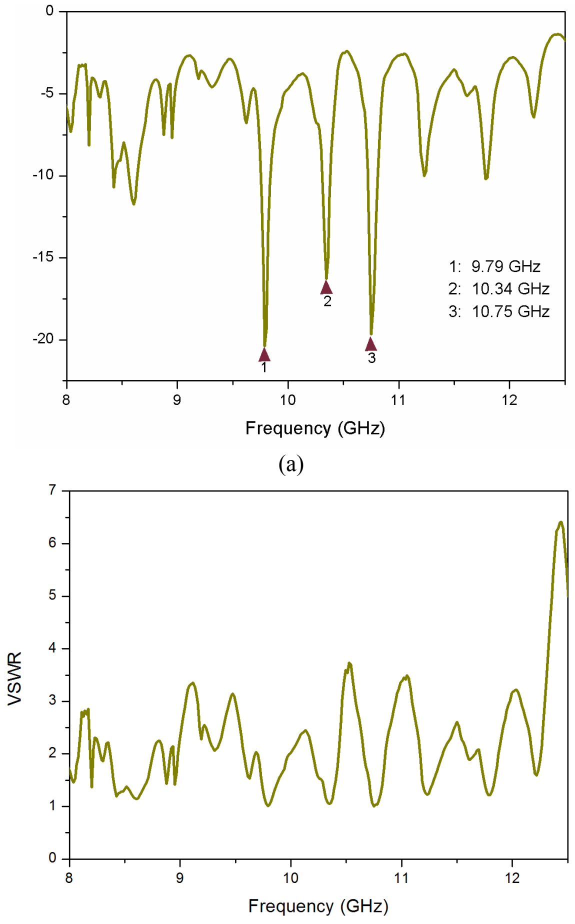
Fig. 5. Simulated E-plane cross-polarized radiation patterns (in dB) for the wire medium antenna at three different frequencies.

The behavior of the patterns in co and cross-polarization shown in Fig. 4 and Fig. 5 indicates that the radiation pattern characteristic of horn antennas is maintained as well as its natural linear polarization.

## IV. EXPERIMENTAL MEASUREMENTS ON THE WIRE MEDIUM HORN ANTENNA

To experimentally verify the radiation characteristics of the loaded horn antenna, measurements on the composite structure were performed with different setups being implemented prior to measuring the radiation patterns. Measurements of the scattering parameter $S_{11}$ and VSWR return losses were initially made to ascertain the influence of the loading wire medium on the transmission frequency spectrum. Measured return loss and VSWR are shown in Fig. 6.

Three strong resonances are observed in Fig. 6(a). Other resonance dips are also observed, characterizing the resonance behavior of the periodic structure, where the cutoff frequency, resonance dips and frequency stop bands are clearly identified. Since the refractive index of the wire slab is less than unity, and consequently the phase velocity is larger than the velocity of light in vacuum, this phenomenon is the one that causes the striking features observed in a metamaterial medium. Measurements of the radiation pattern were performed with the wire medium horn antenna at three frequencies, namely, 9.79 GHz, 10.34 GHz and 10.75 GHz, with different experimental setups been implemented in the anechoic chamber (Fig. 2). The radiation patterns for co-polar and cross-polarizations for these frequencies are shown in Fig. 7.

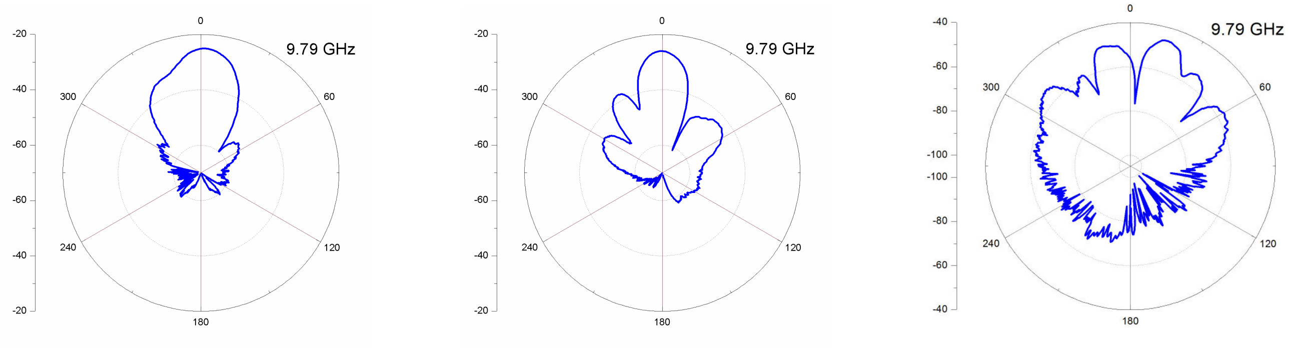


(a)

(b)

Fig. 6. Measured (a) $|S_{11}|$ and (b) VSWR for the loaded antenna.

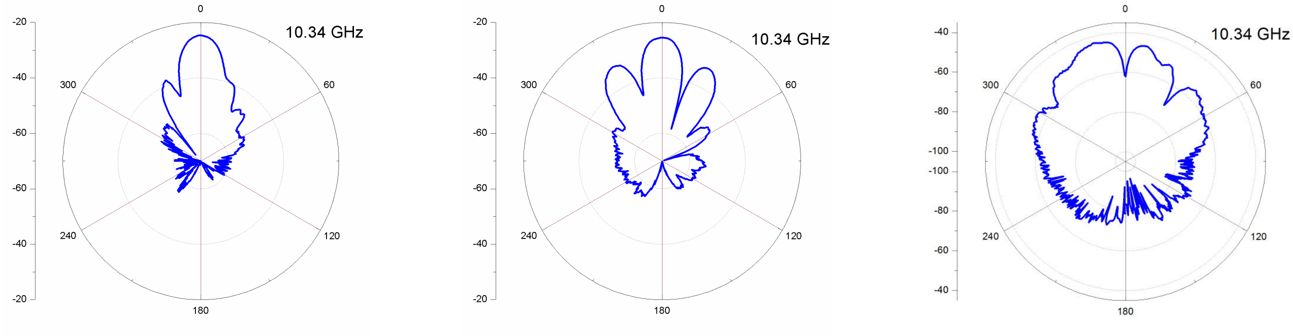
The effect of the wire medium structure on the horn antenna performance is noticeable, where the co-polarization shows wide radiation pattern coverage for the three frequencies. The behavior characteristic of the pattern can be compared with [5], which demonstrates experimental results of the conventional, empty horn antenna. The conventional horn antenna shows a typical gain around the 20 dB [9]. In the present case (Fig. 7), the gains in the co-polarized E-plane are 18.0 dB, 17.0, dB and 18.0 dB for frequencies 9.79, 10.34 and 10.75 GHz, respectively.



(a)
Co-polarized

(b)
Co-polarized

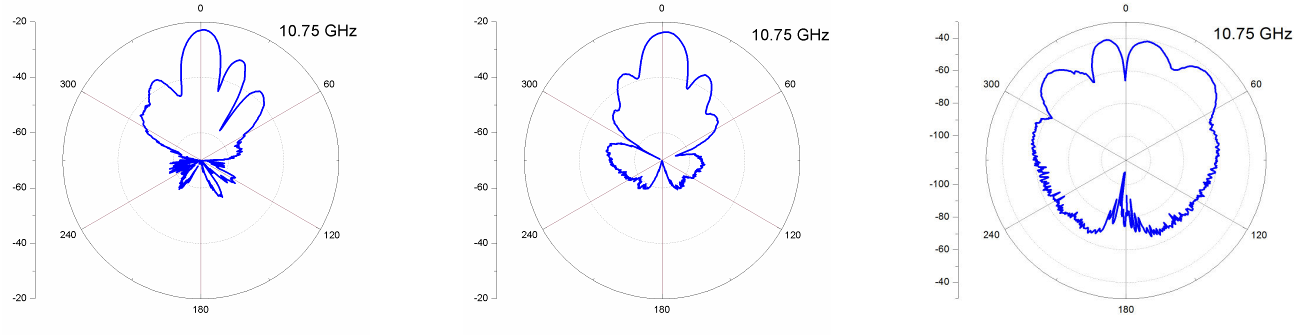
(c)
Cross-polarized



(d)
Co-polarized

(e)
Co-polarized

(f)
Cross-polarized



(g)
Co-polarized

(h)
Co-polarized

(i)
Cross-polarized

Fig. 7. Measured relative radiation patterns (in dB) for the wire medium horn antenna at three different frequencies and setup tests, where (a), (c), (d), (f), (g) and (i) in E plane and (b), (e) and (h) in H plane.

The cross-polarization level for the wire medium antenna was higher than for the linear polarization of the original antenna, as the array of wires produces a strong influence on the wave front radiated from the loaded antenna.

Asymmetries in the radiation patterns (Fig. 7) are ascribed to fabrication imperfections (mounting and alignment of four trapezoidal metallic plates) and to the presence of the aluminum stubs used to stretch the copper wires inside the antenna (Fig. 2).

Notice that the wire medium horn antenna maintains the original configurations in its backlobe, but the sidelobe shows a broader field when compared with a typical horn antenna, which explains the small difference in the measured gain. This effect is demonstrated in the E and H field planes for the three frequencies in Fig. 7.

## V. CONCLUSIONS

This report has experimentally demonstrated that the dispersive properties of a wire medium modify the radiation characteristics of a standard horn antenna. This effect directly arises from the periodicity of the wires. Basic properties of the antenna such as radiation pattern, gain and directivity are directly influenced by the loading medium, thus enabling its applicability as an alternative approach to modify and control the functionalities of standard antennas foreseeing applications in radars, satellite systems and other commercial telecommunications systems.

## REFERENCES

[1] S. Enoch, G. Tayeb, P. Sabouroux, N. Guérin, P. Vicent, “A metamaterial for directive emission”, *Phys. Rev. Lett.*, vol. 89, no. 21, Art. ID 213902, 2002.

[2] Q. Wu, P. Pan, F.-Y. Meng, L.-W. Li, J.Wu. ”A novel flat lens horn antenna designed based on zero refraction principle of metamaterials”, *Appl. Phys. A*, vol. 87, pp. 151-156, 2007.

[3] S. Hrabar, "Application of Wire Media in Antenna Technology", in S. Zouhdi, A. Sihvola, and A. P. Vinogradov , Metamaterials and Plasmonics: Fundamentals, Modelling, Applications (eds.), New York, Springer Netherlands, pp. 139-151, 2009.

[4] S. Hrabar, D. Bonefačić, D. Muha. “Numerical and experimental investigation of basic properties of wire medium-based shortned horn antenna”, *Microw. Opt. Techn. Lett.* Vol 51, issue 11. 2009.

[5] A. Tomaz, J. J. Barroso, P. J. Castro and A. J. F. Orlando, “Experimental investigation on the radiation pattern of a horn antenna loaded by a wire medium”, IEEE International Symposium Antennas and Propagation and National Radio Science Meeting (APS-URSI), Orlando, 2013.

[6] C. R. Simovski, P. A. Belov, A. V. Atrashchenko and Y. S. Kivshar, “Wire metamaterials: physics and applications”, *Adv. Mater.*, vol. 24, pp. 4229-4248, Aug. 2012.

[7] J. Pendry , A. Holden , D. Robbins , W. Stewart , “Low frequency plasmons in thin-wire structures”, *J. Phys. Condens. Matter*, 10, 4785, 1998.

[8] A. Tomaz and J. J. Barroso. “Refractive properties of artificial dielectrics consisting of a periodic wire medium”, IEEE International Symposium Antennas and Propagation and National Radio Science Meeting (APS-URSI), Orlando, 2013.

[9] Datasheet Advacend Technical Materials, Inc. "Horn Antennas - Standard Gain Horn ", 2012.

[10] CST Microwave Studio,Version 2005, CST GmbH, Darmstadt, Germany.