Directivity Enhancement of an X-band Horn Antenna Loaded by a Wire Medium

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Abstract— On the basis of full-wave electromagnetic simulation, the present work reports on a comparative study of the enhanced radiation properties of a standard X-band horn antenna loaded by a wire medium. Acting as an artificial dielectric the wire medium consists of an array of parallel metallic wires installed into the antenna with the wires oriented in the direction of the electric field. Performance of the original empty horn antenna is then compared with the same antenna when loaded by the periodic structure.

1. INTRODUCTION

Recent studies have shown that wire medium structures can provide an interesting approach to improve the radiation performance of microwave antennas. Under proper design, metallic wires periodically arranged in a regular pattern, and embedded in lightweight host material, behave as a homogenized artificial dielectric having a relative permittivity less than unity. Since the index of refraction relates to the permittivity via $n \sim \varepsilon^{1/2}$ such structure exhibits near-zero refractive index, which enables the realization of highly directive beams [1–9]. The present work presents the conceptual study of a wire metamaterial designed to enhance the radiation characteristics of a standard x-band antenna. A performance comparison at 8.87 GHz of the wire-loaded and antenna with its empty counterpart is discussed, highlighting the improvement in beam directivity of the loaded antenna.

2. WIRE MEDIUM STRUCTURE

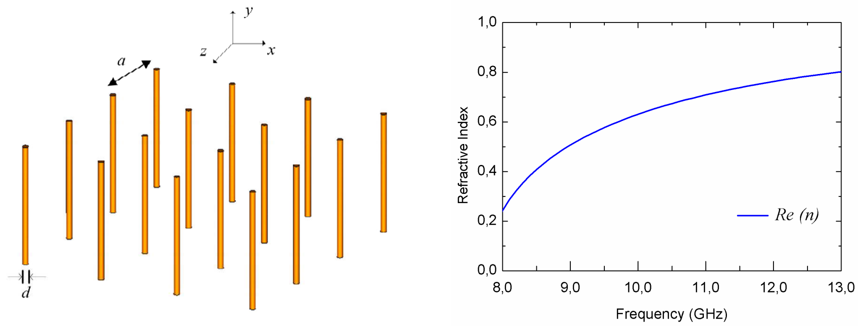
A metamaterial wire medium can be designed by analytical models supported by full-wave electromagnetic simulations to meet specific requirements. In our study, the wire medium consists of thin metallic wires of diameter d and arranged on a square lattice of a periodic spacing a as shown in Fig. 1(a). If the wire radius and the periodic distance are very small in comparison with the wavelength inside the structure and for the case of plane-wave incidence with the electric field parallel to the wires, the wire medium can be described as an artificial dielectric with permittivity (relative to vacuum) given by

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

where ε_h is the permittivity of the host medium, f the frequency of the incident wave, and f_c the equivalent cutoff frequency determined as [8]

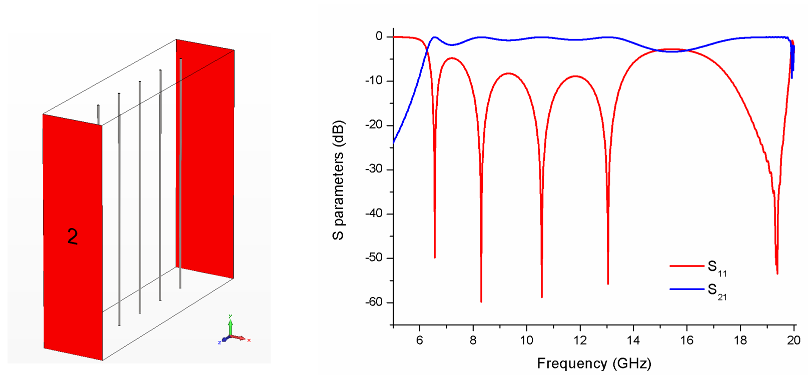
$$f_c = c\left[a\sqrt{2\pi\left(\ell n\frac{a}{\pi d} + 0.5275\right)}\right]^{-1} \tag{2}$$

The wire medium is envisaged to operate in the x-band (8.2–12.4 GHz), and for achieving optimum frequency response the geometrical parameters should be properly chosen by taking into account commercially available diameters for the metallic wire. The lattice constant and the wire diameter were chosen as $a = 10.0\,\text{mm}$ $d = 0.5\,\text{mm}$, yielding from (2) a cutoff frequency of 7.7 GHz. In this way, the effective index of refraction for the wire medium so designed by considering air as the host medium is shown in Fig. 1(b), where the resulting refractive index has an average value of 0.5 over the 8–13 GHz range.



(a) (b)

Figure 1: (a) Wire medium structure and (b) the corresponding refractive index calculated from (1).



(a) (b)

Figure 2: (a) Simulation setup of the periodic array of wires and (b) simulated S-parameters.

3. WIRE MEDIUM SIMULATION

The analytical model was verified through electromagnetic full-wave simulations by using the CST MWS software [10] to ascertain the behavior of the artificial dielectric formed by a periodic array of metallic wires. As displayed in Fig. 2(a), the simulated structure is composed of five 0.5-mm-diameter wires evenly spaced at 10.0 mm.

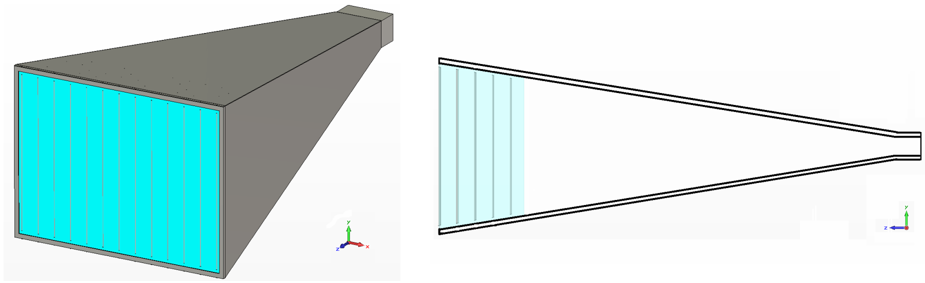
In the simulations, electric and magnetic boundary conditions were applied on the walls perpendicular and parallel to the wires, respectively, and two open ports were used to simulate the S-parameter response to a normally incident plane wave with the electric field polarized along the wires. Fig. 2(b) shows the simulated scattering parameters S_{11} and S_{21} of the periodic structure. In addition to a transmission band starting at about 7.0 GHz and extending up to 14.0 GHz, four resonance dips are noticed. Such resonances are due to the inductive coupling of the wires in the periodic of the structure, whereby N elements give rise to $N-1$ coupled resonances. Beyond the pass band, it appears the Bragg band gap identified by the frequency whose wavelength is twice the periodic distance, such that f_B (GHz) $= 15/a$ (cm). Increasing the number of wires, e.g., to twenty, would make the gap transition much sharper and just starting at 15.0 GHz, which is f_B for the design $a = 1.0$ cm.

4. ELECTROMAGNETIC SIMULATION OF THE WIRE-MEDIUM LOADED ANTENNA

A simulation setup (Fig. 3) was realistically implemented in the CST Microwave Studio [10]. The horn antenna is a replica of a standard commercial antenna fabricated by ATM Microwave [11]. Five rows of the wire medium previously discussed are loaded in the antenna. The arrays of metallic wires are accommodated and fixed in a Styrofoam plate 10.0 mm thick; this host material has a relative permittivity of 1.03 and loss tangent of 0.1×10^{-3} [12].

The simulated return loss of the wire-medium antenna is demonstrated in Fig. 4. Associated with the five loaded layers, four resonance dips are identified at 8.87, 10.08, 10.93, and 11.86 GHz. The leftmost dip at 8.65 GHz is a trapped-mode resonance likely to be ascribed to a mode trapped in the throat of the feedhorn.

Such peculiarities in the S_{11} spectrum result in a change of the radiation characteristics the



(a) (b)

Figure 3: Horn antenna loaded with the wire medium: (a) perspective view and (b) cut-away view.

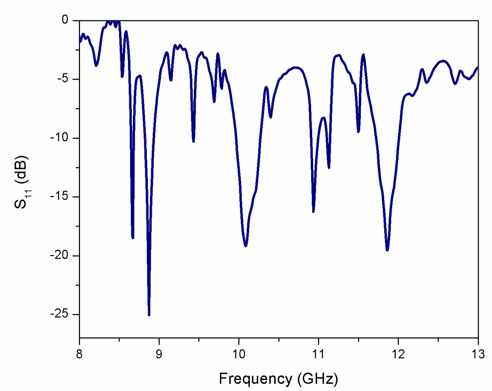
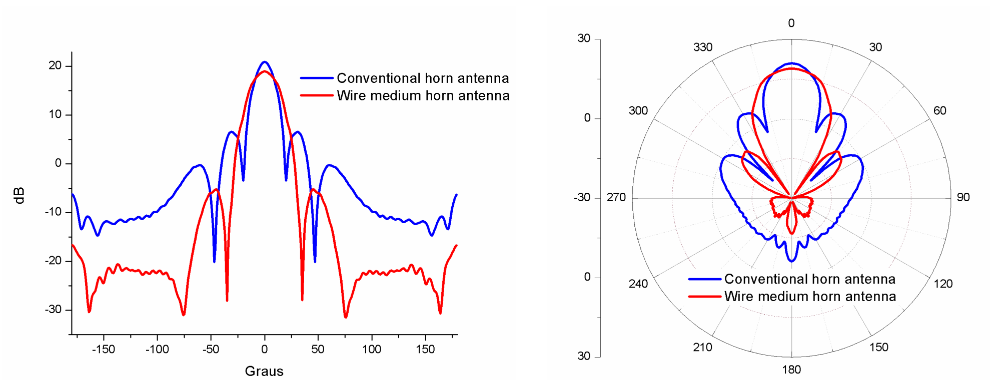


Figure 4: Simulated S_{11}-parameter for the loaded antenna.



(a) (b)

Figure 5: E-plane radiation patterns in (a) rectangular and (b) polar coordinates at 8.87 GHz.

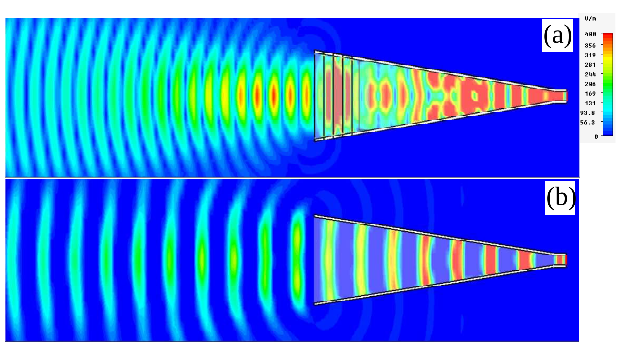


Figure 6: Electric field intensities radiated by (a) the wire-medium antenna and (b) the standard antenna at 8.87 GHz.

original antenna. This is demonstrated in Fig. 5 which compares the performance the loaded and empty antennas at 8.87 GHz. It is clearly apparent that the E-plane radiation pattern for the loaded antenna yields significantly reduced side lobes, at a level lower than -20 dB. Accordingly, we see in Fig. 6 that the intensity of the radiated electric field is far more concentrated along the axis of the wire-medium antenna.

5. CONCLUSION

Through electromagnetic simulations, this report has demonstrated how a properly designed wire-medium can enhance the radiation characteristics of a commercial standard X-band horn antenna. Such an enhancement is due to a refractive index near-zero effect providing a stronger concentration of energy in the central region of the loaded antenna's radiation pattern. The wiremedium antenna exhibits a high directivity and reduced side lobe level, in this case 10 dB below that of the conventional antenna. Wire media with different configurations and arrangements provide similar performance enhancement in other frequency ranges.

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