

# UWB ACTIVE ANTENNA ARRAY FOR LOW FREQUENCY RADIO ASTRONOMY

Konovalenko A. A., Falkovich I. S., Gridin A. A., Tokarsky P. L. and Yerin S. N.

Institute of Radio Astronomy of NAS of Ukraine, Kharkov, Ukraine  
E-mail: akonov@ri.kharkov.ua

## Abstract

The decameter wavelength range is of interest for radio astronomy at the present time. Construction of giant low-frequency radio telescopes has been planned and is being carried out in European Union (Low Frequency Array – LOFAR), USA (Long Wavelength Array – LWA) and in Ukraine (Giant Ukrainian Radio Telescope – GURT). The radio telescope GURT, which is being created in the Institute of Radio Astronomy of NAS of Ukraine, will operate over frequency range from 10 to 70 MHz. The antenna system of telescope will be a phased antenna array consisting of many subarrays, each of  $5 \times 5$  elements. The array element is an active crossed dipole with inclined arms. Phasing inside one section is performed with analog phase shifter. Output signals of the subarrays are transformed into digital form and are processed in DSP-receiver. In this paper the subarray of the GURT radio telescope is considered. The design, electric circuit and some results of experimental and theoretical researches are given and described.

**Keywords:** Radio Telescope, Active Phased Antenna Array, Dipole, Preamplifier, Phase Shifter, Combiner, Directivity, Noise Temperature.

## 1. INTRODUCTION

The low-frequency radio astronomy that covers frequency range from 10 MHz to 100 MHz allows obtaining the priceless knowledge about the structure and characteristics of the Universe. As sensors it uses narrow-beam antenna arrays that have large electrical as well as physical dimensions in this frequency range. For example, such arrays are: UTR-2 (Kharkiv, Ukraine,  $f = 10 \dots 30$  MHz, N-S and E-W arms long are 1800 m and 900 m, respectively) [1] and Nançay Decametric Array (Nançay, France, rectangle of  $87 \times 83$  m) [2]. They were built in the 1970-1980<sup>th</sup> and are in active operation for radio astronomical applications till our days. During the last several years the interest in low-frequency radio astronomy strongly increased because of its ability to obtain unique findings about our Universe inaccessible in other frequency ranges. However, the existing instruments no longer meet the modern requirements and the necessity in new and more effective low-frequency radio telescopes construction is rising [3]. Therefore, construction of several new-generation giant low-frequency radio telescopes started in the last several years. They are: LOFAR in Western Europe, GURT in Ukraine [4] and LWA in the USA [5]. These new radio telescopes are being constructed on new technological base and the active antenna array system with digital signal processing equipment is used. Such solutions allow provision of

greater sensitivity and high space selectivity when receiving extraterrestrial signals in wide frequency range with overlapping from 5:1 to 7:1. In this work the results of development and investigation of a subarray, which will be used as basic unit of the GURT radio telescope are presented.

## 2. GURT CONCEPTION

The new radio telescope GURT is designed to operate in the frequency range 10 - 70 MHz. The new concept of the radio telescope states that its antenna system will consist of many identical subarrays. As the construction of radio telescope will make progress, the number of subarrays will increase, and in perspective it will reach 100 and will cover the area of 2 square kilometers. The received signals on the output of the subarrays are digitized and transferred to the central computer station to be processed in DSP-receiver. A subarray is a square regular 25 elements antenna array arranged in five rows of five elements. The rows are oriented along the East-West direction. The array spacing in two directions is the same and equals 3.75 m. The simplified scheme of the subarray for one polarization is shown in Fig. 1. It contains 25 array elements in the form of integrated circuit antenna modules (ICAM), six five-channel combiner & phase shifters blocks (CPB), and an analog-to-digital converter (ADC).

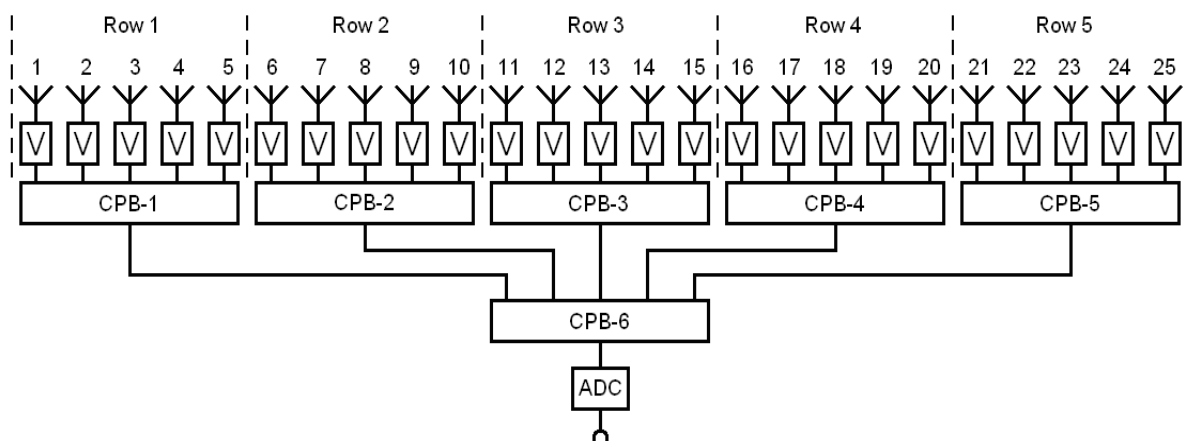


Fig. 1. The subarray structure for one polarization.

### 3. THE ARRAY ELEMENT

The subarray element is an integrated circuit antenna module (ICAM) [6] consisting of a sensor, the matching circuit and a low noise preamplifier.

#### 3.1. THE SENSOR

The sensor is formed by two crossed dipoles with stand-alone terminals which allow receiving the electromagnetic waves of two orthogonal polarizations independently. For extending operating frequency range of the sensor, the arms of the dipoles have flat shape. They made of polyethylene-coated thin-walled copper tubes Q-tec® 16 mm diameter. Q-tec® is a universal system for all types of water supply and indoor central heating systems. Each arm of a dipole is formed by three tubes that depart from the input terminal. Two of them form perimeter of a triangle with the rounded vertexes, and the third tube goes along the triangle median line, that has sharp bend at an angle 45 degrees (Fig. 2). All tubes are fastened by the standard fittings

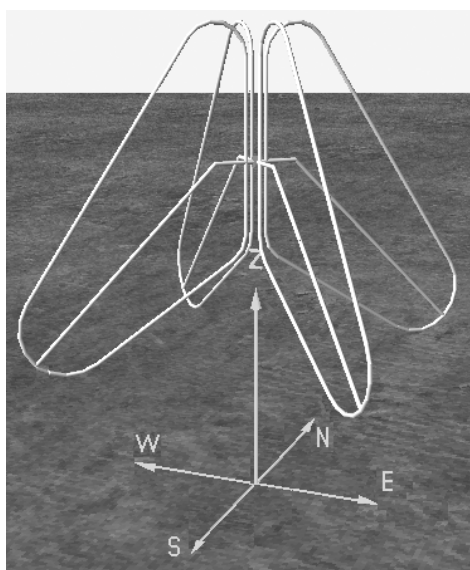


Fig. 2. The two crossed dipoles with bent arms.

and in addition are bridged with copper wires. The total length of the dipole along the arm median is 2.8 m, and maximum width is 0.8 m. Both dipoles are mounted on the vertical rack made of a steel tube in diameter of 60 mm with the upper dielectric nozzle. Inside the top of the rack mounted the dual channel preamp with built-in matching circuits, which inputs are connected directly to the respective dipoles terminals. The dipoles arms are rotated by 45 degrees relative to the cardinal points. The height of driving points of the dipoles over the ground is 1.6 m. The chosen shape of the dipole allows to reduce significantly its input reactance at the lower frequencies of the operating range and to achieve the desired frequency dependence of its impedance (Fig. 3). The slope of the dipoles arms to the ground allows to widening their radiation pattern in E-plane.

In contrast to the LOFAR and LWA projects, we take no action on the metallization of the ground, because it has a high conductivity at the place of location of the GURT antenna array. Estimated reduction of the dipole efficiency caused by imperfection of the ground is obtained through simulation by 4NEC2X [7] and illustrated in Fig. 4. The above graph shows that the dipole efficiency increases steadily from 10% to 74% with increasing frequency in the operating range.

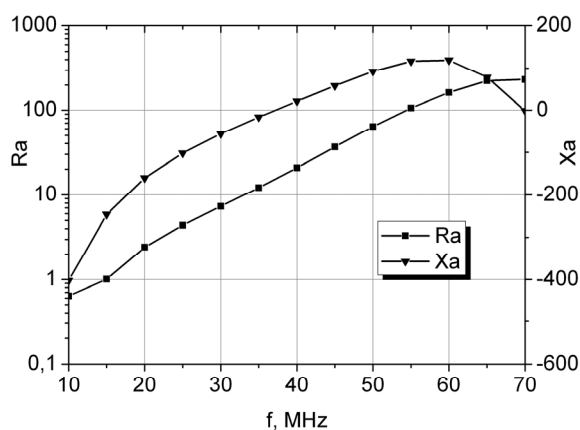


Fig. 3. The dipole impedance vs. frequency.

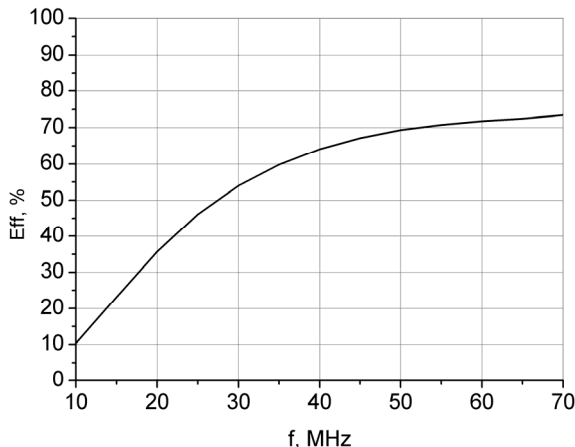


Fig. 4. The dipole efficiency vs. frequency.

3.2. THE PREAMPLIFIER

The preamp in the IC antenna module has three functions: it helps to solve the problem of matching the dipole with cable, plays the role of a balun and finally amplifies the signal to compensate insertion losses caused by following networks (phase shifters, combiners, transmission lines, etc.). To make the amplifier not to degrade sensitivity of the receiving system, its inherent noise should be significantly lower than the external antenna noise. In addition, since near the lower boundary of the working frequency range, there are several powerful HF radio broadcasting stations, there is a danger of intermodulation interference; particularly dangerous are the third-order intermodulation products. In this regard, the design forefront of the preamp extends the task of ensuring its high linearity.

The two versions of the preamp are designed to satisfy the specified requirements. One of them is built under the Norton's scheme and described in detail in [8]. The circuit of the second one is given in Fig. 5. It uses high-frequency transistors BFG67 (V1&V2), and BFR96 (V3&V4), connected as Darlington pairs. Inductance L0 plays the role of the matching circuit.

Parameters of the preamp components, the matching circuit, as well as the geometry of the sensor were chosen to maximize the ratio of  $\alpha = T_{sky}^a / T_{pre}$  over the entire operating frequency range and it does not fall below 2-3 dB, where  $T_{sky}^a$  and  $T_{pre}$  are antenna temperature due to Galactic noise and noise temperature of the preamplifier, correspondingly, both are measured on the preamp input. Testing results of the preamp main parameters: power gain, voltage gain and noise temperature at 40 MHz are 20.6 dB, 12 dB and 153°K correspondingly; the third-order intermodulation product IP3 at 15 MHz is 91.4 dB/ $\mu V$ . The average ratio of  $\alpha$  over the entire operating frequency range equals to 8.3 dB, and in most of the range (18 to 70 MHz), it does not fall below 7.7 dB, and only at the bottom of the range it falls to 2.1 dB (Fig. 6).

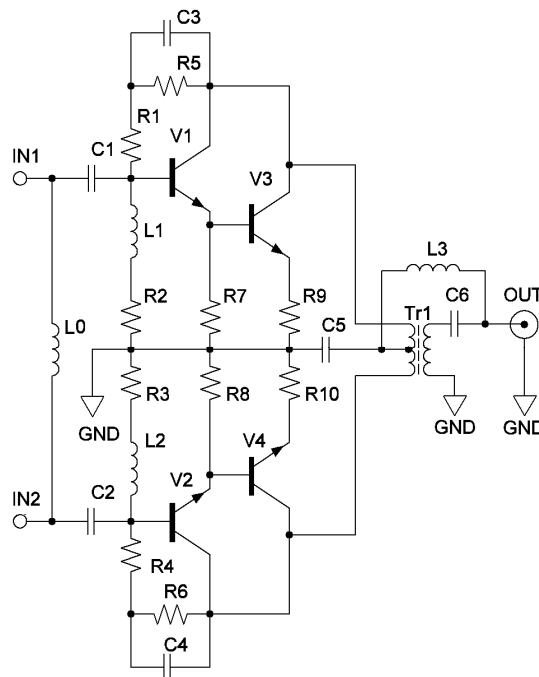


Fig. 5 The Darlington preamp circuit (the one polarization channel).

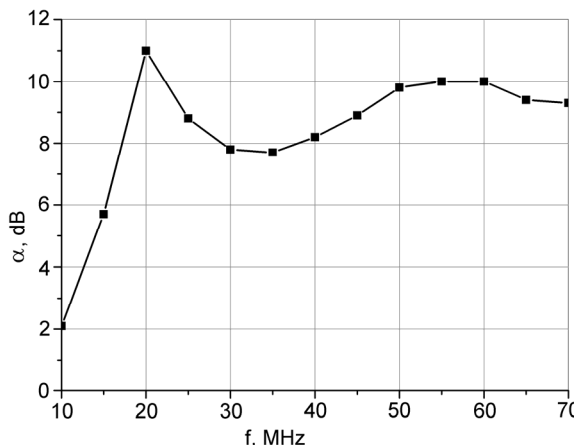


Fig. 6. The ratio of  $\alpha = T_{sky}^a / T_{pre}$  for ICAM vs. frequency.

The values  $\alpha$  given in this graph, were obtained by calculation using the experimental parameters of the amplifier and the dipole, and the average temperature of the Galactic background was estimated by the following expression [8]:

$$T_{sky} = 1.452 \cdot 10^8 \cdot (f, \text{MHz})^{-2.56}, \text{ K.}$$

Comparing the two developed preamplifiers we can see that the Norton preamp has a few better parameters [8] than the Darlington one, but it is more difficult to manufacture and, therefore, is much more expensive because of the presence of several handcraft made Ruthroff transformers. Therefore, in this case, preference was given to the Darlington preamplifier, which has a higher ratio of quality / price.

#### 4. PHASE SHIFTERS & COMBINERS

The signal phases controlling and signal combining in each subarray are carried out by the analogous method with the help of six identical combiner-phase shifter blocks (CPB). Five of these blocks combine and phase signals from the dipoles in each row of subarray, and the last one combines and phases signals from five rows.

The simplified circuit of the CPB is shown in Fig. 7. It consists of a five-input combiner and a five-stage and five-channel discrete phase shifter that is realized on time-delay lines. The combiner is a 5-way power splitter/combiner with uniform amplitude and phase balance. It is realized on chip SCP-5-1 produced by Mini-Circuits company. It has typical values for insertion losses of 0.26 - 0.28 dB per channel, amplitude unbalance of 0.02 dB, isolation between channels of 29.48 - 38.25 dB, phase unbalance of 0.88°, VSWR of inputs is 1.11. These characteristics are given for 60 MHz.

The phase shifter ensures the preset frequency-independent time delays in each channel, that allows to keep a frequency-independent direction of the main beam of the array factor [8]. All the phase shifter channels has equal time delays in the reference position, that corresponds in-phase excitation of the dipoles, and, correspondingly, normal direction of the subarray beam. The time delay  $\tau_0$  in the middle channel of the phase shifter remains constant while beam switching. It corresponds to a phase center of the dipoles row and is assumed as a “defined zero”, from which the count of positive and negative time delays in other channels is carried out.

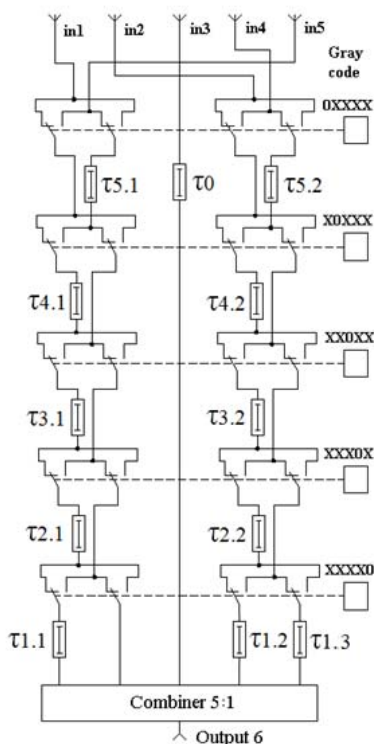


Fig. 7. The simplified phase shifter circuit.

The switching scheme is built so that not to cut off the cable sections from the scheme, but to switch ones to another channel while a beam is being controlled. It allows to significantly reduce the consumption of cable in phase shifter production.

When the main beam is deflecting from the zenith, the discrete cable sections are switching between symmetrical antennas. The discrete step of time-delay line length was chosen 0.3 m that corresponds of 10 degrees phase incursion on the reference frequency of 18.3 MHz for selected cables. The total lengths of all time-delay lines in each channel in zenith direction and the central channel line for all directions are 4.8 meters. When the main beam is deflected to the maximum angle of  $\pm 76.6^\circ$  from zenith, one of the outside channels does not include time-delay lines, and the opposite one includes the maximum total lines length of 9.6 meters.

As a phase shift element the section of coaxial cable RG-58C/U is used. It possesses the attenuation of 34.7 dB/100 m for frequency 900 MHz. The switching devices are high-frequency relays OMRON G6K-2F-RF. The effective lengths of time-delay lines were slightly adjusted during the tuning of the phase shifter to compensate parasitic phase incursions in other channel elements.

The control of phase shifter operation is carried out by delivering the five-bit Gray code by the data bus from the central computer to the controlling circuit of the high-frequency relay.

The characteristics of the CPB calculated using CAD programs and measured by vector network analyzer “Obzor 103” match well with each other [9]. The measured frequency responses of phase shifter channels transmission gain for 10 degrees phase difference between adjacent channels are shown in Fig. 8.

It is clear from the picture that different channels have different attenuations. It occurs because the values of attenuation are proportional to total length of connected cables. Only in the case of equal time-delays and therefore equal total cable lengths in all channels the attenuations in all channels are also equal and fit the curve S36 in Fig. 8.

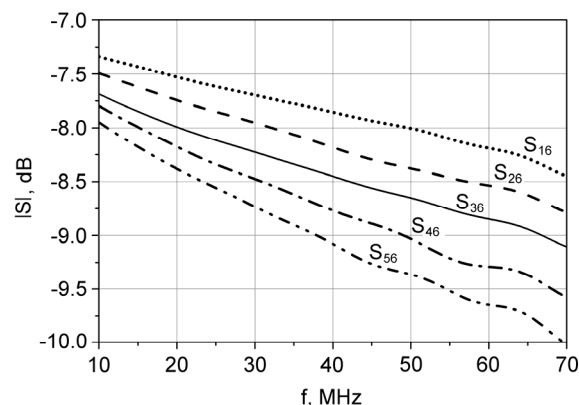


Fig. 8. The transmission gain for 60° phase difference combining.

## 5. SUBARRAY PERFORMANCES

The described array network allows combining in-phase the signals induced in the 25 sensors of the subarray by incident waves that come from the 213 directions, shown in Fig. 9.

These directions do not depend on the frequency and correspond to the main beams peaks of the array factor for various phase distributions. The real directions of the subarray main beam somewhat differ from those indicated in Fig. 9. Because of the subarray elements directivity they move to the zenith with frequency decreasing. The main beam width of the subarray depends on the frequency and the declination angle. Its minimum is 8 degrees that corresponds to the normal beam at frequency of 70 MHz and a maximum of 45 degrees corresponds to the maximum deflected beam at the frequency of 10 MHz. The adjacent beams cross at the 3 dB points at the highest frequency, and this level is increasing with decreasing frequency.

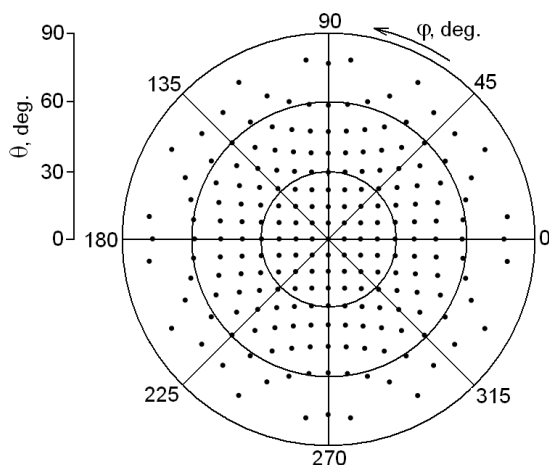


Fig. 9. The beam-points of the subarray factor.

## CONCLUSION

Currently, the GURT is under construction. Sensors have been installed for six subarrays, now they are equipped and prepared for tests. Subsequent subarrays will be constructed and put into operation upon receipt of project funding.

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