7X8 ELEMENT MMIC ARRAY AT 26-30 GHZ FOR RADIO ASTRONOMY APPLICATIONS

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Multi-element MMIC array architecture for RATAN-600 radio telescope is offered. The proposed solution can be used for other wide-angle reflector radio telescopes with offset illumination as well. The description and characteristics of MMIC array prototype are given. Antenna characteristics of RATAN-600 in multi-beam operational mode and some radio astronomical applications are presented.

1. Introduction

Focal receiver arrays seem to be an unavoidable solution for the existing and the next generation reflector radio telescopes where high sensitive (or high speed) mapping is the main goal [1-2]. The significant progress in MMIC array technologies [3] gives us a chance to fully realize an important RATAN-600 radio telescope advantage - the wide aberrationless focal zone [4]. A multi-element feed array if placed along the focal plane may significantly increase RATAN-600 sensitivity and the field of view.

2. Multi-element “terraced” MMIC array architecture

The main difficulty of construction of multi-element feed arrays for a radio telescope consists in necessity of their maximum dense packing. So it is a problem to fully sample all the information in the focal plane and fully illuminate the reflector. The main technical problem in MM range is how to place a receiver near an antenna element of an active focal array. The traditional solution is the "module architecture" where a compact receiver is placed behind the waveguide or a dipole microstrip radiator [5]. One of the practical examples of 91 element MMIC array uses module-honey-comb architecture[6]. In SKA bow-tie array elements are printed on PCB's and vertically oriented[7], so one board includes 64 or more radiators and receivers lying in one plane. We propose multi-level "terraced" architecture with horizontally oriented patch radiators and receivers. This construction is the most suitable for a radio telescope with offset illumination. In fact, together with technological advantages it gives us the best beam efficiency in comparison with a flat array.

The «terraced» three-dimensional construction of 7x8 element MMIC focal array in MM band is shown in Fig.1 a,b.

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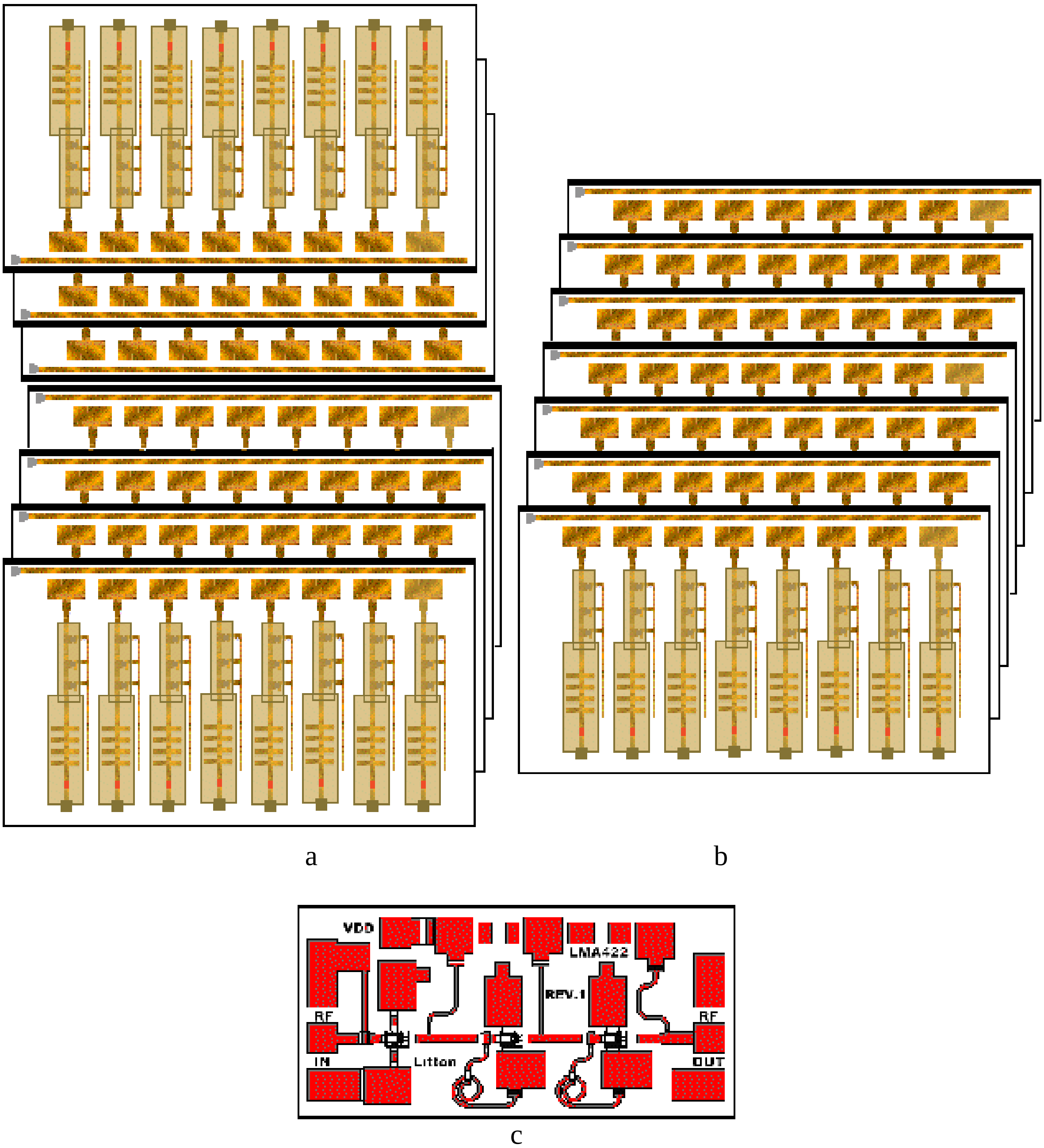
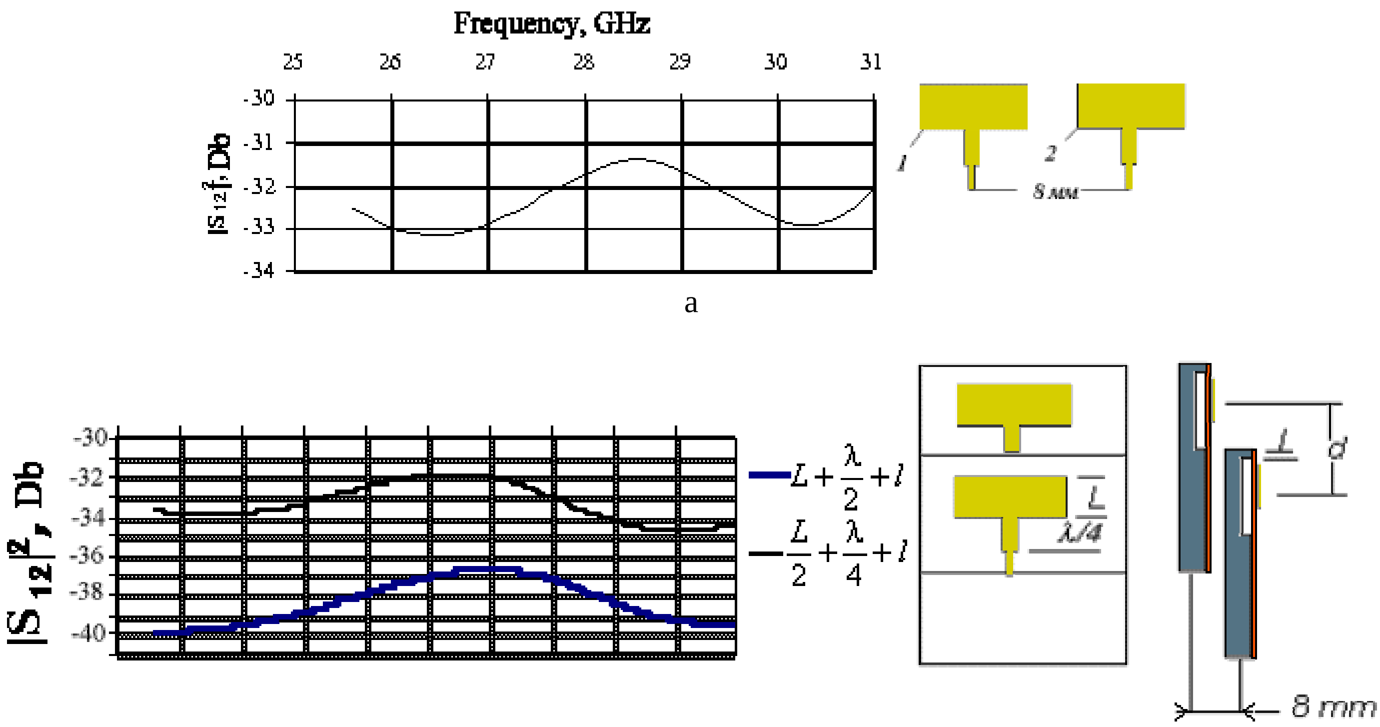


Figure 1. "Terraced" 7x8 element MMIC array architecture (a, b), MMIC amplifier LMA422 of Litton SSD(c).

3. Description and characteristics of MMIC focal array

For the array substrate we used Rogers Corp. ceramic filled composite materials with 0.0013 loss tangent and 3.02 dielectric constant. Microstrip radiators of each level are fed by microstrip lines lying in the plane of radiating sheet. In the first array prototype radiators receive the signal of Y polarization, X/Y linear or circular polarization will be available with the next prototype as well. Microstrip front-ends with "warm" MMIC LMA-422 (Fig 1, c) of Litton SSD (NF=2.5 dB) give us direct RF amplification in receiving channels in the "total power" mode. With the best existing GaAs MMIC amplifiers (NF=1.8 dB at 30 GHz) we expect the noise receiver temperature less than 200 K. Mutual radiator coupling is provided at -30 dB level (Fig.2 a,b), the direct losses in a patch radiator make no more than 0.2 dB, VSWR<1.35 in the range of 26.5-30.5 GHz. A rather wide bandwidth for the microstrip radiator is reached by an air cavity under the dielectric substrate (Fig.2b).



(b)

Figure 2: Mutual coupling $|S_{12}|^2$ for microstrip radiators (5.9x3.4) mm of one array level in H-plane (a), mutual coupling $|S_{12}|^2$ for radiators of different array levels in E-plane(b).

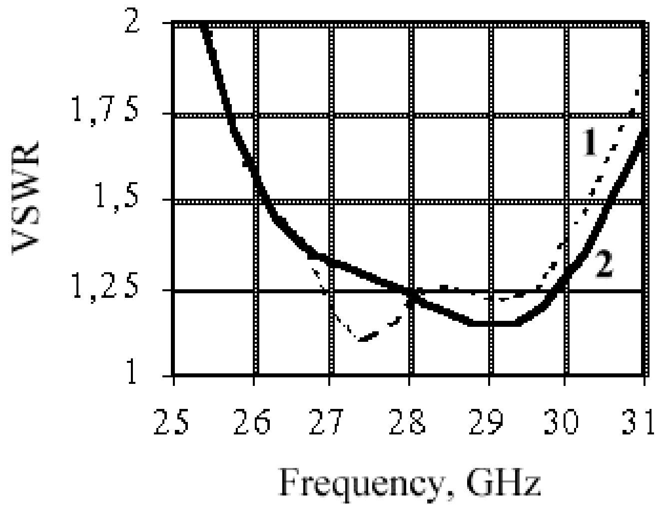


Figure 3: VSWR of microstrip radiator for one (1) and three (2) dimensional arrays.

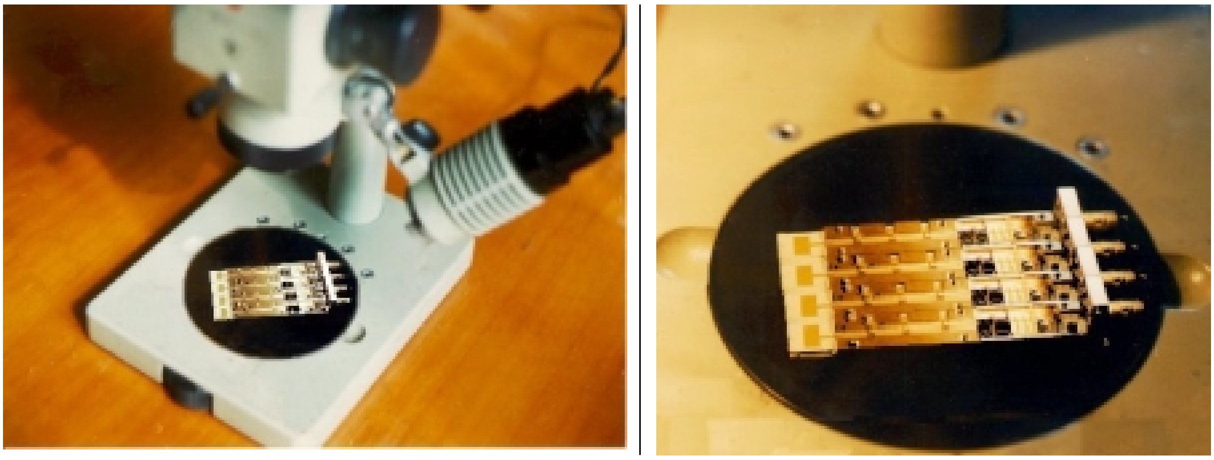


Figure 4: 4-element sub-array prototype at 26-30 GHz.

VSWR of the microstrip radiator for one and three-dimensional arrays as function of frequency is presented at Fig.3.

Input-output and mutual channel coupling is provided at a low enough level with the help of a cut-off waveguide covering each channel up to the detector (Fig.1). The microstrip bandpass filters put before detectors limit channel bandwidth to 4 GHz in agreement with the input radiator bandwidth. A communal input channel calibration is produced through a special loaded 50 Ohm microstrip line (Fig.5) connected with a loaded LMA-422 which is used as a noise oscillator in the same frequency range. Mutual coupling of the microstrip line with radiators is provided at -40 dB level.

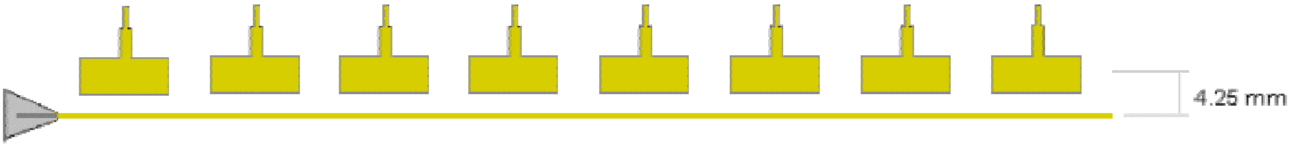
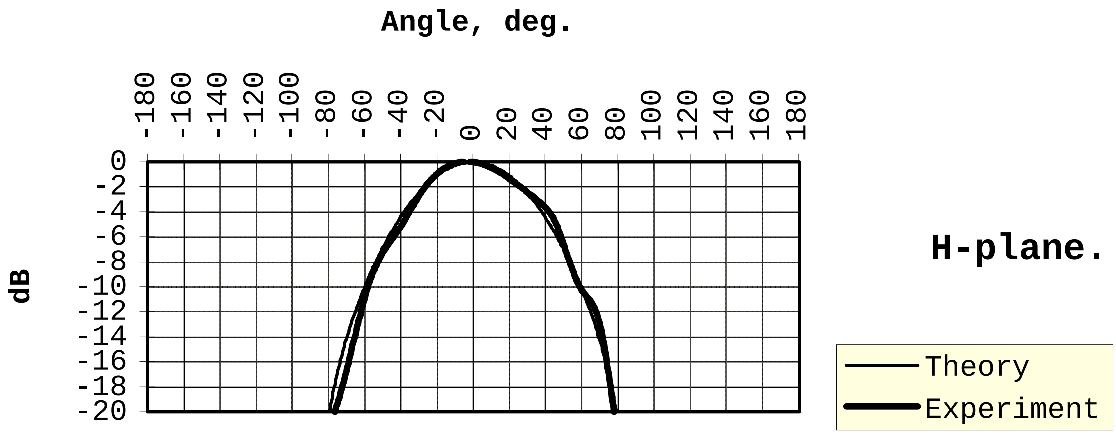


Figure 5: The loaded microstrip line for communal channel calibration

Super low noise HP Schottky square low detectors complete VHF parts of array. Low noise high precision AD FET monolithic operational amplifiers are applied in the wide band multi-channel back-end.

Beam patterns in E an H planes of a microstrip radiator in the one dimensional 8-element array give us a good enough agreement with theory (Fig.6). Some asymmetry of the radiation pattern in E-plane caused by reflection from the top of the array was removed with the help of an absorber at the top later.



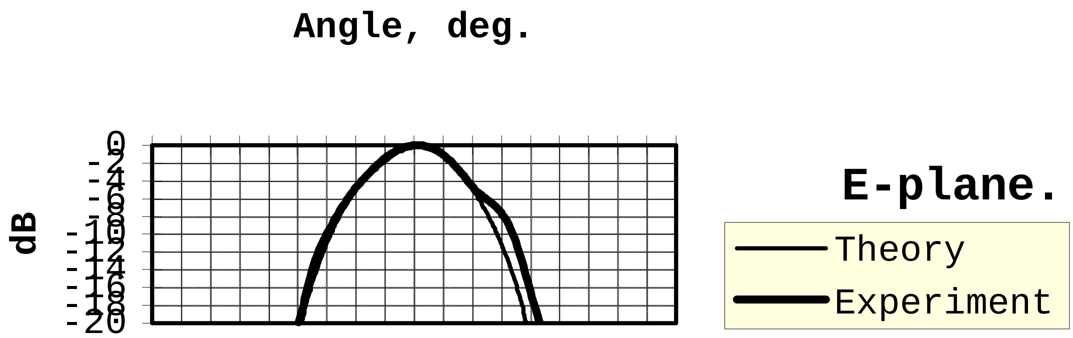
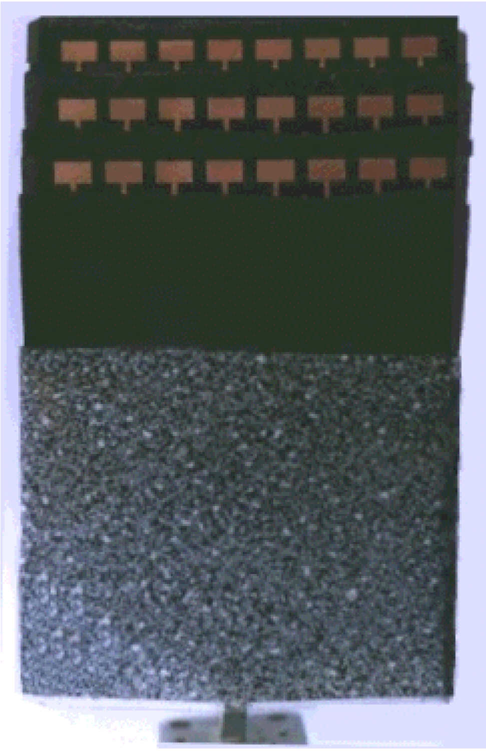
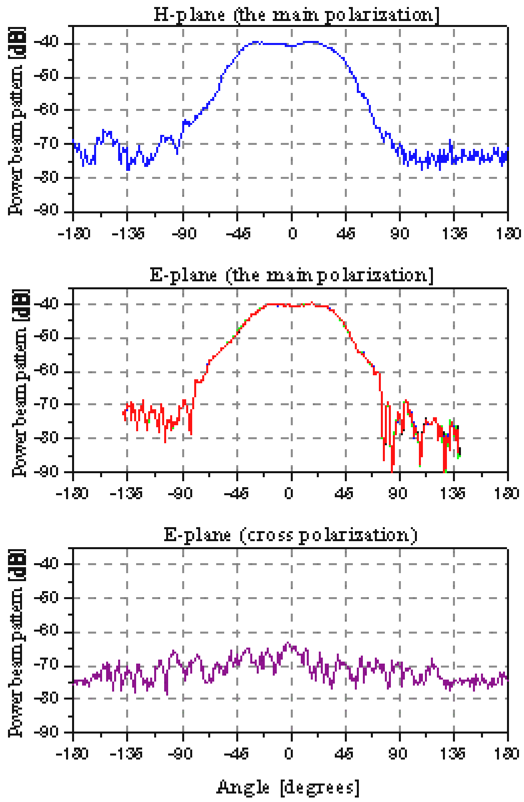


Figure 6: Power beam pattern of a microstrip radiator (5.9x3.4 mm) in 8-element array in E and H-planes

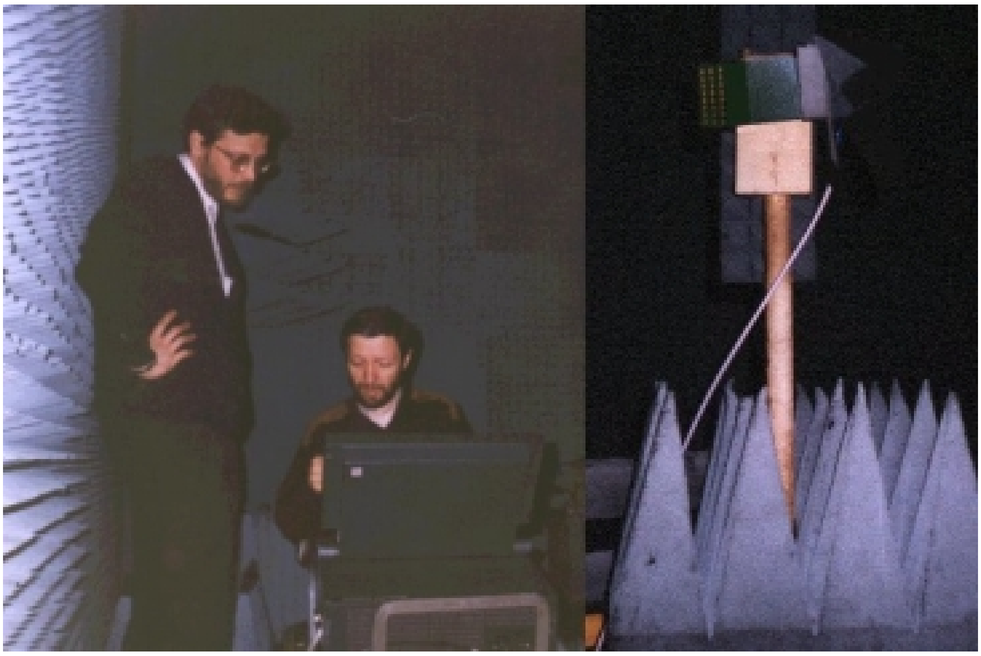
Beam patterns (Fig.7b) of a microstrip radiator in a 3x8-element array prototype at 26-30 GHz (Fig.7a) measured in HUT anechoic chamber are close to expected. Fig.7 c shows the process of measurements.

The measured system temperature of the 8-element MMIC sub-array prototype is 300 K. We expect 10-15 mK sensitivity per second in a channel in the "total power" receiving mode. As it is well known 1/f “knee” noise is the most critical aspect of the “total power” receiver scheme. An alternative is a pseudo-correlation receiver which has shown a very low 1/f noise [8]. However it is rather complicated and expensive solution for multi-element receiver arrays as it requires two integrated stripline gibrids, two phase shifters, two detectors, additional LNA amplifiers in each channel. Besides the reduction of gain variations in this scheme is especially good if the reference load temperature is close to signal noise temperature, so a crio-load is needed in each channel.





a b



c

Figure 7: 3x8 element array prototype at 26-30 GHz(a), beam pattern measurements in HUT anechoic chamber (b), the measurement process(c).

To reduce 1/F noise and ΔG/G contribution into sensitivity we are testing now a modified radiometric “total power” scheme with a monochromatic “compensating” signal added via communal calibration channel that can give us a factor 2-3 in sensitivity at one second and more at longer time scales. Gann oscillator with relative amplitude instability of $4x10^{-6}$ per second has been manufactured and tested for this purpose.

4. Multi-beam mode at RATAN-600 radio telescope

For large enough focal ratios (f/D ≥ 1) the far field beam patterns and the distribution in the radio telescope focus are the same [9]. To fully sample the cosmic source distribution we must use a spacing equal to or less than Nyquist power sampling interval in the telescope focal plane:

$$dL = \frac{1}{2}\frac{\lambda f}{D}$$

where f is focal distance, D is aperture size. In RATAN-600 case f/D is close to 1 at high elevation angles where an array may have the greatest element number. For an effective RATAN-600 illumination the minimal receiving element feed size is at least twice more in a waveguide horn solution. An attempt to improve the radiating pattern and decrease the side lobe level would extend the feed size further. We can instead consider the dipole type feed which has smaller size and is almost free from spillover effects. However an attempt to achieve a closely packed multi-feed system will reduce the sensitivity of each pixel [10]. Really, elements which work well in isolation will not effectively work when placed close together due to "crosstalk" or mutual coupling [11]. To avoid the above mentioned effects and reach highest integrated sensitivity (factor $1/\sqrt{N}$) a multi-feed construction and spacing dL should provide practically uncorrelated output noise in neigbouring channels and lowest level of mutual coupling (not less than -30 dB).
The field of view of a radio telescope is limited by aberrations as a receiver element is moved to off-axis positions. Aberrations lead to an efficiency loss and a distorted beamshape. Both the field of view and sensitivity of a large radio telescope in MM band strongly depend on the number of independent receiver elements which give undistorted elements of a sky picture - pixels. Multi-pixel reception may significantly (one-two orders) increase RATAN-600 sensitivity and the field of view in survey tasks such as investigation of 3 K Cosmic Microwave Background (CMB) anisotropy at subdegree scales S. Together with high effective wide-scale beam-scanning [12] two-pixel subtaction at PC level is one of ways to suppress variations of atmospheric radiation at scales S:

In some observation modes aberrationless zone along the focal plane may exceed 3 m (Fig.9) for the largest RATAN-600 secondary mirror (Fig.8a) (12 m size). Our calculations show that up to 500

$$S' = \frac{NdL}{2f} > S$$

receiver elements may be placed along the focal line. Cross direction of the focal plane is also available for the tight packed feed array. Vertical RATAN-600 beam patterns with a 7x8 element tight packed flat feed array are shown in Fig.10 a. So if we fully occupy the available focal surface a total number of RATAN-600 beams can exceed 3000(Fig.10 c).
"Terraced" focal array architecture shown in Fig.1 b not only gives us significant advantages in the manufacturing process but also the less fall of power beam efficiency in comparison with a flat array (Fig.10 a,b). This result is reached inspite of the fact that the element spacing in E-plane was 1.5 times less for the flat array (Fig.10 b).

An optimal distance between array levels in "terraced" array in RATAN-600 case is 3.5 - 4.0 mm (Figure 11).

a

b

Figure 8: The largest secondary mirror N5 of RATAN-600 (a), a focal plane of the secondary mirror N1 with single receivers at present (b).

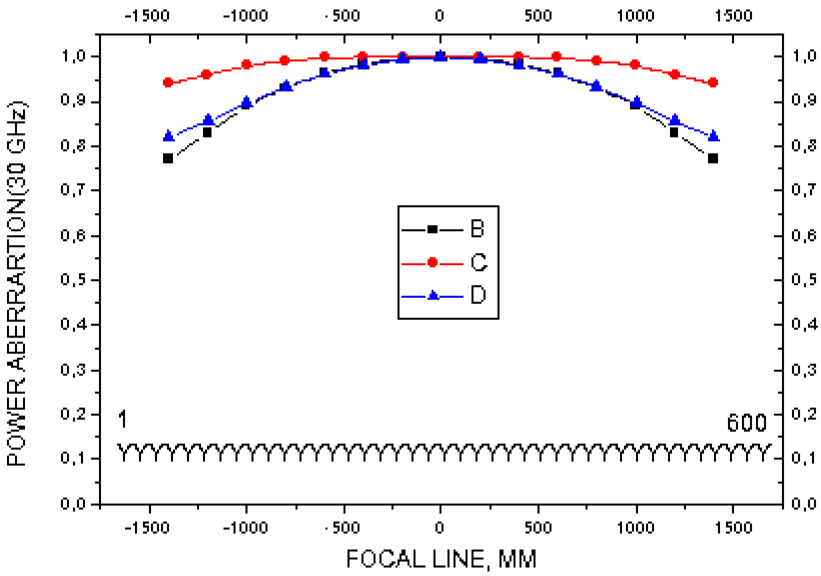
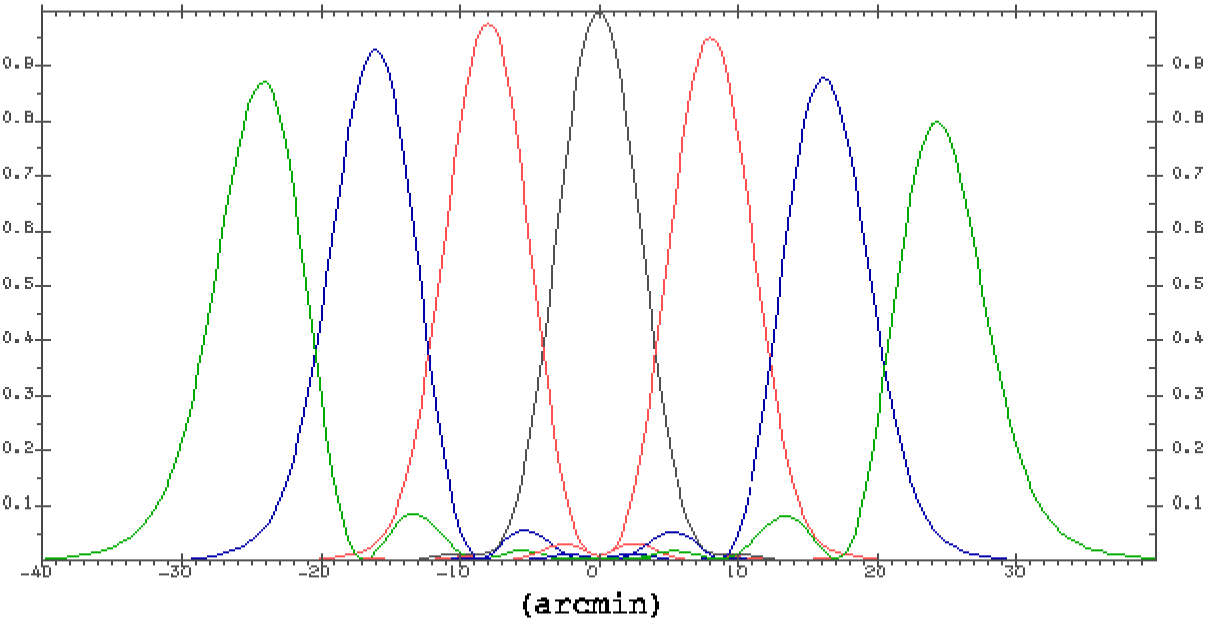
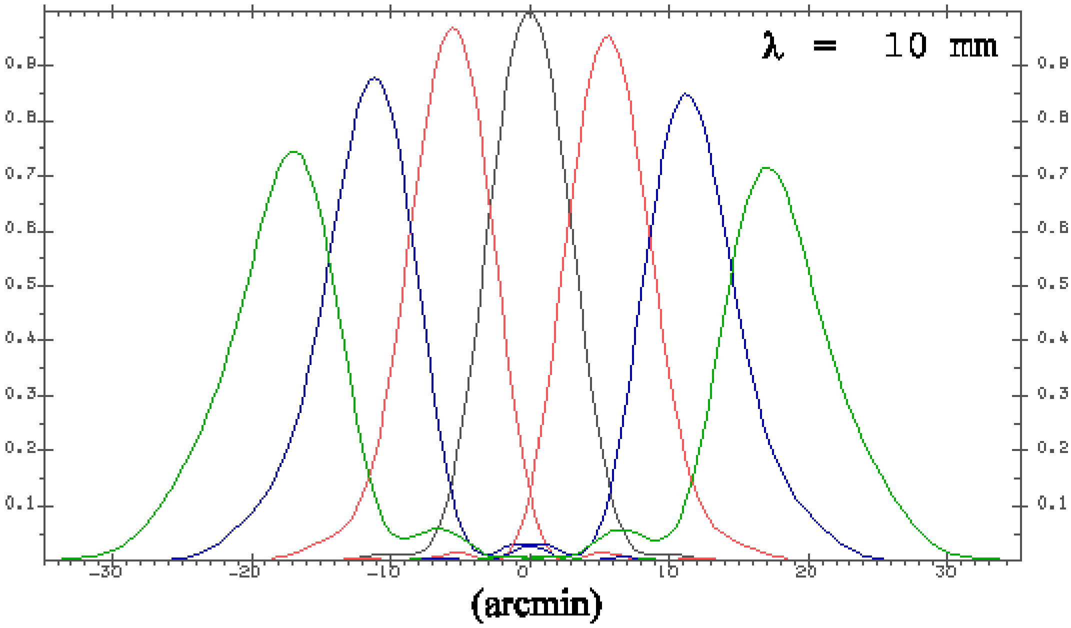


Figure 9: RATAN-600 power aberration curves along the focal plane
C-Zenith mode (H=90 deg.) with 400 meter aperture.
B-Zenith mode (H=89 deg.) with 400 meter aperture.
D-Radio-Schmidt mode with 100 meter aperture (H=45deg).



a



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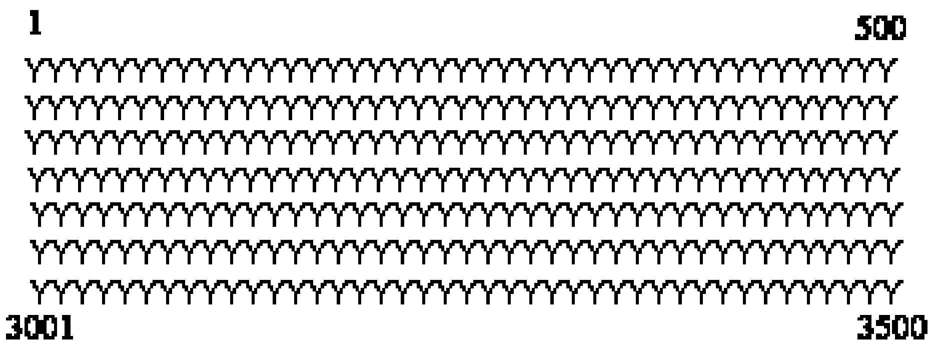

c

Figure 10: a) Vertical "knife type" power beam patterns of RATAN-600 at λ =10 MM for 7x8 element flat (b) and "terraced" (a) focal arrays, full array occupation of the focal region (c)

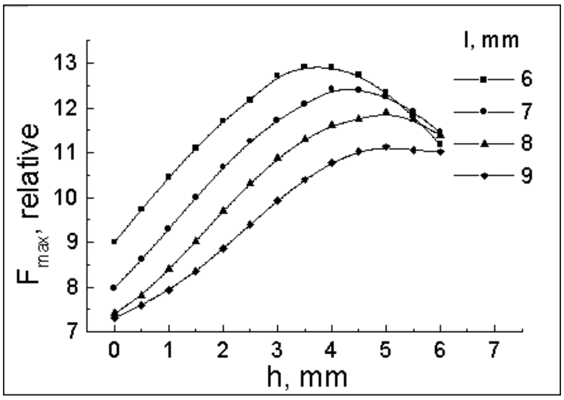

Figure 11: Maximal beam patern amplitude F =F(h,l), where h and l are distance between array levels and radiator spacing correspondently.

In the Radio-Schmidt mode [4] RATAN-600 can track cosmic sources with an unmovable main mirror and an array in the focal plane during one hour. The RATAN-600 beam patterns in Radio-Schmidt mode for different elevation angles and azimuths of cosmic source α are shown in Fig.12. For a shortened aperture we can use this mode up to 10 mm wavelength.

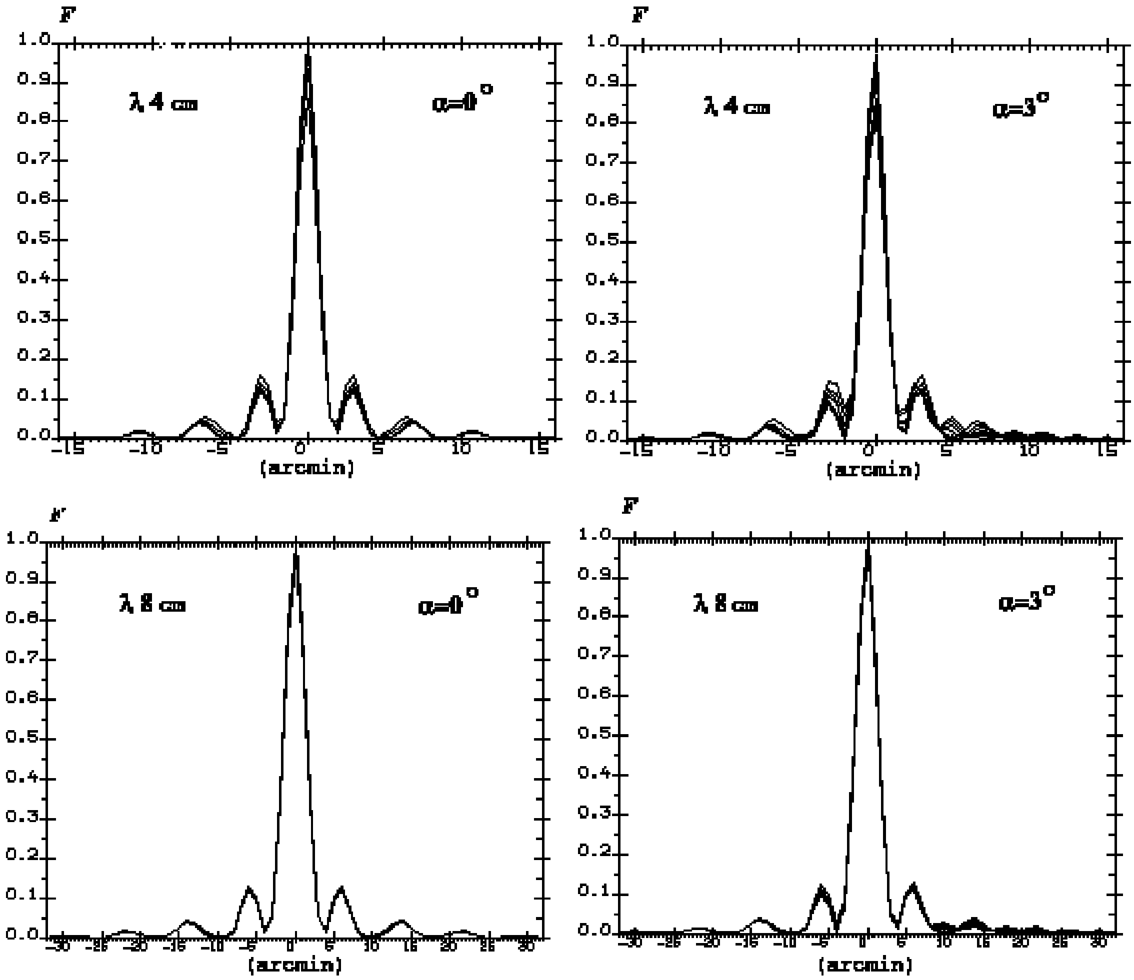

Figure 12: RATAN-600 power beam patterns in Radio-Schmidt mode for different elevation angles and half an hour cosmic source tracking

6. MMIC array applications for a radio telescope

The described array technology can be used at RATAN-600 for different radio astronomy applications. It can give us new possibilities to study CMBA at sub-degree scales with high integrated

sensitivity in a wide field of view [12]. The search of Synaev-Zeldovich effect at RATAN-600 is among other possible applications. Using focal arrays we can study quick-variable cosmic objects like pulsars or Sun as well.
Another exciting possible field of application for multi-element “terraced” MMIC arrays at radio telescopes is holographic antenna measurements. So 8x8 element MMIC array can significantly (in 64 times) decrease time necessary to restore surface error map on strong cosmic or beacon satellite source that gives us a chance to correct surface errors practically in quasi-real time. It may give a powerful impulse to the development of an active and adaptive optics technique at radio telescopes including wave front correction.
We believe that described front end technology may be used together with correlator for self-correction of wide-angle radio telescope with “off set” illumination. It was shown in [13] that to capture 80% of the power incedent on a reflector with r.m.s. surface accuracy $\lambda/8$ and M=D/5-D/20 (D is diameter of an aperture, M is the number of error coherence patches across the aperture) a total number of focal array elements may exceed 20-2000 so an inexpensive array technology with a very big element number is needed. It may be shown that “terraced” array do not lead to the loss of phase information or fall of S/N ratio for this type tasks.
We believe the described “terraced” MMIC array architecture may be applied for RATAN-600 or other wide-angle reflector radio telescope with offset illumination at least up to 40 GHz. Construction shown in Fig 1 a may be used at a radio telescope with symmetrical illumination but with longer wavelengths. In some cases an off-axis illumination may be made artificially.

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