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Research Article

First Radio Astronomy Examination of the Low-Frequency Broadband Active Antenna Subarray

A. A. Stanislavsky,[1] I. N. Bubnov,[1] A. A. Konovalenko,[1] A. A. Gridin,[1] V. V. Shevchenko,[1] L. A. Stanislavsky,[2] D. V. Mukha,[1] and A. A. Koval[1]

[1] *Institute of Radio Astronomy, 4 Chervonopraporna Street, Kharkiv 61002, Ukraine*
[2] *Kharkiv Radio Engineering College, 18/20 Sumskaya Street, Kharkiv 61057, Ukraine*

Correspondence should be addressed to A. A. Stanislavsky; astex@ukr.net

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We present the 25-element active antenna array and its remote control in the framework of the GURT project, the Ukrainian Radio Telescope of a new age. To implement beamforming, the array is phased with the help of discrete cable delay lines in analog manner. The remote control of the array is carried out through the paired encoder and decoder that can transmit parallel data about antenna codes serially. The microcontroller provides the online interaction between personal computer and beamformers with the help of the encoder-decoder system through wires or wireless. The antenna pattern has been measured by radio astronomy methods.

1. Introduction

The discovery of cosmic radio signals by Karl Jansky was started with low frequencies (more precisely 20.5 MHz) [1]. Although the low-frequency technology was easier to implement, radio astronomy migrated to higher frequencies together with the development of technology. This is explained by crucial disadvantages of longer wavelengths in spatial resolution of antennas proportional to a wavelength and because of ionospheric effects limiting radio observation quality as well as the ionospheric cut-off below 10 MHz. Nevertheless, low-frequency cosmic radio emission contains exclusive information about the universe. In particular, there is a wide range of astrophysical problems accessible for studies only at low radio frequencies (~10–100 MHz) [2]: the epoch of reionization (to search emission from the first stars and galaxies), transient phenomena, and others. For this purpose, the low-frequency astronomy continues to be developed fruitfully in our days. One aspect of this progress is to build a low-frequency antenna array with excellent sensitivity and high spatial resolution. This trend becomes a reality in new radio telescopes such as the LOFAR (The Netherlands) [3], E-LOFAR (LOFAR stations in Europe), LWA (USA) [4], and MWA (Australia) [5]. Similar project is realized in France (LSS-LOFAR Super Station) [6] as well as in Ukraine (Giant Ukrainian Radio Telescope (GURT)) [7]. The implementation of new effective systems for steering the antenna arrays is the key point in such scientific programs.

2. The GURT Project

The GURT radio telescope will operate as a large array consisting of many identical subarrays. The construction is in progress. Now, we have built 9 subarrays (one of them is represented in Figure 1), and in perspective the number of subarrays will increase to reach about 100, covering the area of 2 square kilometers. Each of the subarrays is a square regular antenna array using active dipole techniques. It includes 5 × 5 wideband active (with preamplifier) dipoles. All turnstile antenna elements are mounted at a height of 1.6 m above the ground.

Active antennas give some very useful advantages in comparison with passive ones. In particular, below about 30–40 MHz, where the external (Galactic) noise exceeds the internal one considerably, shortening the radiator length of

Figure 1: Active antenna array of 5 × 5 elements as a basic part of the GURT radio telescope.

a tuned antenna does not affect the signal-to-noise ratio at the antenna output, but shortening the radiator will dramatically change its input impedance, and therefore the preamplifier transforms the dipole impedance back to the cable one. Thus, the length of a short-wave antenna can be reduced noticeably. The dipole and preamplifier permit us to obtain the maximum possible ratio between the antenna temperature due to Galactic noise T_{sky} and the noise temperature of the preamplifier T_{pre}; that is, $10 \log T_{sky}/T_{pre} \approx 10$ dB over the whole 10 to 70 MHz range [8]. To implement beamforming, the subarray is phased with the help of discrete cable delay lines (analog beamformer). Next, the signals received by such subarrays will be digitized and transferred to the central computer for subsequent phasing and data processing. The dual polarization dipoles of the GURT radio telescope are optimized for operation at 10–70 MHz to have a steady (no resonance) frequency response. In this paper, we are going to consider only constructive features of one separate subarray (for short array) and its remote control.

The main parameters of the active antenna array are the following:

(i) array step equal to 3.75 m;

(ii) electric scan sector ±76.6° from the zenith in both coordinates;

(iii) array size 18.75 × 18.75 m;

(iv) effective area 275 m^2;

(v) beamwidth 25° × 25° in the mid-frequency range, at 40 MHz;

(vi) antenna amplifier dynamic range > 90 dB relative to 1 μV.

For each polarization, the turnstile antenna element has its own independent beam steering system, and the system is identical for both polarizations.

3. Beam Steering System

Figure 2 shows the functional block diagram of the active antenna array describing its beam steering. The system provides remote automatically changes in the orientation of the main beam lobe position in two planes by a given program. The beam steering device of the array consists of 6 identical 5-bit beamformers. Firstly, signals of 5 active dipoles in a row are phased and summed in u coordinate, and then the sixth beamformer is used for phasing the array in v coordinate. The discrete time delay lines of beamformers are coaxial cable segments. The devices switching the lines are high-frequency relays. The isolation of the radio frequency circuits and the digital control equipment is carried out by optocouplers. Each beamformer provides 17 beam positions (see Table 1).

Table 1: Beamformer codes and beam angles from the zenith.

Codes	Beam position	NU, NV
01000	−76.6°	−8
01001	−58.3°	−7
01010	−46.9°	−6
01101	−37.4°	−5
00100	−29.1°	−4
00111	−21.4°	−3
00010	−14.°	−2
00001	−7.°	−1
00000	0°	0
11000	76.6°	8
11001	58.3°	7
11110	46.9°	6
11111	37.4°	5
11100	29.1°	4
10101	21.4°	3
10110	14.°	2
10011	7.°	1

The basic parameters of the beamformer were measured and show its good quality as follows:

(i) frequency range 10–70 MHz;

(ii) voltage standing wave ratio (VSWR) ≤ 1.4;

(iii) maximum loss on the upper frequency ≤ 3 dB;

(iv) isolation between any two inputs ≥ 30 dB;

(v) maximum phase error relative to the calculated value ≤ 5%.

To manage the beam steering, it is necessary to supply 5-bit control signals from a remote control system to beamformers of the antenna array through wires or wireless.

4. Remote Control

The remote control system (Figure 3) of the array is based on the paired encoder and decoder to transmit 20 bits of antenna codes (5 bits of NU and 5 bits of NV in two polarizations). As an encoder-decoder pair, we used chips HT12E and HT12D made by "Holtek Semiconductors." The encoder chip takes parallel data and converts them into serial data. The decoder does the opposite. The two devices are very useful in implementing a communication protocol. Encoder sends a packet, and decoder receives it. Each packet has its

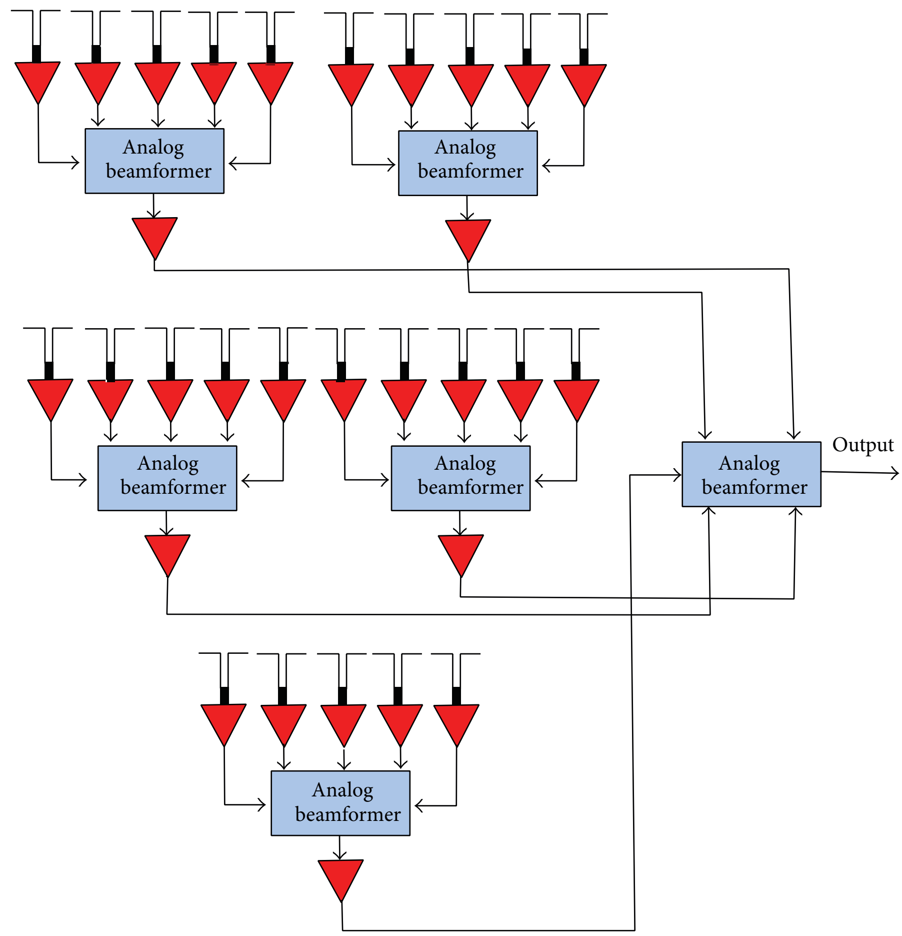

FIGURE 2: Block diagram of the active antenna array in one polarization. Red triangles denote amplifiers.

address (8 bits) and data (4 bits). But the packet is accepted by the decoder, if only the encoder address is equal to the decoder one. Otherwise, the decoder saves a previous state obtained from a true packet. The encoder chip can transmit only 4 bits of data. To transmit 20 bits of antenna code data, we divide them into five independent packets with different addresses serially. The remote control is implemented from personal computer through microcontroller, where the USB port is configured as a Virtual COM Port. For reliability, when the computer sends 20-bit data to microcontroller, we use a special protocol. It has two delimiters, in the beginning and in the end of each parcel, to protect the sent data from possible random errors during the data exchange. The two delimiters are different and fixed. The special protocol assumes 7 characters. Immediately behind the start delimiter, we pass five characters (data about antenna codes) in hexadecimal notation. Final seventh character is another delimiter. The microcontroller serves as an interface device between the encoder and the computer. The latter calculates the antenna codes NU and NV to track a cosmic object according to its sky coordinates:

$$\mathrm{NU} = -\mathrm{round}\left[\frac{8\cos\delta\sin t}{\sin|\theta|}\right],$$

$$\mathrm{NV} = -\mathrm{round}\left[\frac{8\,(0.762\cos\delta\cos t - 0.647\sin\delta)}{\sin|\theta|}\right], \quad (1)$$

where t is the hour angle, δ the declination, and θ denotes the maximum possible angle of the antenna beam inclination from the zenith (see the upper row of Table 1). The normalization coefficient $\sin|\theta|$ characterizes a view field of this antenna array. By using the second paired encoder-decoder, the antenna array informs the microcontroller and the user via his personal computer about the codes obtained by the array. The feedback defends the antenna applying against any false switching in the process of tracking cosmic objects (Figure 3).

5. Testing in Real Observations

Traditionally, power patterns of antennas in radio astronomy are examined by using calibrator sources such as the Sun, Cassiopeia A, or other bright radio sources [9]. However, these sources only traverse a limited range of sky and require that the radio telescope in question would be steered. Fortunately, our array possesses such capabilities. Figure 4 is a chart of the radio source, Cassiopeia A, taken when the rotation of the Earth moved the beam of our active antenna array across

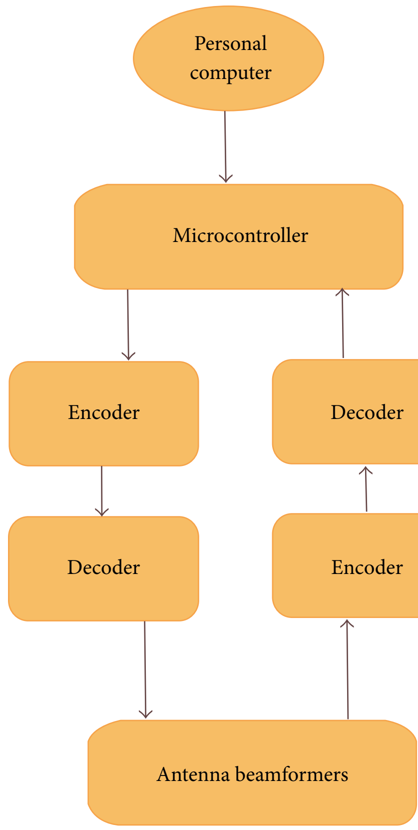

Figure 3: Block diagram of the remote control system for the active array.

this region of the sky. The radio source size is a point for this antenna pattern, and its signal capture width is equal to the width of the main lobe taking into account the source velocity on the sky. To improve the signal-to-noise relation in getting the antenna array pattern properties, the correlation method is very useful [10]. In this case, a reference antenna (e.g., another antenna array) is permanently directed in the chosen cosmic radio source, following it, and the pattern of the tested antenna scans relative to this source. Both antennas are connected to a two-channel correlation receiver forming the interferometer. Consequently, we can observe not only the main lobe of this tested array but also its nearest sidelobes. In fact, the correlation method considerably reduces the impact of radio disturbances and the distributed radiation of galactic background noise. The records were obtained by using a special two-channel wideband digital receiver/spectrometer [11]. It works in the band 0–33 MHz with the sampling frequency of 66 MHz. The maximal resolution in frequency and in time is about 4 kHz and 1 ms, respectively. Using high-resolution analog to digital conversion in 16 bits, the spurious-free dynamic range (SFDR) of this device is about 112 dBc (decibels relative to the carrier). The detection of radio astronomy signals above 33 MHz was realized by undersampling (or in other words, bandpass sampling) the signals.

During July-August of 2013, the remote control device has been tested in real radioastronomical observations of radio emission from the Sun, Jupiter, radio sources, and

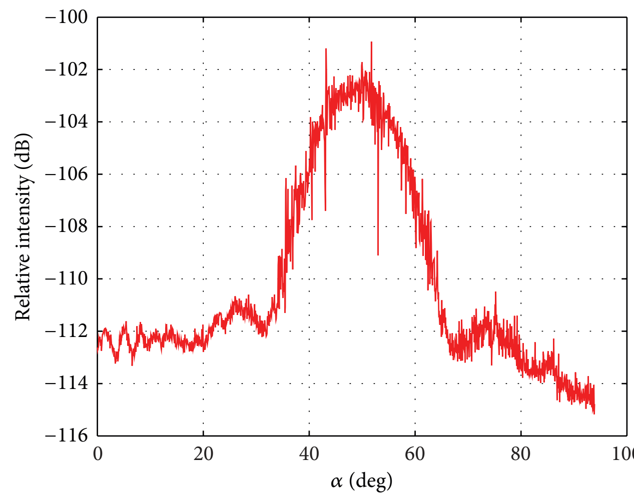

Figure 4: Strip chart of Cassiopeia A passing through the antenna array pattern due to the Earth's rotation at 57.105 MHz. The angle $\alpha = v_\delta t$ is proportional to the travel time t of Cassiopeia A, and the source velocity on the celestial sphere for the declination δ is defined as $v_\delta = 15(''/\text{sec})\cos\delta$ in angular seconds per (time) second.

others. Preliminary results have shown that with help of the above-mentioned remote control system, the procedure of radio astronomy observations has become easier and more effective. The detailed astrophysical analysis of the observations will be reported elsewhere.

6. Conclusion

We have reported some results about the active antenna array and its remote control system that was carried out in the framework of the radio telescope building of a new generation. We have shown that the progress in computer and digital technology opens wide doors in the development of the best antenna arrays for low-frequency radio astronomy. The current conjunction of the parameters of GURT subarrays and back-end facilities meets modern requirements of radio astronomy at the frequency range 10–70 MHz. This allows us to use different observational modes (tracking, scans, on-off, and others) including synchronized observations together with other radio telescopes.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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