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Spline-Profile Horn for Array Applications in Radio Astronomy

R. Ye. Chernobrovkin, N. O. Popenko, V. B. Khaikin[1], and C. Granet[2]

O. Ya. Usikov Institute for Radiophysics and Electronics of NAS of Ukraine,
12, Akad. Proskury St., Kharkiv, 61085, Ukraine
ireburan@yahoo.com

[1]Special Astrophysical Observatory of Russian Academy of Sciences (NRTT Lab.)
21, Polytechnicheskaya St., off. 201, St. Petersburg, 194021, Russia
vkhstu@mail.ru

[2]BAE Systems Australia,
40-52 Talavera Road, North Ryde NSW 2113, Australia
Christophe.Granet@baesystems.com

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In this paper the properties of an optimized compact smooth-walled spline-profile horn for the $30 \div 38$ GHz frequency band is described. The measured 3 dB beamwidths are $40°$ in the *H*-plane, $37°$ in the *E*-plane, and $38°$ in the $45°$-plane. The measured sidelobe levels are less than –30 dB in *H*-plane, –23 dB in *E*-plane, and –25 dB in $45°$-plane. The maximum gain is 13.8 dBi. The measured cross-polarization level is less than –20 dB at the top of the band. The antenna measurement and test results are in good agreement with simulation. The results of the trial observations at the RATAN-600 radio telescope with the horn are given. We consider using such a horn as an efficient element in a multi-beam receiving array for a radio telescope.

1. Introduction

Over the past few years, some of single-reflector radio telescopes have moved towards a multi-beam mode of operation allowing one to expand essentially the field of view and to receive multi-pixel radio images of some extent of the sky area or a rapidly variable cosmic source without mechanical scanning [1-3]. For the realization of such a mode of operation, a multi-beam receiving array with elements as densely packed as possible is required to avoid a map undersampling. The significant challenges in designing the multi-beam receiving array feed-elements are the compactness and preservation of their characteristics (radiation pattern, gain, return loss, side lobe level, cross-polarization level, mutual coupling of adjacent elements, etc) over the generally wide bandwidth required by modern receivers.

In this paper the simulated characteristics and test results of a compact and efficient smooth-walled spline-profile horn are presented. Such a horn may be used for both radio astronomy as an effective single antenna [4] and the radio telescope as an efficient compact feed of the multi-beam receiving array [5].

2. Smooth-Walled Spline-Profile Horn

The conventional corrugated horn with a linear profile is widely used in radio astronomy and is effective enough, but the corrugation-depths are added to the overall cross-section size of the element that restricts a possibility of packing the elements close to each other in array applications. The radiation pattern of the smooth-walled spline-profile horn is formed by exciting, through a change in the profile, the higher-order modes with correct amplitude and phase relationships. Such a spline profile allows us to optimize both the radiation pattern characteristics and size of the horn. The optimization method being employed here is described in [6]. It is worth noting that this optimization algorithm is fast and accurate and has been now adopted by others, such as [7]. A number of nodes and profile coefficients at these nodes (from a_1 to a_5 and a_0 in Fig. 1) are chosen to create the spline-profile providing a suitable radiation pattern over the entire operational frequency band. The constraining coefficients (from d_1 to d_5 and d_0 in Fig. 1) are applied to create the optimized spline-profile which could be realized in the horn prototype.

Regarding to the multi-beam receiving array applications the aperture size of the horn is limited to about $1.6\lambda_0$ (where λ_0 is the wavelength). Therefore the size a_0 is a fix-value that is not optimized. Furthermore, the radiation pattern has to have a –10 dB beamwidth of about 80° and a target cross-polarization level lower than –20 dB. All these conditions, and a return loss target of –20 dB, were taken into account using the technique in [6] and the horn geometry was optimized to cover the $30 \div 38$ GHz frequency band. The calculated radiation patterns of the optimized smooth-walled spline-profile horn are shown in Fig. 2. Note that the mismatch at the aperture and the flange effect are taken into account in this simulation.

The input reflection coefficient $|S_{11}|$, horn gain and mutual coupling coefficient $|S_{12}|$ versus the frequency were simulated by using the Software Package CST Microwave Studio. As can be seen from Fig. 3, the mutual coupling between adjacent horns is less than –38 dB over the entire operational frequency band.

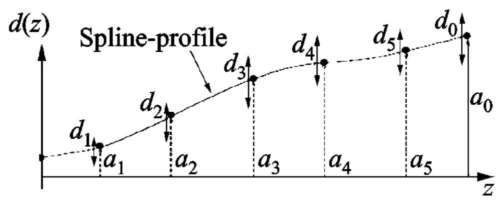

Fig. 1. *Spline-profile horn geometry*

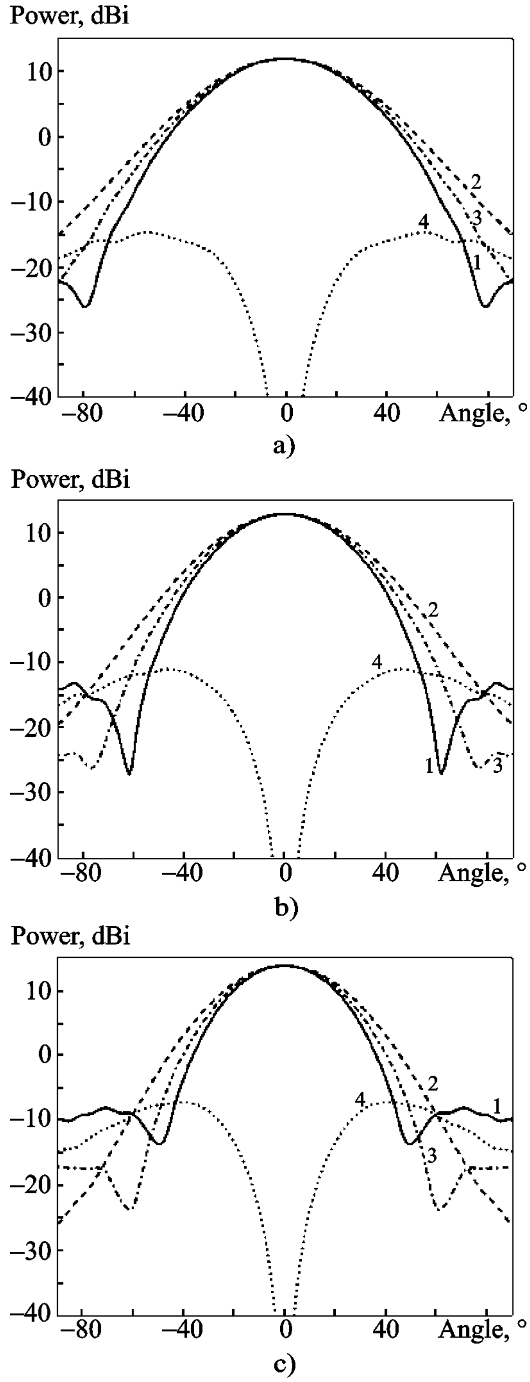

Fig. 2. *Calculated radiation patterns of the smooth-walled spline-profile horn with the circular-to-rectangular transition at 30 GHz (a), 34 GHz (b), and 38 GHz (c): 1 – E-plane; 2 – H-plane; 3 – 45° -plane; 4 – cross-polarization*

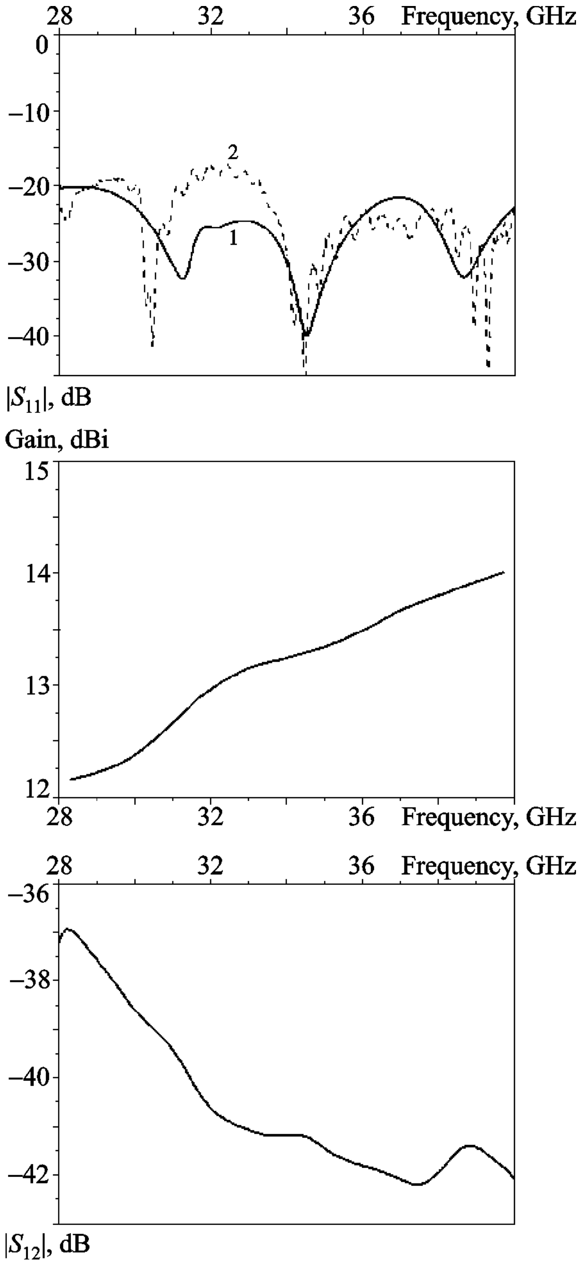

Fig. 3. *Calculated (1) and measured (2) reflection coefficient* $|S_{11}|$, *calculated gain G and mutual coupling coefficient* $|S_{12}|$

The optimized profile of the horn is given in Fig. 4 (top). The antenna prototype (Fig. 4, bottom) consisting of the optimized smooth-walled spline-profile horn and a transition from the rectangular to circular waveguide has been manufactured.

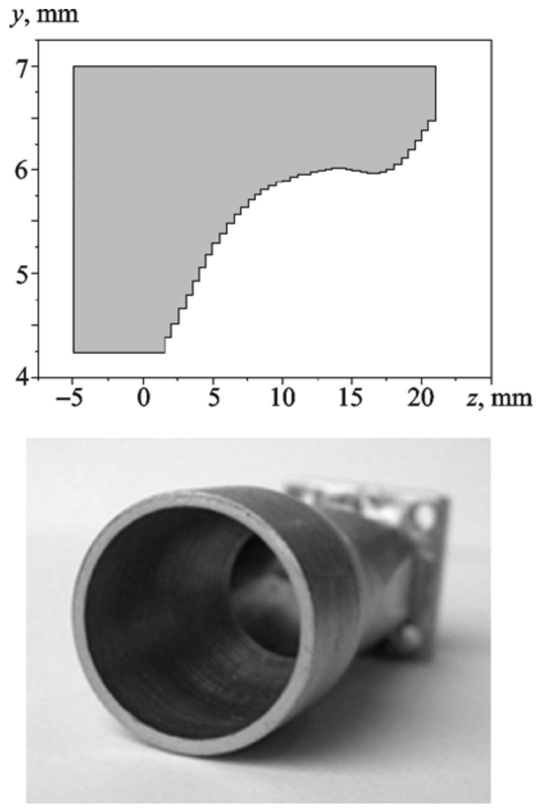

Fig. 4. *The optimized spline-horn profile (top) and antenna prototype (bottom)*

3. Antenna Measurements and Test Results

The radiation pattern of the horn was measured by the method described in [8]. The measured and simulated beamwidths at different levels are given in Table which shows good agreement between the calculated and experimental results. Measured radiation patterns of the horn are given in Fig. 5 at the top of the frequency band (38 GHz).

The sidelobe levels are less than –30dB in *H*-plane, –23 dB in *E*-plane, and –25 dB in 45° -plane. The maximum gain is 13.8 dBi. Measured cross-polarization level is less than – 20 dB at the top of the frequency band.

The antenna performances of the RATAN-600 radio telescope with the smooth-walled spline-profile horn as a feed were measured in November 2008. Subsequent observations of the Sun (Figs. 6, 7) have shown the real fine structure

Table. *Comparison of the simulated and measured results*

	Horn + circular-to-rectangular transition			Measurements		
Level	*E*-plane	*H*-plane	45° -plane	*E*-plane	*H*-plane	45° -plane
–3 dB	35.8°	42°	38.6°	37°	40°	38°
–10 dB	62.8°	77.2°	68.8°	59°	76°	70°
–20 dB	82.5°	111.6°	94.8°	79°	114°	96°

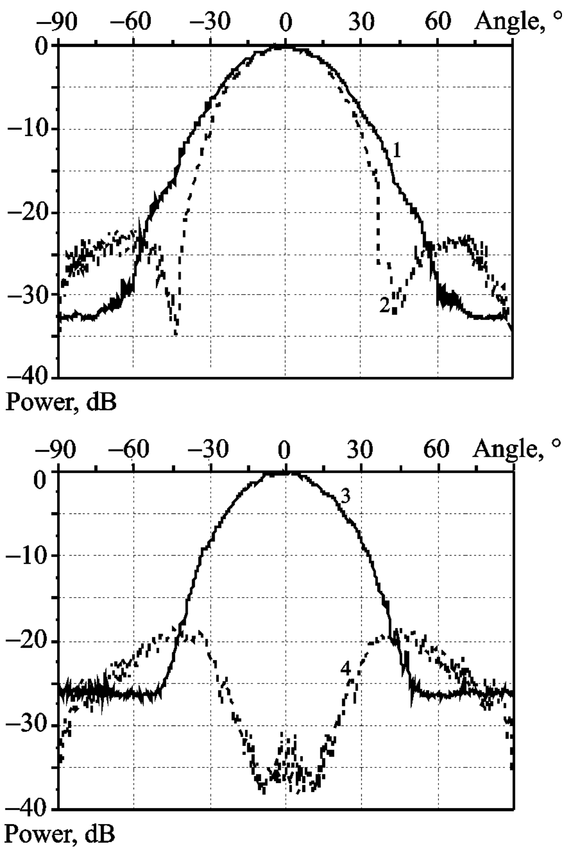

Fig. 5. *Measured radiation patterns of the smooth-walled spline-profile horn at 38 GHz: 1 – H-plane; 2 – E-plane; 3 – 45° -plane; 4 – cross-polarization*

of the Solar emission in the 8 mm band including the Super granulation and some other events which were also recognised at longer wavelengths of the Panoramic Analyser of Spectrum [9]. Trial observations were done on the "South-sector+Periscope" antenna system of the RATAN-600 radio telescope with a single beam receiver, which

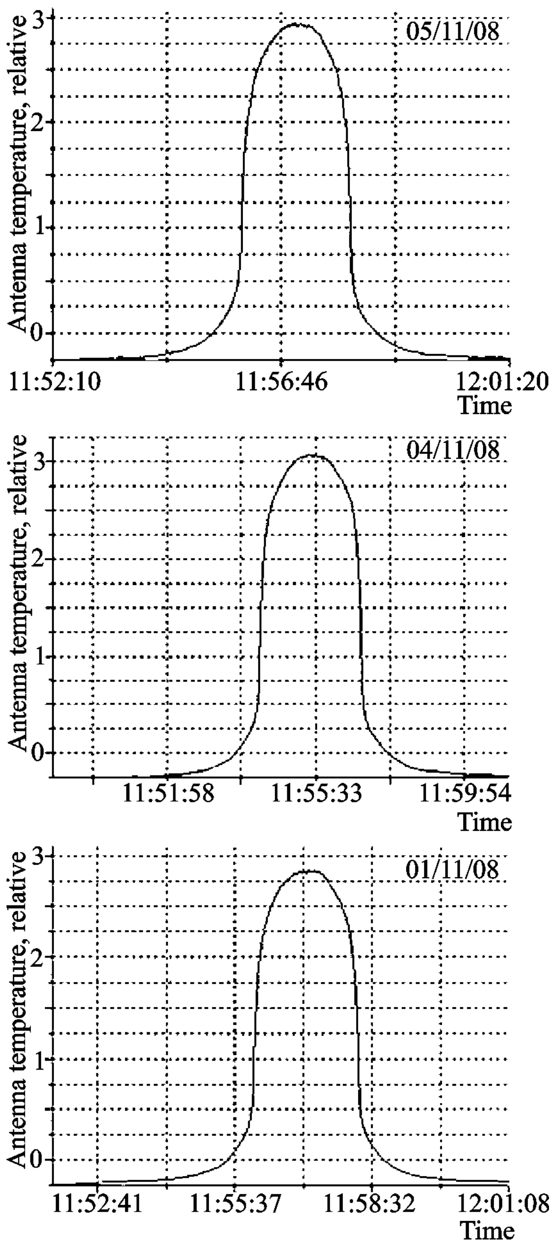

Fig. 6. *The Sun passing the RATAN-600 beam in 3 days of November 2008*

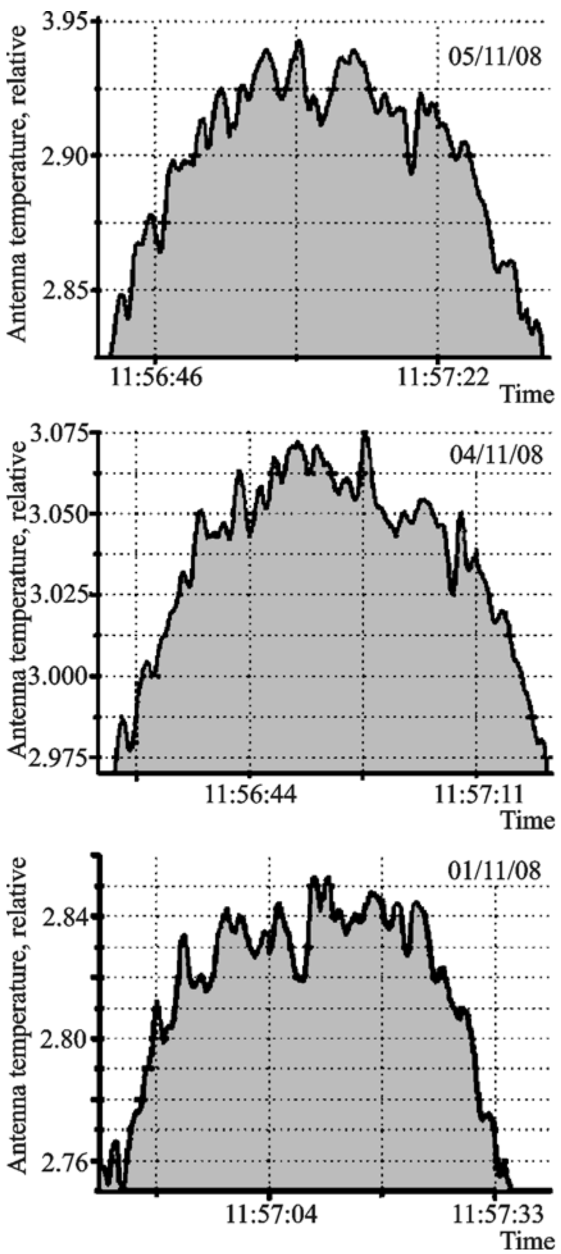

Fig. 7. *The top of the Sun passing the RATAN-600 beam in 3 days of November 2008*

is similar to the array receiver operating in a modulation mode with a digital output, described in [5]. The following observations of calibration cosmic sources at the North sector of the RATAN-600 with the single beam receiver and the new horn have demonstrated a similar aperture efficiency which was simultaneously achieved with a scalar horn at lower frequency ($30 \div 32$ GHz).

4. Conclusions

A smooth-walled spline-profile horn operating in the $30 \div 38$ GHz frequency band has been optimized, manufactured and tested. The horn is compact and the mutual coupling between adjacent horns is less than –38 dB. The measured horn performances are in good agreement with the simulated ones. The trial observations of the Sun on the RATAN-600 radio telescope with aforementioned feed-horn show the expected radio telescope performances. In this respect we can conclude that the proposed smooth-walled spline-profile horn is a good candidate for the radio telescope multi-beam focal array.

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Рупор со сплайн-профилем для применения в решетках в радиоастрономии

Р. Е. Чернобровкин, Н. А. Попенко, В. Б. Хайкин, К. Гранет

В работе описаны свойства оптимизированного компактного гладкостенного рупора со сплайн-профилем для диапазона частот $30 \div 38$ ГГц. Измеренная ширина диаграммы направленности на уровне –3дБ равна 40° в *H*-плоскости, 37° в *E*-плоскости, и 38° в 45°-плоскости. Измеренный уровень боковых лепестков меньше чем –30 дБ в *H*-плоскости, –23 дБ в *E*-плоскости и –25 дБ в 45°-плоскости. Максимальный уровень коэффициента усиления равен 13.8 дБ. В верхней части диапазона измеренный уровень кросс-поляризации меньше –20 дБ. Результаты численного моделирования хорошо соответствуют результатам экспериментального исследования. Приведены результаты тестовых измерений на радиотелескопе РАТАН-600 с предложенным рупором. Мы считаем, что представленный рупор может быть использован как эффективный элемент в многолучевых приемных решетках радиотелескопа.

Рупор зі сплайн-профілем для використання в решітках в радіоастрономії

Р. Є. Чорнобровкін, Н. О. Попенко, В. Б. Хайкін, К. Гранет

В роботі описано оптимізований компактний гладкостінний рупор зі сплайн-профілем для діапазону частот $30 \div 38$ ГГц. Виміряна ширина діаграми спрямованості на рівні –3 дБ була 40° у *H*-площині, 37° у *E*-площині, 38° у 45°-площині. Виміряний рівень бокових пелюсток –30 дБ в *H*-площині, –23 дБ в *E*-площині, –25 дБ у 45°-площині. Максимальний рівень коефіцієнта підсилювання був 13.8 дБ. У верхній частині діапазону виміряний рівень кросс-поляризації був нижчим –20 дБ. Результати чисельного моделювання добре співвідносяться з результатами експериментального дослідження. Наведено результати тестових вимірювань на радіотелескопі РАТАН-600 з розглянутим рупором. Ми вважаємо, що описаний рупор може бути використаний у якості ефективного елементу в багатопроменевих приймальних решітках радіотелескопа.