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RESEARCH ARTICLE

Metamaterial inspired featherlight artificial plasma horn antenna for astronomical and communication applications

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Abstract

In this article, we introduce a novel type of horn antenna constructed using artificial plasma sheets. This metamaterial inspired negative permittivity antenna fabricated using thin metallic wires in a specialized manner is observed to have same radiation performance of an equivalent conventional metallic horn structure. This novel plasma antenna can replace the conventional one in all microwave applications. The featherlight weight and the ability to remove the problems related with wind resistance and rain accumulation of this new structure may result in a rethinking of the use of horn antennas in astronomical data collection.

KEYWORDS

artificial plasma medium, horn antenna, metamaterials, radiation pattern, satellite application

1 | INTRODUCTION

From its introduction by J. C. Bose, horn antennas were extremely popular in all fields of microwave application including astronomical research due to its moderate bandwidth, high gain, good power handling capability and ease of fabrication. Modified versions of horn antennas are extensively used as the primary feed in parabolic reflectors and as a universal standard for calibration and gain measurements.[1,2] To make the pyramidal horn more compact, many approaches that include dielectric loading[3–5] and lens-correction[6] have been considered. Further approaches like loading by metal baffles[7] have also been considered for modifying its radiation characteristics. However, these modifications make the structure heavy and expensive which cause them not suitable for many applications like space research.

In recent years, researchers have attempted to give modifications to horn antennas by making use of metamaterial inclusions of negative permeability medium (split ring resonator) and negative permittivity wire medium (artificial plasma). The effects of incorporating a wire medium inside horn antennas have been investigated by simulation and experimental studies.[8] In this article, we present a novel type of horn antenna constructed by replacing the metallic walls of a conventional horn structure with artificial plasma sheets. Usually negative permittivity metamaterial sheets are constructed using periodic array of thin metallic wires in a 3D manner. But even a single layer of periodic wires can be considered as artificial plasma (sheet of thickness equal to the diameter of the wire) with effective medium parameters.[9] Here the plasma sheets are specially oriented for maintaining the field distribution inside the new horn as in a conventional metallic horn structure.

2 | ANTENNA FABRICATION

The schematic diagram of the proposed plasma horn antenna is presented in Figure 1. Plasma structure constructed using thin copper wires is attached to the wave guide via a pyramidal launcher of length 2 cm. The axial length of the horn is 14 cm and the flare angles in E and H planes are 30° and 40°, respectively. Plasma medium for constructing the sidewalls of the horn structure is made of a single layer of thin metallic wires of radius 250 μm arranged with a periodicity of 5 mm in the H walls and an angular spacing of 2° with respect to the apex of the horn in the E walls. The

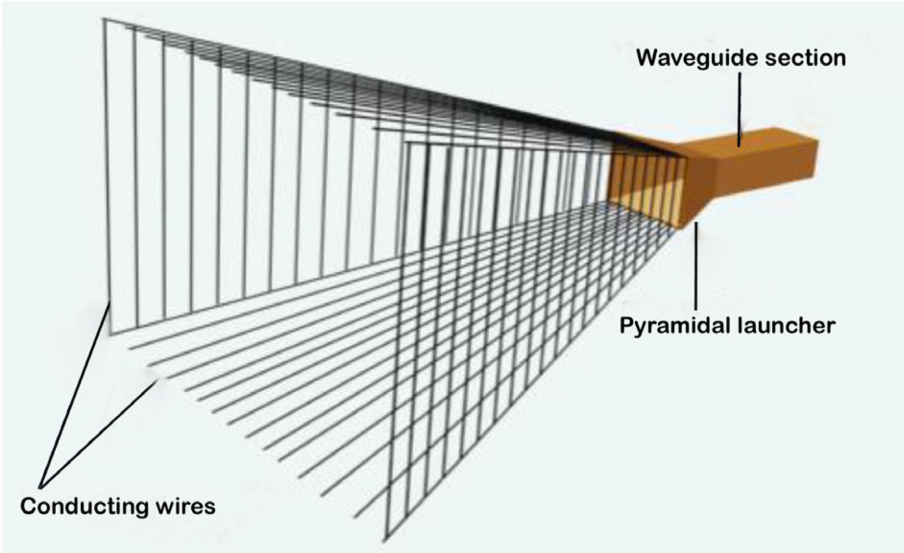

FIGURE 1 Schematic presentation of proposed plasma horn antenna [Colour figure can be viewed at wileyonlinelibrary.com]

effective plasma frequency of this artificial medium is obtained from the equation.[9]

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

where f_{p}, plasma frequency; c, velocity of light in free space; a = spacing between the wires and d = diameter of the wire. With the present values of a and d, the plasma frequency will be 18.44 GHz. Below this frequency the medium acts as a perfect reflector and hence the horn constructed using this artificial plasma sheet shows the same properties as that of the metallic horn antenna.

Though the copper wires used for making plasma sheet can be arranged in different orientations for constructing the E and H walls of the plasma antenna, for getting radiation properties similar to the conventional metallic horn antenna, they need to be arranged in the following manner. For the H walls, the direction of the copper wires of the plasma sheet should be parallel to the E vector of the radiating field (TE_{10} mode) so that the boundary condition for E (tangential component) behaves similar to that of its metallic counterpart. With respect to E walls, the direction of the wires should be parallel to the propagating wave vector $\boldsymbol{k}$ in order to guide the electromagnetic wave properly through the horn structure. For other possible orientations of copper wires in the

FIGURE 2 Photograph of plasma horn antenna arranged inside anechoic test box [Colour figure can be viewed at wileyonlinelibrary.com]

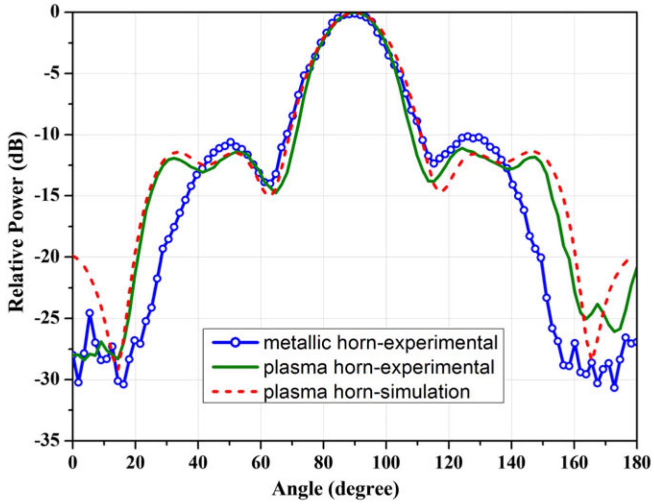

FIGURE 3 E plane radiation pattern of test horn and corresponding metallic horn [Colour figure can be viewed at wileyonlinelibrary.com]

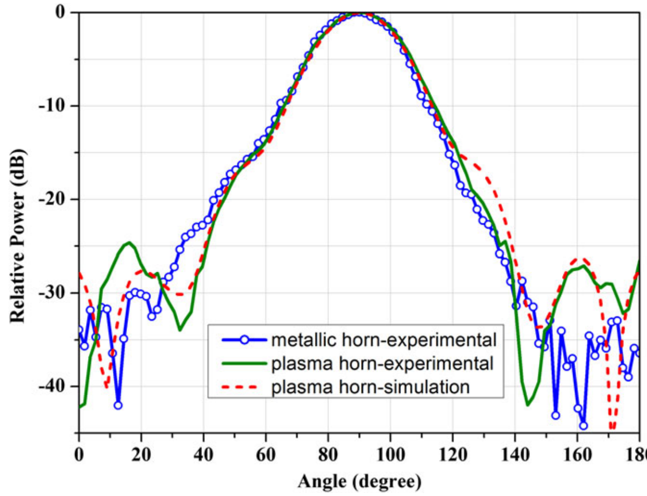

FIGURE 4 H plane radiation pattern of test horn and corresponding metallic horn [Colour figure can be viewed at wileyonlinelibrary.com]

plasma sheet, the boundary conditions are not satisfied perfectly as for the conventional horn antenna.

3 | MEASUREMENTS AND RESULTS

The E and H-plane radiation patterns of the plasma horn (X band) are drawn using a vector network analyzer by arranging it inside an anechoic test box as depicted in Figure 2. A pyramidal frame made up of low loss dielectric strips of thickness 2 mm and width 3 mm is used for loading the metallic wires.

E-plane radiation pattern of the antenna under test (AUT) for frequency 8.5 GHz is shown in Figure 3. The result obtained by simulation is also plotted in the figure which is found to be in excellent agreement with the experimental one. The radiation pattern of an equivalent metallic horn is included in the figure for comparison purpose. The patterns of the metallic horn and the plasma antenna are remarkably similar except for small deviations in side lobe width which may be due to slight leakage of the power through the plasma medium. But their half power beam widths are found to be in excellent agreement.

Figure 4 depicts the H-plane radiation pattern obtained for the AUT (8.5 GHz) along with the simulation result and that obtained for the metallic counterpart. The similarity of the radiation patterns of the plasma horn with an equivalent metallic horn clearly verifies the possibility of replacing the conventional one with this new light weight antenna. Increase in voltage standing wave ratio compared with its equivalent metallic horn is negligible due to the presence of the launcher, which reduces the mismatch between metallic waveguide and the plasma horn. A slight decrease in axial gain ($\lesssim$ 2 dB) is observed which may not be a major concern while considering its manifold positive advantages.

It is observed that plasma sheets fabricated using metallic wires of smaller radius shows same results whereas if the radius is increased beyond 1 mm, the pattern shows deviations from the expected one. Plasma sheets fabricated with wires of different radii between 20 μm and 1 mm are used for constructing various test horns and the radiation patterns obtained are found to be identical.

4 | CONCLUSION

The performance of a new featherlight plasma horn antenna constructed using artificial negative permittivity metamaterial medium has been presented. It is fabricated by replacing the metallic walls of the conventional pyramidal horn with plasma sheets made with array of very thin copper wires. The results clearly show that the proposed horn is capable of producing almost the same radiation characteristics as that of an equivalent metallic horn. The attractive feature of the proposed plasma horn is the considerable reduction in weight compared to its metallic counterpart. With proper strengthening mechanism this novel antenna is ideal for the situations like satellite communications where the antenna weight is a major concern. Since it is easy to fabricate the proposed plasma antenna with large collecting aperture, it can also be employed in astronomical data collection purposes by installing them in the form of a 2D array to obtain a pointed radiation beam. Since the structural deformities due to wind and rain and the installation difficulties of this antenna are comparably lower than the other antennas presently employed in the field, our antenna may find a wide variety of applications associated with various microwave technologies.

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