Characteristics of Smooth-Walled Spline-Profile Horns for Tightly Packed Feed-Array of RATAN-600 Radio Telescope

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Abstract. In this paper we present a design of highly packed multi-beam receiving array. The requirements to the individual element of antenna array are formulated and the smooth-walled spline-profile horn as the adequate candidate is proposed. The utilization of such array in the RATAN-600 radio telescope will allow for providing the minimum beam spacing about (1.16-1.32) HPBW that is close to the best results in the highly packed multi-beam receiving array.

1. Introduction

In order to expand essentially the field of view and receive both the multi-pixel radio images of some extent of the sky area and a quickly variable cosmic source without mechanical scanning the multi-beam receiving array with tightly packed feed elements is required. With respect to the millimetre wavelenght range the use of the phased focal plane array is not always acceptable due to small aberrations in the case of feed removal from the main mirror focus and the large insertion loss in the radiation forming matrix. Therefore, the non-phased focal receiving feed-array is a more preferable one for the millimetre radio telescopes. Here, the highly sensitive compact receiving module with a cross section less than the horn's cross section follows the each feed of the array [1]. The characteristics and optimization method of highly packed multi-beam receiving array with stripline radiators are considered in [2]. The resonance nature of such radiators allows one to achieve the cross section less than /2 λ thereby realizing densely packed multi-beam receiving array. However, the low radiation efficiency and narrow bandwidth make these radiators undesirable for radio astronomy applications.

In this paper the problems concerning a design of the highly packed multi-beam receiving array are discussed and the preferable single radiator as a feed of tightly packed array of RATAN-600 radio telescope is presented.

2. A Tightly Packed Multi-Beam Receiving Focal Array for the Radio Telescope

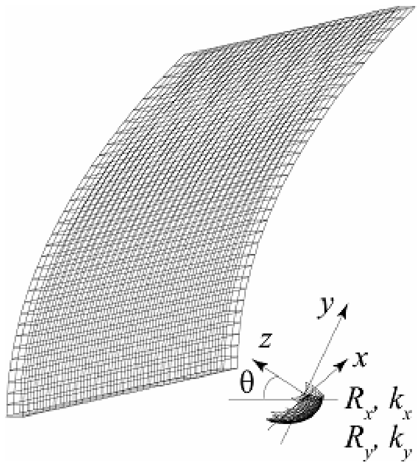
As a distinctive feature of the multi-beam receiving array is the ability to form the multi-pixel image in the wide field of view without mechanical scanning and special phasing techniques. A property like that is achieved by means of employing in the modern radio telescopes the low aberration long-focus optics and packing density as much possible (ideal) of the focal array. Under the ideal packed of the multi-beam receiving focal array we understand the satisfaction of the spatial sampling theorem conditions in accordance with the Rayleigh criterion. In this case the neighbouring beams of radio telescope are overlap at the half power level and the distance between the adjacent beams equals to the half power beam width (HPBW). It allows one to create a map of the sky part under investigation without the "holes".

The main limitation of the hight packing density achievement is the impossibility to agree the physical size (diameter) of the primary feed (horn) with the physical size (diameter) of the focal spot (FS). In accordance with the Gaussian beam optics, the intensity of EM field within the limits of FS decreases 2e times (86.5%) at the distance 0 w from the reflector axis thereby determining the effective radius of the FS [3]:

$$\omega_0 = 0.22\,\lambda \frac{f}{D}\sqrt{T_e}$$

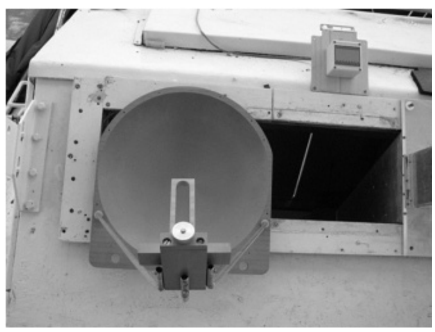
where f is the focal length, D is the aperture size, T_e is the edge taper level of the reflector in dB. Than the diameter of FS for $D/f = 0.4$ equal $2w_0 \approx 1.12\ \lambda$.

At the array step $2w_0$ the spacing of beams of the radio telescope is close to be optimal and equal (1.16 -1.32) HPBW depending on the decreasing level of radiation on the aperture edge (-10 ÷ -13*dB*). However, the practically attainable aperture diameter of the efficiency horn is usually larger than 1.12 λ. As a result, the radio telescopes with the most closely packed multi-beam receiving array in the millimetre wavelength range have the spacing of beams (1.8 − 2.8) HPBW [3]. In this case the minimum is usually achieved by meance of the pre-focal quasi-optical focusing. This allows one to optimize the size and shape of the FS.



a)

b)



c)

Fig. 1. Model of the secondary and the tertiary mirrors (a), photo of the secondary (b) and the tertiary mirrors (c).

Figure 1. shows a standard focusing optics with the secondary mirror and new tertiary mirror installed in the secondary focus. The tertiary mirror has the non-symmetrical quasi-elliptical form.

The feed of the highly packed multi-beam receiving array has to provide the high aperture efficiency (more than 98%) and to have a reduced aperture cross section to diminish the step of the focal plane array. Therefore, the reasonable compromise between the high aperture efficiency and the acceptable side-lobe level this feed should be found. To this end, the comparative analysis of characteristics of the corrugated horn, the horn with a dielectric filling, and the smooth-walled spline-profile horn has allowed us for choosing the latter as the best feed. By employing the horn optimization method described in [4], the smooth-walled spline-profile horn has been optimized.

The feed prototype consists of the smooth-walled spline-profile horn with a transition from the rectangular waveguide to the circular one. Sixteen individual feeds for the multi-beam focal plane array have been manufactured and tested (Fig. 2). The radiation patterns were measured on the experimental set-up described in [5], while the input reflection coefficient was measured on the Agilent Network Analyzer PNA-L N5230A. By taking into account that the input reflection coefficient and radiation pattern are virtually the same for all sixteen feeds, we show this coefficient (Fig. 3) and readiation pattern (Fig. 4) only for a one of them. The discrepancy of calculated and measured results can be caused by the small dimensional deviations during the manufacturing process. The radiation patterns were measured at 34GHz, 36GHz and 38GHz. As one sees from this picture the radiation pattern is virtually the same in both principal planes. The side-lobe levels are less than -18dB in both planes for all the frequencies and the cross-polarization level is less than -20 dB. The maximum gain is 18dBi at a top of the frequency band.

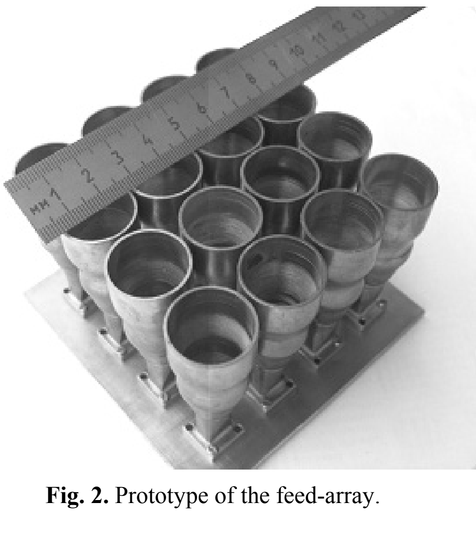


Fig. 2. Prototype of the feed-array.

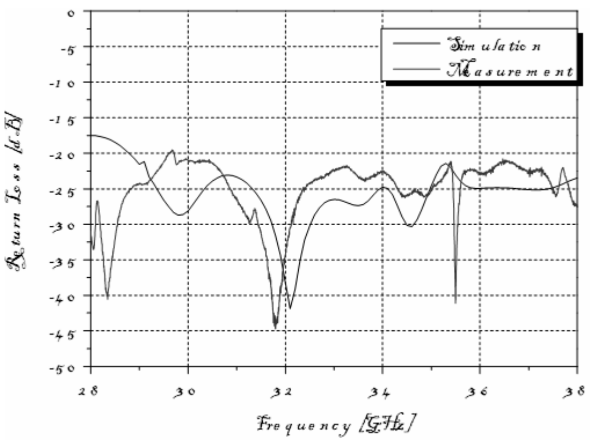


Fig. 3. Simulated and measured input return loss of the smooth-walled spline-profile horn.

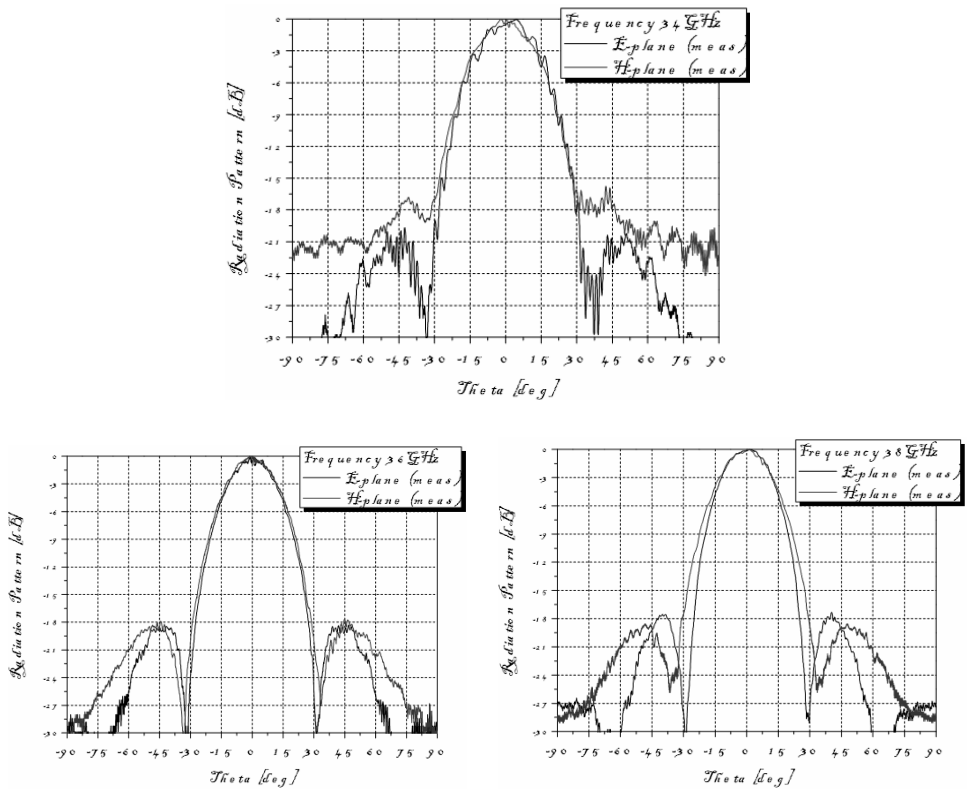


Fig. 4. Measured radiation pattern of the smooth-walled spline-profile horn.

As it follows from simulations, the feed-array composed of such the smooth-walled spline-profile horns will allow one to achieve the beam spacing of the radio telescope RATAN-600 about (1.16 −1.32) *HPBW*. This value is close to the best results in the highly packed multi-beam receiving array without applying the special pre-focal quasi-optics.

3. Conclusion

The features in designing the highly packed multi-beam focal array for RATAN-600 have been examined.

The experimental investigations of the smooth-walled spline-profile horn have shown that the individual radiator design like that meets to stringent requirements to the size and efficiency of the compact radiators from their applications in the highly packed multi-beam focal array located in the tertiary focus of the radio telescope point of view. The measured beamwidth of the optimized smooth-walled spline-profile horn at the level -10dB is less than 45^0 in the H- and E-planes. The side lobe level is less than -18dB in both principal planes and the input reflection coefficient is better than -20dB in the frequency range 30GHz-38GHz. The experimental results are in good agreement with simulated ones in the operational frequency band 34GHz-38GHz. The use of the proposed feed in the RATAN-600 radio telescope will allow for providing the minimum beam spacing about (1.16 − 1.32) *HPBW* and the compact array packaging close to the ideal.

References

[1] V.B. KHAIKIN, V.R. ZAKAMOV, V.I. SHASHKIN, S.E. KUZMIN and V.N. RADZIKHOVSKY, *A wideband receiver-module for passive mm wave imaging array: optimization and test results*, In Proceed. of MSMW, pp. 45–47, Kharkov, Ukraine, June 2010.

[2] E.K. MAJROVA, V.B. KHAIKIN, *Characteristics of radio telescopes with multi-element strip focal arrays*, Izv. VUZov. Radiofizika, v..XLVIII, N2, pp. 245–251, 2005.

[3] P. GOLDSMITH, Quasioptical Systems, IEEE, New York, 1998.

[4] C. GRANET, G.L. JAMES, R. BOLTON and G. MOOREY, *A smooth-walled spline-profile horn as an alternative to the corrugated horn for wideband millimeter-wave applications*, IEEE Trans. Antennas Propag **52** (3), pp. 848–854, 2004.

[5] A.S. ANDRENKO, I.V. IVANCHENKO, D.I. IVANCHENKO, S.Y. KARELIN, A.M. KOROLEV, E.P. LAZ'KO, N.A. POPENKO, *Active Broad X-Band Circular Patch Antenna*, IEEE Antennas and Wireless Propagation Letters **5**, pp. 529–533, 2006.