# Implementation of a Wire Medium in a X-Band Horn Antenna: Simulation and Experiment

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***Abstract* — This work describes the implementation of a wire medium in an X-band horn antenna and discusses the effects of the loading medium on the radiation characteristics of the modified antenna. Two configurations consisting of four and five layers of a periodic wire structure are electromagnetically simulated and experimentally tested. In both cases the return losses of the loaded antennas are compared with that of a standard commercial horn antenna. Using different setups, the radiation diagrams patterns are measured at frequencies corresponding to minimum reflection coefficient.**

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

## I. INTRODUCTION

Analysis of wave propagation in artificial dielectrics consisting of a wire medium has long been of interest to improve the radiation performance of microwave antennas [1-3]. In particular, this arises from the fact that artificial dielectrics can exhibit a near-zero refractive index refraction, enabling applications in directivity enhancement and side lobe reduction [4-5]. In this regard, the wire medium provides an interesting approach to improve a desired property or functionality of a given antenna [6-10]. In telecommunications system such horn antennas can be designed to operate over a broader band of frequencies with negligible loss [10].

From this motivation, the present work concerns the implementation of a wire medium structure in X-band frequencies, and the investigation of how a loaded antenna performs at some specific frequencies. Details about the present design and experimental results on epsilon-near zero (ENZ) refraction effects are described in [8].

The remaining of this paper is organized as follows. Section I depicts the wire-medium structure and its geometric parameters to the present design. Section II describes constructive details and implementation of the periodic structure. Full-wave simulated results and experimental measurements are shown in Section III, and Section IV gives the conclusions.

## II. WIRE MEDIUM STRUCTURE AND DESIGN

Consisting of parallel conducting wires equally spaced, the wire-medium artificial structure is shown in Fig. 1 wires. The corresponding cutoff frequency of the wire medium can be calculated by [2],[8]

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

where $c$ the speed of light in free space, $a$ the periodic spacing between the wires and $d$ the diameter of this wires. As discussed in [2],[6], the design elements 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 [6].

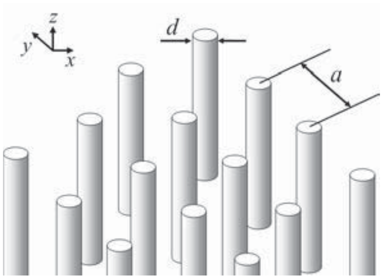



Fig 1. The wire-medium structure.

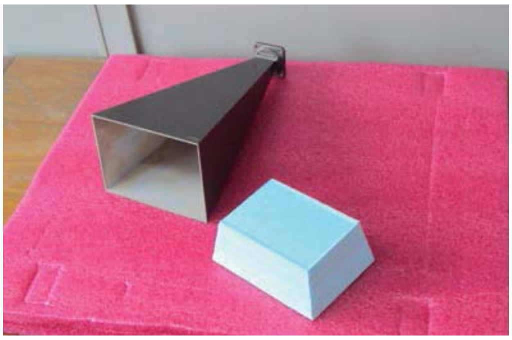
To enhance its mechanical stability, the wire-array structure can be embedded in a homogeneous material, named host medium [4],[9]. This wire-medium structure has shown to perform well in X-band with strong resonances and with reflection coefficient below 20 dB as detailed in [2],[6].

## III. CONSTRUCTION DETAILS AND IMPLEMENTATION OF THE WIRE MEDIUM IN THE HORN ANTENNA

The horn antenna employed in the experiments and installed in an anechoic chamber is a standard X-band antenna [11]. From commercial copper wire, the wires were cut and clamped at both ends on the host medium, consisting of polystyrene plates 10.0 mm thick. The polystyrene foam is a low loss material with dielectric constant of 1.03 and loss tangent $1.0\times10^{-4}$. To verify this, return-loss measurements were made with the empty antenna, and then with the antenna loaded with polystyrene plates [Fig. 2(a)], and no differences were noticed in the measured parameters. As can be seen in

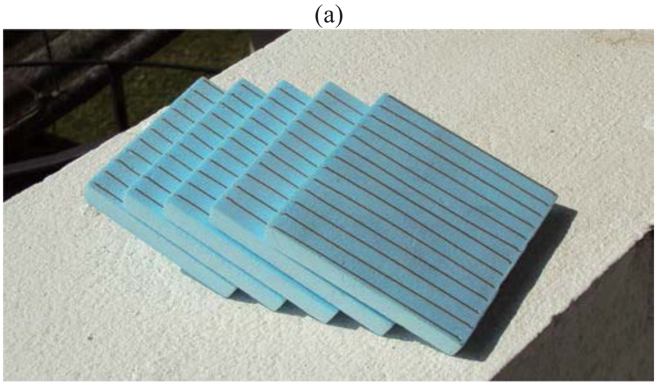
Figs. 2 (b)-(d), the wires are not in electric contact with the flared metallic walls of the antenna.

Full-wave electromagnetic simulations were also carried out [12]. This step was conducted to ascertain in advance the construction design. In the first setup, the cutoff and resonance frequencies of the periodic structure were found in good agreement with analytical calculation. In the second setup the fully loaded antenna was simulated from which radiation patterns were obtained. These results are compared with experimental measurements in the next section.

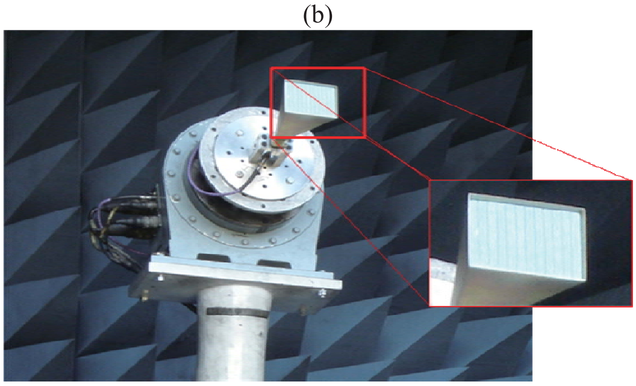


(a)

(b)



(c)



(d)

Fig. 2. Construction details of the wire-medium antenna: (a) horn antenna and polystyrene foam plates, (b) loaded antenna, (c) five layers of the wire-medium structure, (d) antenna installed in the anechoic chamber.

## IV. Experimental Measurements on the Wire Medium Antenna

The first set of measurements was performed on the antenna fully loaded with five layers. The measured and simulated reflection coefficients are shown in Fig. 3, where it is noticed two sharp dips of -30 dB at 9.87 GHz and 12.5 GHz, far below than the $|S_{11}|$ curve corresponding to the empty antenna. The second configuration tested included four internal layers, without the outermost external layer as pictured in Fig. 2(d). In this case, a strong resonance dip appears at 11.70 GHz (Fig. 4).

These measurements indicate that the loaded antenna is well matched to the feeding waveguide with a return loss of 30 dB at specific frequencies. Accordingly, such behavior manifests itself in both experimental and simulated curves. In particular at the frequency of 11.70 GHz associated with the sharpest dip in the four-layer structure, the corresponding E-plane radiation patterns are shown in Fig. 5. It is seen that in loaded-antenna pattern the back sidelobes appear enlarged. The radiation patterns were measured in an anechoic chamber using a reference broadband antenna as the transmitter and the test antenna as the receiver.

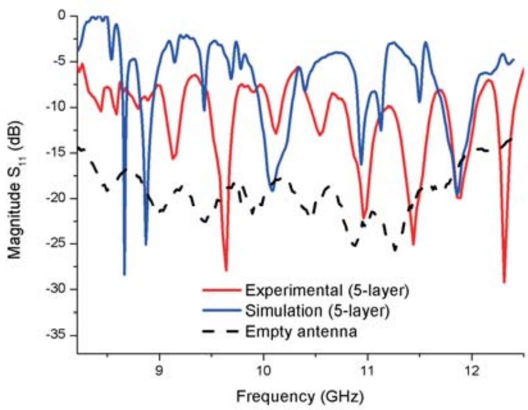



Fig. 3. Magnitude of the reflection coefficient $S_{11}$ for the loaded (with five layers) and empty antennas.

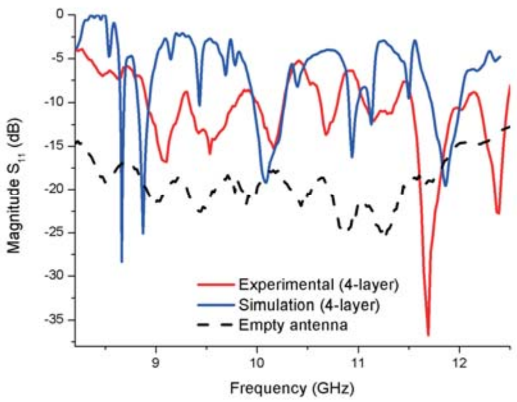



Fig. 4. Magnitude of the reflection coefficient $S_{11}$ for the horn antenna loaded with four layers of the wire medium.

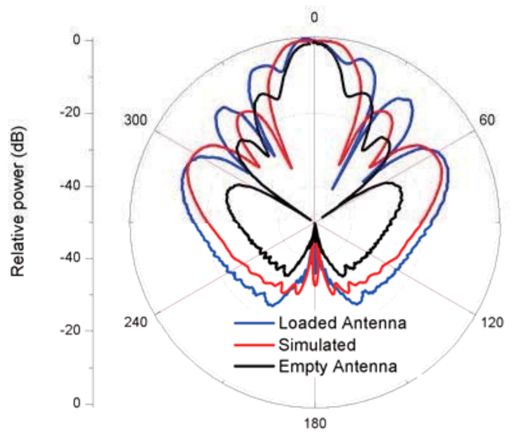



Fig. 5. E-plane co-polarized polar radiation patterns at 11.70 GHz for the loaded (with four layers) and empty antennas.

## V. CONCLUSIONS

The periodic structure built up by the wire medium shows as interesting approach to modify the radiation characteristics of a horn antenna, alternative solution and change parameters in this antenna. Strong effects of the loading wire medium on the antenna functionality have been demonstrated. Pronounced dips down to -35 dB in the reflection spectrum of the loaded antenna have been noticed and compared with those for a standard antenna.

Such effects directly arise from the periodicity of the wires. Basic properties of the antenna such as radiation pattern 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] W. Rotman, "Plasma simulation by artificial dielectrics and parallel plate media", IRE *Trans. Antennas Propag.,* vol. 10, no.1, pp. 82-92, Jan. 1962.

[2] 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.

[3] V. G. Veselago "The electrodynamics of substances with simultaneously negative values of ε and µ". *Sov. Phys. Usp*., vol. 10 no. 4, pp. 509–514, 1968.

[4] 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.

[5] H. Lalj, H. Griguer, M. Drissi. “Very compact bandstop filters based on miniaturized complementary metamaterial resonators”, *Wirel. Eng. Techn.*, vol. 4, no. 2, pp. 101-104, 2013.

[6] J. J. Barroso, A. Tomaz, U. C. Hasar, A. J. F. Orlando. "Microwave focusing by a wire medium", PIERS Proceedings, Stockholm, 2013.

[7] R. Zhou, H. Zhang, H. Xin. "Metallic wire array as low-effective index of refraction medium for directive antenna application", *IEEE Trans. Antennas Propag.*, vol. 58, no. 1, pp. 79 - 87, Jan. 2010.

[8] P. Ikonen, M. Kärkkäinen, C. Simovski, P. Belov, S. Tretyakov. "Light-weight base station antenna with artificial wire medium lens", *IEE Proc. Microw. Antennas Propag.*, vol. 153, no. 2, pp.163-170, April 2006.

[9] S. Zouhdi, A. Sihvola, and A. P. Vinogradov , Metamaterials and Plasmonics: Fundamentals, Modelling, Applications (eds.), New York, Springer Netherlands, pp. 139-151, 2009.

[10] E. Lier, D. H. werner,C. P. Scarborough, and J. A. Bossard, “ An octave-bandwidth negligibleloss radiofrequency metamaterial”, *Nature*, vol. 10, pp. 216-22, March 2011.

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

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