Design of a Broadband Shortened Horn Loaded with a Flat Wire-Medium Annular Lens

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Abstract

In this contribution, we present the design of a flat wire-medium annular lens to be applied to the aperture of a shortened horn antenna in order to achieve gain performances similar to the ones of the corresponding optimum horn over a broad frequency range. The lens operation is based on the phase-compensation concept and the wire-medium is designed such that it behaves as an epsilon near-zero metamaterial at the frequencies of interest. The annular shape of the lens allows adjusting the phase-front of the field propagating along the short flare of the horn in order to achieve an uniform phase distribution at the horn aperture and maximizing, thus, the gain. As an example, we report the design of the proposed lens for a C-band conical horn. The length of the horn is half the length of the optimum horn, while the obtained gain performances are similar to the ones of the optimal horn over the entire mono-modal frequency band of operation of the feeding waveguide. This result may open the door to several interesting applications in satellite and radar systems.

1. Introduction

In modern radar and satellite systems, high-directivity microwave antennas are required for tracking, space, and remote sensing applications [1]. In this framework, horn antennas represent the most common radiators, due to their easy fabrication and excitation, bandwidth performances, good radiation efficiency and high gain. Among these appealing properties, gain is strongly related to the physical dimensions of the antenna, making often the antenna system heavy and rather bulky [2]. The availability of shortened horn antennas with gain performances comparable to the ones of regular and even optimum horns would represent a remarkable achievement in the field.

Recently, exploiting the spatial filtering behaviour of a metamaterial slab, whose real part of the effective permittivity is close to zero [3], the length of an optimum pyramidal horn has been reduced [4]-[5]. In the mentioned works, the aperture of the horn has been covered by a flat and uniform wire-medium lens, leading to an effective enhancement of the antenna gain within a narrow frequency band. The reason of the narrowband operation resides in the high sensitivity of the spatial filtering properties of the wire-medium when moving from the design frequency. This limitation does not make the proposed horn suitable for several applications, where broadband operation is required.

In this contribution, we propose the design of a flat wire-medium annular lens that can be used to enhance the gain of a short horn over a broad frequency range, making the gain performances of the horn similar to those ones of the corresponding optimum horn.

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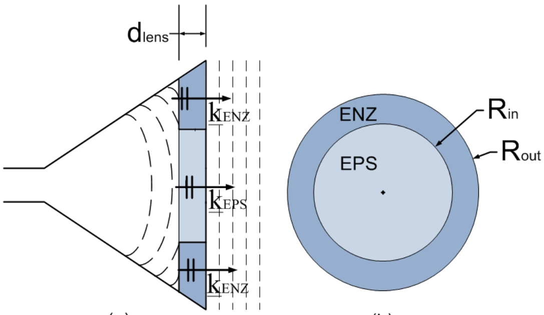
2. Design of the flat wire-medium annular lens

Let us consider a short horn antenna having the same aperture dimensions of the optimum horn. As reported also in [4]-[5], phase distribution on the aperture is highly non-uniform, leading to a reduction of the aperture efficiency and, thus, of the gain [1]-[2]. In order to recover the gain performance of the optimum horn, we propose to cover the aperture with a flat annular metamaterial lens, characterized by epsilon-near-zero (ENZ) values of the real part of the permittivity (see Fig. 1).



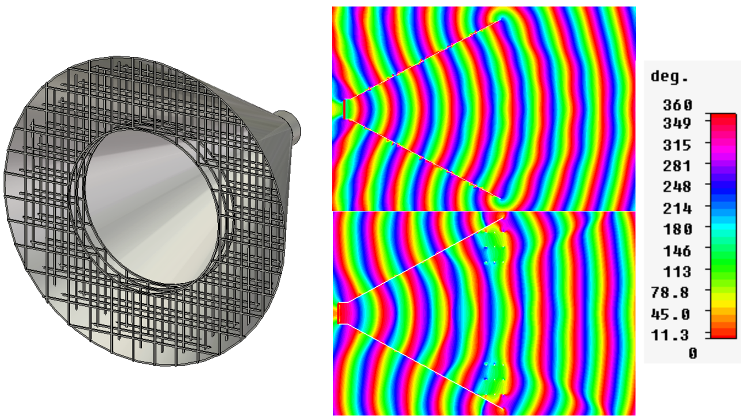
(a) (b)

Fig. 1: (a) Side view and (b) front view of a short horn antenna loaded with a flat annular ENZ lens.

Exploiting the properties of the ENZ material, the spherical phase-front of the propagating field before the lens is transformed into a plane one. The annular shape of the lens is justified by the fact that the ENZ material must compensate the phase-delay at the edges of the horn, where the phase-fronts are more curved. The central part of the lens can be made by a regular epsilon-positive (EPS) dielectric or even air. Assuming a Drude-like dispersion for the ENZ material, the thickness of the lens d_{lens}, the inner radius R_{in} and the plasma frequency of the ENZ material can be designed such that the short horn presents a uniform phase distribution at the horn aperture within a broad frequency range.

3. Realistic implementation and numerical results

As an example, we report here the realistic implementation of a short C-band conical horn loaded with the lens described in the previous section (see Fig.2a). The horn length has been assumed as half of the length of the optimum horn, but any reduction is in principle possible. The lens has been implemented through a wire-medium having an effective plasma frequency of 5.5 GHz, whereas the EPS material is just air. We have assumed as reference the optimum conical horn [6], whose broadside gain is around 22 dBi in the frequency range 5.5-7.0 GHz. Then, we have simulated the behaviour of the short conical horn in Fig. 2a by using CST Microwave Studio 2011 (frequency domain solver) with and without the lens. The corresponding phase maps at 6.0 GHz are reported in Fig. 2b.



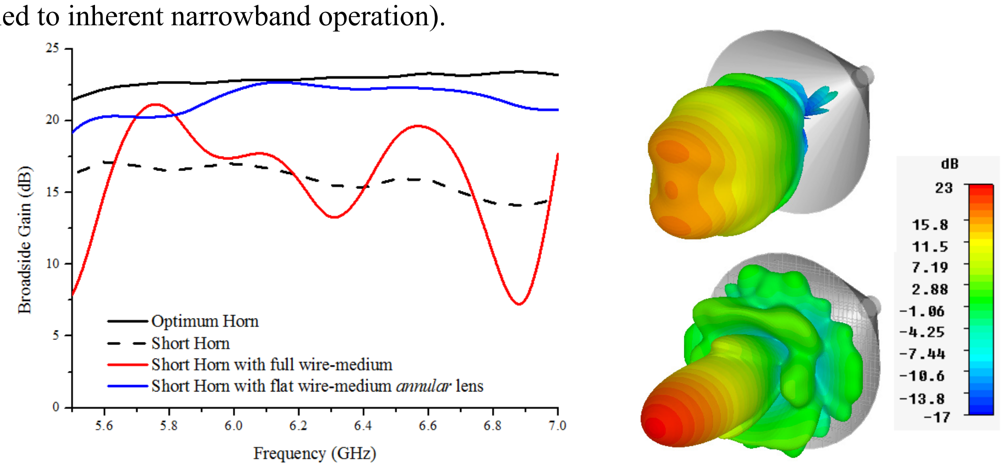
(a) (b)

Fig. 2: (a) Short conical horn with the wire-medium annular lens. (b) Phase maps at 6.0 GHz without (up) and with (down) the lens.

As it can be seen, thanks to the lens, the phase-fronts at the aperture are almost flat, leading to a significant gain enhancement.

In Fig. 3a, we report the broadside gain within the mono-modal frequency band of the feeding waveguide for the short conical horn with and without the lens. These results are compared to the ones of the optimum conical horn and of the short conical horn loaded with a full (not annular) wire-medium lens, similar to the ones proposed in [4]-[5]. Finally, the 3D gain patterns at a representative frequency (6.15 GHz) of the short conical horn with and without the lens are reported in Fig. 3b.

The preliminary results we have shown here are very encouraging and verify the effectiveness of the proposed approach, which leads to the design of short horns having similar gain performances of the optimum ones (with a dramatic reduction of the length) over a broad frequency band (while previous attempts led to inherent narrowband operation).



(a) (b)

Fig. 3: (a) Broadside gain of different horns as a function of the frequency. (b) 3D gain patterns of short conical horn at 6.15 GHz without (up) and with (down) the proposed lens.

4. Conclusions

In this contribution, we have presented the design of a new flat wire-medium annular lens to be used for enhancing gain performances of short horn antennas. The basic operation of the lens has been reviewed and its realistic implementation in a C-band conical horn has been proposed. The design example presented in the paper shows that, thanks to the proposed annular lens, a short horn, whose length is half of the one of the corresponding optimum horn, has similar gain performance of the optimum horn over the entire mono-modal frequency band of the feeding waveguide. The results have been compared also to inherently narrowband previous designs of horn antennas with full (not annular) wire-medium lenses, showing the superior performance of the new proposed approach. The obtained results are quite encouraging and stimulate us to continue this research, moving to the experimental part. We hope to present some preliminary experimental data already at the conference.

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