THZ BAND HORN ANTENNAS DESIGN

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Abstract

The report is concerned with the development of the irradiating antennas for THz radiation source. The THz radiation is irradiated by relativistic high brightness electron bunch traveling through the Cherenkov decelerating capillary channel [1]. Irradiation systems are built as horn antennas type with circular and rectangular cross-sections. Irradiating antennas are constructed directly to the open end of the capillary channel and are used for the THz radiation directivity enhancement after passing through the capillary output. The investigation of the horns directivities were performed using the far-field analysis of the emerging radiation. The antennas were also investigated to perform low values of the reflected power.

INTRODUCTION

High-power THz radiation source based on photoinjector and decelerating capillary channel is now one of the most discussable compact facilities providing monochromatic THz radiation of power high enough to be used for cargo introscopy [2].

Facility is based on two main parts: accelerating structure and decelerating radiating channel. Capillary is placed right after the accelerating structures and is made of copper with either dielectric coated inner surface or corrugated surface.

For effective irradiation of THz radiation from the capillary structure the high values of capillary RF matching with the open space and high directivity values are out to be fulfilled. Capillary that irradiates in the free space with its open end doesn't provide enough directivity that can be seen from the angular pattern shown in the Fig. 1. To enhance the directivity of the radiation the open end of the capillary must be attached to the irradiating antenna. As the capillary has a circular cross-section the optimal geometry of the horn is based on the horn antenna that is directly fitted to the metal parts of the capillary and is fabricated with it as a whole entity.

Main parameters of the antenna are the directivity, angle between the longitudinal axis and main lobe, main lobe angular width and horn power reflection coefficient. Angular width of the main lobe is the parameter defining the distance between two directions of the lobe with 3dB power decay between them. Important parameter is also bandwidth of the horn that is defined as frequency difference between horn working frequency (resonant frequency of the capillary) and the frequency of horn -20dB power reflection level.

There are several different types of horn designs. This article is concerned with the modelling of the horns with circular and rectangular cross sections. All antennas are discussed for the metal Cherenkov irradiating capillary with 300 μm aperture and 31 μm polytetrafluoroethylene coating on the metal surface. Resonant frequency of this type of capillary is 0.96 THz. Work band on the level of -3 dB of the maximal power transmission is 3.2%.

CIRCULAR HORN ANTENNA

Circular antenna is the most conventional type of antenna for such devices (Fig. 2). The model of the horn was built and calculated using the CST Microwave Studio [3]. To define the maximum effective horn parameters the electrodynamics characteristics were studied while varying the horn geometrical parameters. The opening angle was varied while the horn length was kept L=1 mm (fig. 3). After that with the angle equal 14.5 degrees (that corresponds to maximal directivity of the horn) length of the horn was varied (Fig. 3). The investigations were held in the frequency band of 0.7-1.1 THz.

The graphs in the Fig. 3 show that the increase of the horn opening angle decreases its directivity and bandwidth. Main lobe width is increased at the same time. Variation of the horn length leads to the enhancement of the directivity at the 4.8 mm length and then results in its reduction with higher values of the parameter. Inverse relationships are specific for main lobe direction and angular width.

Minimum of the reflection coefficient is defined at the 1 THz region for all discussed geometries. Opening angle enhancement leads to growth of the reflection on the resonant frequency value and bandwidth of the horn decreases. The frequency dependent values of the power reflection coefficients for varying geometrical sizes are depicted in the Fig. 4.

For more clearance the visualization of the horn directivity the directional diagrams are depicted in the Fig. 5. The diagrams are shown for the maximal directivity case of the horn antenna (length of the horn is 4.8 mm and 14.5 degrees opening angle). For maximal values of the mail lobe angular width the same graphs are shown in the Fig. 6. Antenna has corresponding parameters: 4.8 mm length and 57 degrees opening angle.

Characters of all dependences confirm the convention model of horn antennas modeling for lower frequency ranges.

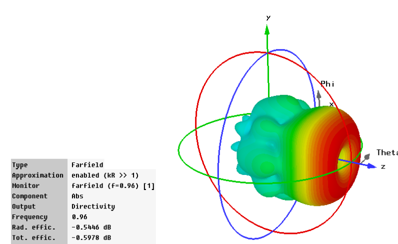

Figure 1: Directivity diagram of the open capillary end.

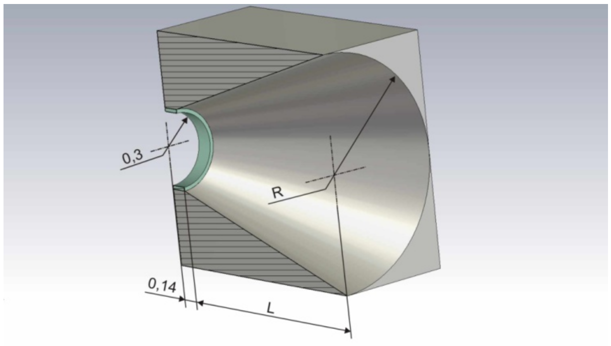

Figure 2: Circular horn antenna and the capillary.

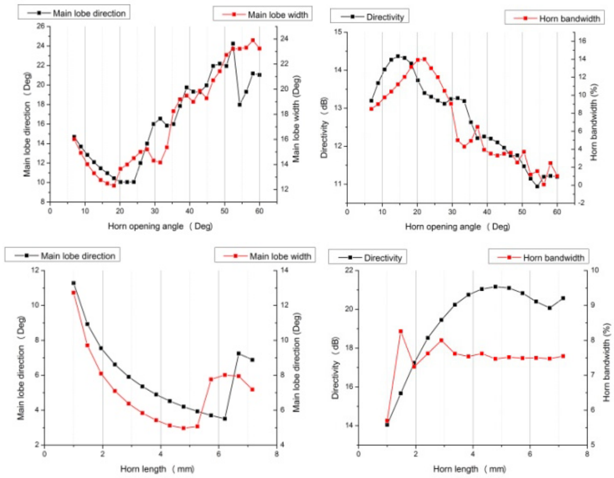

Figure 3: Dependences of electrodynamics characteristics vs. circular horn geometrical sizes.

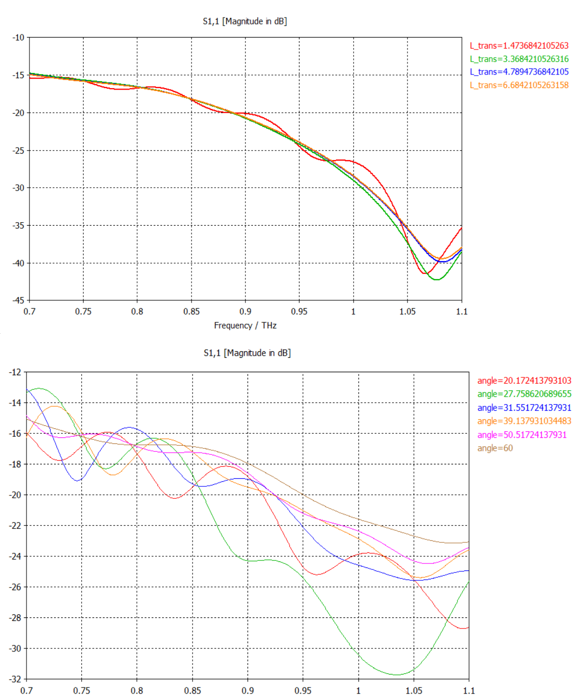

Figure 4: Reflection coefficients of the horn for different geometrical sizes of the horn.

At one definite point of horn opening it has maximal directivity and minimal value of main lobe angular width, minimal reflection coefficient and maximal bandwidth. Increasing of reducing of the angles leads to characteristics dramatic changing. Reduction of angular opening leads to unoptimized parameters levels and increasing – to enhanced values of phase distortions in its opening [3].

RECTANGULAR HORN ANTENNA

The second type of considered horns is the horn with variable cross-section (transition from circular to rectangular). The horn is attached directly to the coated capillary. The transition from circular to rectangular cross-section is done directly inside the opening (Fig. 7). To investigate the horn parameters the electrodynamics characteristics were tracked while changing the horn geometry.

The outstanding feature of this type horn vs. the circular horn is possibility to acquire the straightforward main lobe of the radiation. Dependences reveal the increase of horn directivity while opening angles reduction in both directions (Fig. 8). Increase of the openings in one of the planes leads to dramatic increase of the main lobe in this plane and a little less increase in another plane. Power reflecting coefficient of the horn increases if one of the opening angles equals zero. At even more increase of the parameter doesn’t change. Horn bandwidth increases with opening increase and reaches the borders of investigated frequency region with the vertical opening angle equal 7.5 degrees [4].

For the case of maximal directivity of the horn (15 degrees opening angles in both planes) the length variation was held. The results of investigation consist in maximal directivity equal 22.5 dB with the horn length 2 mm. In whole band of 0.7-1.1 THz the reflection coefficient doesn’t increased of -20 dB.

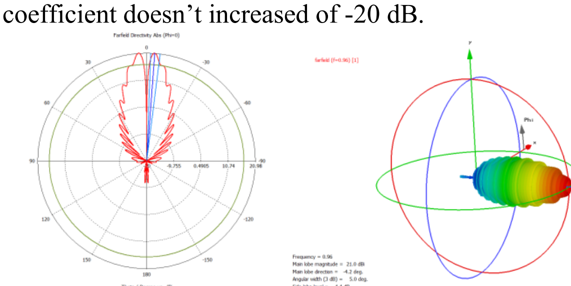

Figure 5: Circular pattern and 3D diagram for maximal directivity of circular antenna.

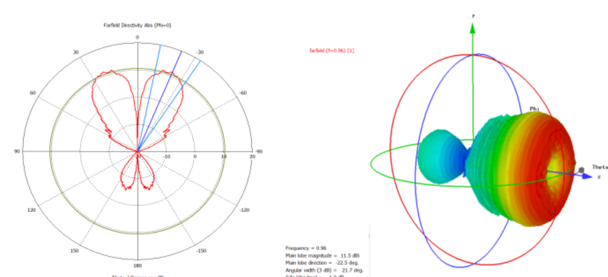

Figure 6: Circular pattern and 3D diagram for maximal main lobe angular width of circular antenna.

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For the horn with maximal directivity (2.71 mm length, opening angles 15 degrees) the circular patterns of the horizontal and vertical directions and 3D directivity diagram were acquired. The side lobes are practically absent and the main lobe is directed straight forward (Fig. 9). For the case of maximal main lobe angular width (7 mm length, 15 degrees vertical opening angle and 60 degrees horizontal one) the diagrams are represented in the Fig. 10.

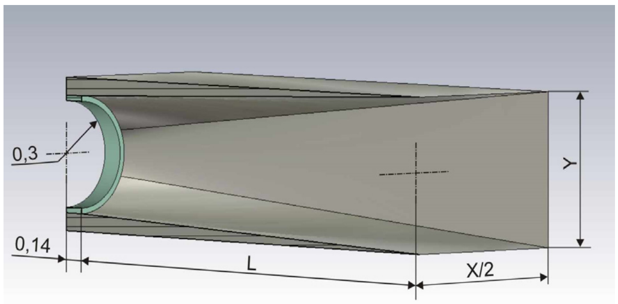

Figure 7: Horn antenna with circular to rectangular cross section transition and the capillary.

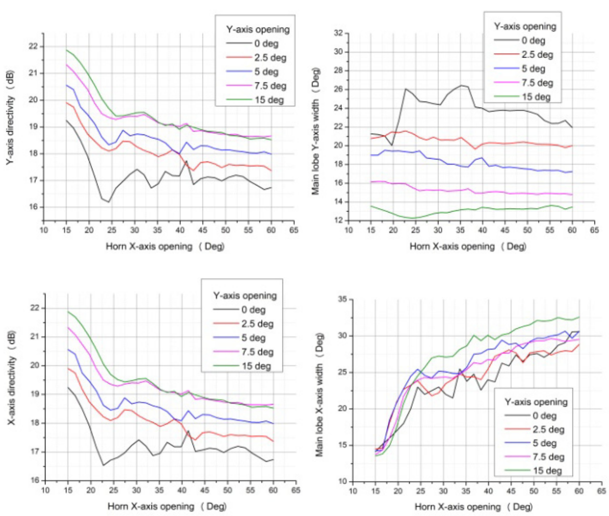

Figure 8: Dependences of electrodynamics characteristics vs. rectangular horn geometrical sizes.

CONCLUSION

By the means of the investigation results it turns out that to acquire high directivity of the THz radiation from the Cherenkov channel irradiating horn antenna can be effectively exploited. For the case when there is no need to irradiate the object placed directly on the axis of the channel the circular cross-section horn can be applied. If there is a demand for irradiation of the axis-aligned objects the rectangular cross section antenna can be used. Herein both types of the horns can be well-directed (~20 dB main lobe) after optimization and provide low levels of power reflection rates (<20 dB). Parameters and directivity diagrams of the both types of horns are declared for the cases of maximal directivity and for maximal main lobe angular widths.

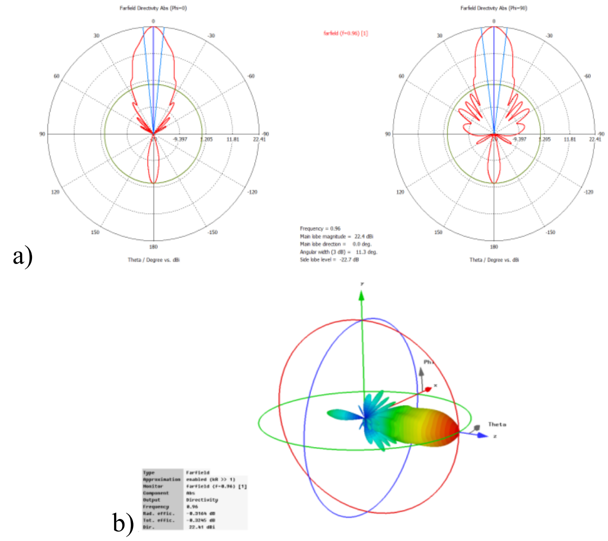

Figure 9: Circular pattern in horizontal plane (a - left), in vertical plane (a - right) and 3D directivity diagram for maximal directivity of rectangular antenna.

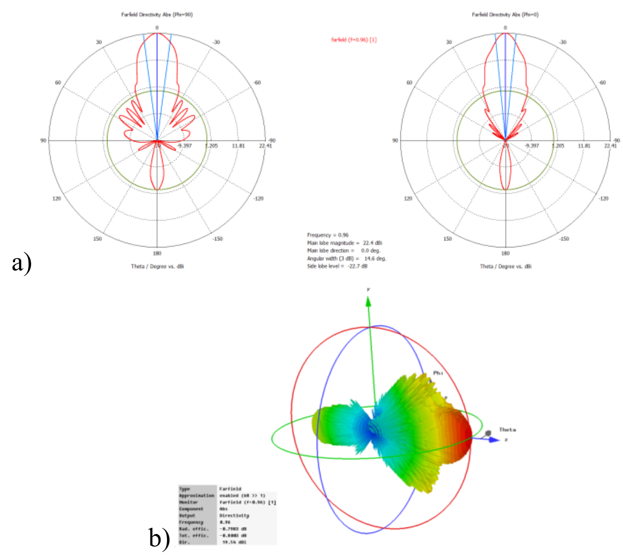

Figure 10: Circular pattern in horizontal plane (a - left), in vertical plane (a - right) and 3D directivity diagram for maximal main lobe angular width of rectangular antenna.

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