# Elaboration of ERT5 Beam Pattern and Deconvolution

İsmail Yusifov[1]* and İbrahim Küçük[2]

[1] National Academy of Sciences of Azerbaijan, Institute of Physics, AZ-1143, AZERBAIJAN,ismail.yusifov@gmail.com
[2] Erciyes University, Dept. Astronomy and Space Sciences, 38039, Kayseri, TURKEY,kucuk@erciyes.edu.tr

**Abstract** In this paper we inform about the last stage of start and adjustment procedures of Turkish radio telescope ERT5. Here we report on the methods of observational data reduction and receiver calibration, more detailed estimation of the shape of antenna power pattern and the process of deconvolution of observational data. We also describe two (ground based and satellite) methods of antenna pattern measurements of ERT5 and their results. Beam estimations of ERT5 have been made for two frequencies (1.4 and 10 GHz) and the results are in good agreement with the theoretical estimations. We found that at the frequencies of 11 GHz ERT5 power pattern has the elliptic shape with the HPBW about $23'.5$ and $45'.7$. At the 1.4 GHz these values are correspondingly $160'$ and $225'$. Estimated beam efficiency of ERT5 is nearly 0.5. After precise beam estimations we performed 2D restoration of observed data with some methods of deconvolution (simple FFT, Lucy-Rychardson and maximum entropy (MEM)). Obtained results are in good agreement with each other and with other observations.

**Key Words:** Radio Astronomy, Radio Telescope, Telescope Calibration

## 1 Introduction

Converted from the 5m satellite antenna Erciyes University Educational Radio Telescope ( ERT5 ) is the first working radio telescope in Turkey. The telescope was constructed by the financial support of Erciyes University Research Development Projects Department (Project No: FB. 03.12 and FB. 03. 18) and on the base of 5m satellite antenna which was presented by Turkish TELECOM.

Preliminary results of ERT5 calibrations can be found in: Yusifov et al. (2006), Yusifov et al. (2007), Yusifov and Küçük (2008). These measurements show (Yusifov et al. (2007)) that the antenna pattern of ERT5 has deformed circular (nearly elliptic) shape, which is the consequence of antenna deformation during the transportation. For this reason, in order to perform precise deconvolution we decided to perform precise estimation of the shape of power pattern of ERT5 by fitting it with 2D Gauss distribution which is described in this report.

* ismail.yusifov@gmail.com

Antenna pattern measurements were made for both systems of receivers of ERT5: a wide band radiometer with central frequencies of $\nu_o = 10.5$ GHz and bandwidth $\Delta\nu = 1$ GHz and 1420 MHz HI receiver SC from Radio Astronomy Supplies (RAS ). For the antenna pattern measurements we used ground based transmitter, which was located nearly 5 km from telescope and satellite TV transmitter from TURKSAT 1C.

The obtained results and conclusions are given at the end of the paper.

## 2 Measurement of ERT5 Antenna Pattern

Antenna Pattern of Radiation or simply Antenna Pattern (AP) of ERT5 have been measured by two methods: with the help of simple transmitter and with the geostationary satellite Turksat 1C. In the first case the transmitter with nearly 11 GHz central frequencies was placed on the top of hill which was located nearly 5 km distances from the ERT5. This distance is much far than the far field region of ERT5. Scanning the transmitter we obtain the inverted power pattern of ERT5. Then inverting it once more we obtain real AP of ERT5 which is shown with solid line in Fig. 1.

In the second case AP of ERT5 we obtain by scanning the satellite Turcsat 1C, which has the following azimuth and elevation: $168^{\circ}.67$ and $44^{\circ}.55N$ correspondingly in our geographic coordinates. Inverted results of these measurements are shown by solid line in Fig. 2.

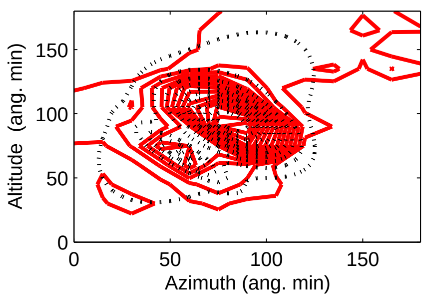


**Figure 1.** Observed (solid) and modeled (dotted) AP of ERT5 at 11 GHz obtained with the help of ground based transmitter

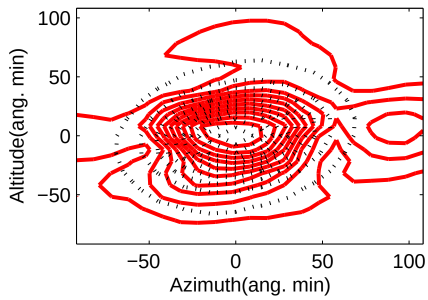


**Figure 2.** Observed (solid) and modeled (dotted) AP of ERT5 at 11GHz obtained by scanning the satellite Turksat 1C

## 3 Modeling and Canonization of ERT5 Antenna Pattern

As it is seen from Figures 1 and 2 cross-section of the beams have nearly elliptical shape. In order to compare obtained results with each others and to simplify deconvolution process we modeled AP and fitted the observed patterns in Figures 1 and 2 with 2D Gauss surfaces. We modeled ERT5 AP with the sum of two or three 2D Gauss distribution which has the form

$$f(x,y) = \frac{1}{2\pi\sigma_x\sigma_y\sqrt{1-r_{xy}^2}} \exp\left\{-\frac{1}{2\sqrt{1-r_{xy}^2}}[A+B+C]\right\}, \tag{1}$$

where

$$A = \frac{(x-m_x)^2}{\sigma_x^2}, \qquad B = \frac{2r_{xy}(x-m_x)(y-m_y)}{\sigma_x\sigma_y}, \tag{2}$$

and

$$C = \frac{(y-m_y)^2}{\sigma_y^2}, \qquad r_{xy} = \frac{K_{xy}}{\sigma_x\sigma_y}. \tag{3}$$

In these relations $m_x$ and $m_y$ are mean values, $\sigma_x$ and $\sigma_y$ are standard deviations of Gauss distributions. $K_{xy}$ and $r_{xy}$ is covariation and correlation coefficients correspondingly (Ventcel and Ovcharov 1988).

Cross-section of this 2D surface with the plane parallel to the $x0y$ plane is ellipse. Major axis of this ellipse form angles $\alpha$ with the $0x$ axis of coordinate system, which is evaluated by the relation:

$$\tan 2\alpha = 2r_{xy}\sigma_x\sigma_y/(\sigma_x^2-\sigma_y^2) \tag{4}$$

When the symmetric axis of the ellipse coincide with the coordinate axis, ellipse equation will have symmetric ( canonical ) form:

$$(x'/\sigma'_x)^2 + (y'/\sigma'_y)^2 = b^2 \tag{5}$$

where

$$(\sigma'_x)^2 = \sigma_x^2\cos^2\alpha + r_{xy}\sigma_x\sigma_y\sin 2\alpha + \sigma_y^2\sin^2\alpha \tag{6}$$

$$(\sigma'_y)^2 = \sigma_x^2\sin^2\alpha - r_{xy}\sigma_x\sigma_y\sin 2\alpha + \sigma_y^2\cos^2\alpha \tag{7}$$

and $b$ is the parameter which is dependent on the distance of cutting plane from the $x0y$ plane (Ventcel and Ovcharov 1988). HPBW of ERT5 AP in one or another direction can be derived from the canonic elliptic form ( 5) with the help of following relations:

$$\theta'_x = 2\sigma'_x\sqrt{2\ln 2} \quad \text{and} \quad \theta'_y = 2\sigma'_y\sqrt{2\ln 2} \tag{8}$$

## 4 Results of ERT5 AP Modeling at 11 GHz

In order to find the parameters of ERT5 power pattern in the frequencies 11 GHz observed patterns from Fig.1 and Fig.2 have been fitted with the sums of two or three 2D Gauss distributions (1) and the results are shown by dotted lines in Figures 1 and 2.

From this fitting surfaces we can found AP parameters of ERT5 ( HPBW in two directions $(\theta'_x, \theta'_y)$ and inclination angle $\alpha$ of main symmetric axis of ellipse to $0x$ axis). For ground and satellite measurements correspondingly derived values are: $\theta'_{xg} = 46', \theta'_{yg} = 23', \alpha_g = -44^\circ$ and $\theta'_{xs} = 73', \theta'_{ys} = 57', \alpha_s = 36^\circ$. From these data are seen that obtained ERT5 HPBW from satellite measurements nearly 2-3 times more than the expected theoretical value $(1.02\lambda/D = 21')$. The reason of this may be observation of either double closely located satellites or projection of some extra solar sources in the direction of measurements and requires additional more precise measurements with other alone satellites in other times. For this reason in this stage we excluded satellite date from our considerations and ERT5 AP derived only ground based measurements ( Fig. 1).

Numerical experiments of deconvolution with the simulated sources show that better results of map restorations may be obtained, if the ERT5 AP ( Fig.1) is fitted with sum of two 2D Gauss surfaces. Final results of AP modeling are shown in Fig. 3 and Fig. 4. In Fig. 3 is shown 3D model of AP. Cross-section of ERT5 AP along major and minor ellipse axis are shown in Fig. 4. For the parameters of two functions (1) fitting ERT5 AP we obtain following values: $\sigma_{x1} = 19'.23; \sigma_{y1} = 10'.44; \alpha_1 = -44^\circ.42$ and $\sigma_{x2} = 41'.42; \sigma_{y2} = 62'.58; \alpha_2 = -34\circ$. Main shape of ERT5 AP defines the first surface with parameters $(\sigma_{x1}; \sigma_{y1}; \alpha_1)$ and derived HPBW values have the following parameters: $\theta'_x = 46', \theta'_y = 23', \alpha = -44^\circ$. Finally, just this pattern was chosen for deconvolution of ERT5 observations.

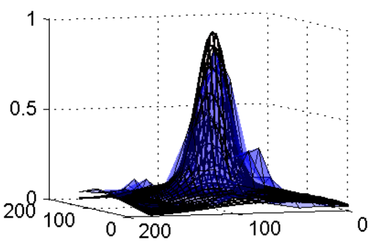


**Figure 3.** 3D view of observed (dark) and modeled (gray) AP of ERT5

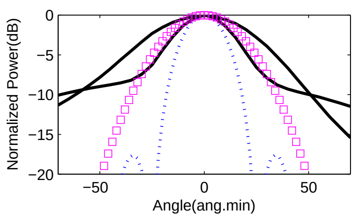


**Figure 4.** Comparison of theoretical and modeled AP of ERT5. Cross-section of AP along major and minor axis of ellipse shown by solid line. Theoretically expected shape is shown by dotted line. And expected profile for 2 m size antenna is shown by squares

## 5 AP Modeling of ERT5 at Frequencies 1.4 GHz

For the estimation of AP at frequencies 1.4 GHz we used the results of previous section and based on the next assumptions:

a) AP of ERT5 has nearly the same (elliptic) shape in these two frequencies (1.4 and 11 GHz);
b) orientation of symmetric axis of ellipsis in two frequencies is nearly same (nearly $-44°$ relative $0x$ axis);
c) in previous section we found that at 11 GHz in the direction of minor axis of ellipse, HPBW of ERT5 is nearly equal to the theoretical value ($1.02\lambda/D = 21'$). We assume that at frequencies 1.4 GHz this relation is held also and in the direction of minor axis of ellipse, HPBW of ERT5 is nearly equal to the theoretical value ($1.02\lambda/D = 2°.5$). This value is in agreement with HPBW estimation from Cyg A observation by ERT5 (Yusifov and Küçük (2008).
d) in previous section we found that at 11 GHz ratio of major to minor axis of ERT5 AP ellipse is 2. Until more precise estimations, here we accept compromised value nearly 1.5 for this ratio at 1.4 GHz and assume that HPBW of ERT5 along major axis of ellipse is nearly equal to $3°.75$.

Constructed shapes of ERT5 AP on the base of these assumptions are shown in Fig.5. In future must be done precise estimation of ERT5 AP on the base of additional observations.

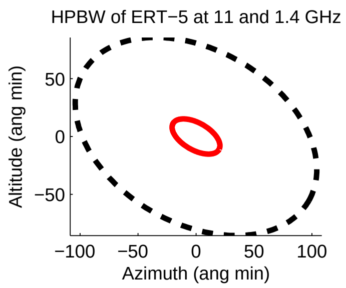


**Figure 5.** Comparative shapes ERT5 AP in two frequencies: 1.4 GHz (dashed line) and 11GHz (solid line)

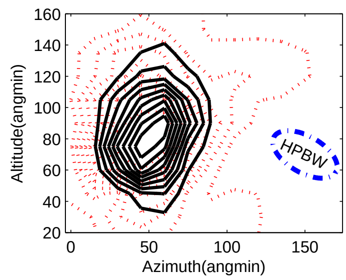


**Figure 6.** 11GHz map of Sun before (dotted) and after (solid) deconvolution

## 6 Deconvolution of Some Observational Data of ERT5

During the calibration period of ERT5 we performed preliminary observations of some celestial sources (Yusifov and Küçük (2008). In the results of observations we obtained blurred maps of the sources which are shown as dotted maps in

Figures 6, 7 and 8. In order to reveal fine details these maps must be deconvolved. For deconvolution of blurred maps or images radio astronomers applies various algorithms: CLEAN, MEM, Lucy-Richardson (L_R) etc. More detailed information on these algorithms can be found in: Högbom (1974), Cornwell and Evans (1985), Rohlf and Wilson (1996), Thompson et al. (2001) etc. Some times in low noisy systems with simple 2D Gaussian shaped AP for deconvolution successfully can be applied simple FFT method, also.

We carried out some numerical experiments of deconvolution of ERT5 observations with some of mentioned algorithms ( namely MEM, L_R and simple FFT). In this stage of knowledge AP of ERT5, there were not great differences between deconvolved maps obtained by applying various algorithms and for deconvolution of ERT5 observations we used L_R algorithm. Obtained maps after deconvolution in Figures 6–8 is shown by solid line. In Figures 6 and 7 for deconvolution we used ERT5 AP which has been derived in section 5 and contours are shown by dash-dot lines. But in Fig. 8 we used 1.4 GHz AP of ET5 derived in section 6.

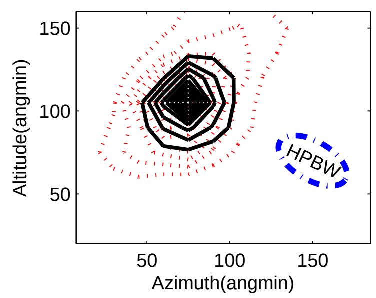


**Figure 7.** 11GHz map of Moon before (dotted) and after (solid) deconvolution

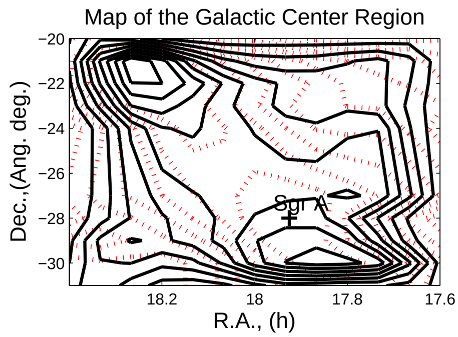


**Figure 8.** 1.4 GHz map of Sgr A region obtained by ERT5 before (dotted) and after (solid) deconvolution

From Fig. 8 is seen that in ERT5 observations although the galactic plane and bright sources are detected clearly, the map is very crude and fine details are absent. The main reason of this is the receiver instabilities and tracking system errors which were discussed in Yusifov and Küçük (2008).

## 7 Conclusions

In this paper the precise shape estimation of AP of ERT5 radio telescope is presented. It is shown that at 11GHz ERT5 AP has elliptic shape with minor and major diameters (at the half power intensity) nearly $23'$ and $46'$. At the 1.4 GHz ERT5 AP has the same shape and orientation with corresponding axis nearly $160'$ and $225'$. Major axis of ellipse has the angle $-45°$ with respect of $0x$ axis or with the azimuth direction.

Naturally, that for the high quality radio astronomical observations ERT5 requires more stabile and high quality receiver. Additionally, in Yusifov and Küçük (2008) was shown that ERT5 tracking system has large residual errors. After overcoming these disadvantages, more precise estimations of AP parameters of ERT5 in future must be done.

However the results of present study generally are enough for draft deconvolution of observation results and the use of ERT5 for educational purposes and teaching principles of radio astronomy.

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