# Description for antenna movement for BURT radio telescope area scan in horizontal coordinate with correspond equatorial coordinate

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Using a BURT telescope for the study of the relation between horizontal and equatorial coordinates. By using BURT archive files on observation for sun. Four files for sun observation have been used at different observation parameters, such as date and time. These files are assigned by file 1, file 2, file 3, and file 4. These observations are carried out at different horizontal coordinate (El) ranges, which are almost covered from horizon to zenith (28 to 32 for file 1, 54 to 59 for file 2, 64 to 69 for file 3, and 42 to 52 for file 4). These horizontal coordinates will be almost covered in the equatorial coordinate (DEC) range (-19 to -24 for file 1, 7 to 12 foe file 2, 8 to 14 for file 3, 9 to 19 for file 4). The BURT raster area scan technique is studied at different area sizes ($AS_H$) and step sizes ($SS_H$). This technique uses horizontal coordinates, and the corresponding area sizes ($AS_E$) and step sizes ($SS_E$) in equatorial coordinates are also studied for each observation files.

**Keywords:** BURT radio telescope; Area scan; Horizontal coordinates; Equatorial coordinates.

## 1. INTRODUCTION

The Baghdad University Radio Telescope (BURT) is a small radio telescope (3 meters in diameter) with a 3.7-half-power beam width. It is located at the University of Baghdad (longitude 44.38° E, latitude 33.275° N), Baghdad, Iraq. BURT is used to detect the neutral hydrogen emission line at a wavelength of 21 cm (1.42 GHz) [1,2]. This study is concentrated on the type of antenna, BURT mount, BURT area scan technique, and antenna movement sequence, such as raster scan technique.

*1.1. Antena mount of BURT radio telescope*

The antenna of the BURT radio telescope has a mount type of Altazimuth (alt-az). That has two motions, azimuth and elevation, which are electric motors that help the telescope rotate horizontally (0° to 360°) and vertically (0° to 90°) [3]. The horizontal coordinate system is a celestial coordinate system for locating objects in the sky as seen from a specific point on Earth's surface. It has two primary coordinates: altitude (elevation) and azimuth. Elevation (El) is the angular distance of a celestial object above the observer's horizon. It is measured in degrees ranging from -90° to +90°, with zero at the horizon. Azimuth (Az) is the direction of a celestial object relative to the observer's position, usually measured clockwise from the north point of the horizon. Az is also measured in degrees (0° to 360°) [4]. Equatorial coordinates are the projection of the Earth's equator onto the celestial sphere, resulting in the formation of the celestial equator. It has two coordinates: declination and right ascension. Declination (DEC) is an angle measured in degrees ranging from -90° to +90°, with zero at the equator. Right ascension (RA) is the angle measured from west to east in time units of hour-minute-second, ranging from 0 to 24 hours [5].

*1.2. Area scan*

Area scan mapping allows a single-dish radio telescope to map tiny areas of the sky more efficiently. The area scan technique is similar to the on-the-fly mapping technique employed in large telescopes. There are three main types of scanning that could be applied by radio telescopes: raster scanning, spiral scanning, and hypocycloid scanning [6]. The Baghdad University Radio Telescope BURT scanning method is a raster scan (Figure 1). It is the first scanning geometry implemented in a telescope because it is the easiest to implement into a telescope monitoring and control system.

*1.3. BURT radio telescope movement sequence in area scan*

To scan an area in the sky, we open a two-dimensional window with the observed source in the Center (C) (Figure 1), and the dimensions of this window in horizontal coordinate are determined by the Area Size ($AS_H$) in square degrees and the Step Size ($SS_H$) in degrees as the BURT radio telescope software input parameter. To start scanning an area, for example, $AS_H = 4$ square degrees and $SS_H = 1°$ (Figure 1). The telescope antenna is directed to the center of the window (c) and three files are opened to record the Az and El coordinates and power data. When all the information required to scan the area is determined, the scanning process begins when you click on start scanning. The movement starts from the bottom left of the window at the starting point (Sp) and goes to the right. Each line consists of several points depend on Equation (1), each of which is equidistant from the other points by a distance ($SS_H$). When the first line is completed at the point ($Sp+AS_H$), the antenna moves by the same distance ($SS_H$) and moves backwards from right to left to scan the second line. Thus, the point scan process is repeated on all the points of the window until the Finish Point (Fp). For this example, the Number of points (No.) can calculate using Eq. (1) which equal to 25 points, for each point the antenna will stop to record three values Az, El and power and save than the corresponding file.

$$\text{No.} = \left[\left(\frac{AS}{SS}\right)_H + 1\right]^2 \qquad (1)$$

where $AS_H$ is area size for horizontal coordinates in degrees and $SS_H$ is the step size for horizontal coordinates in degrees.

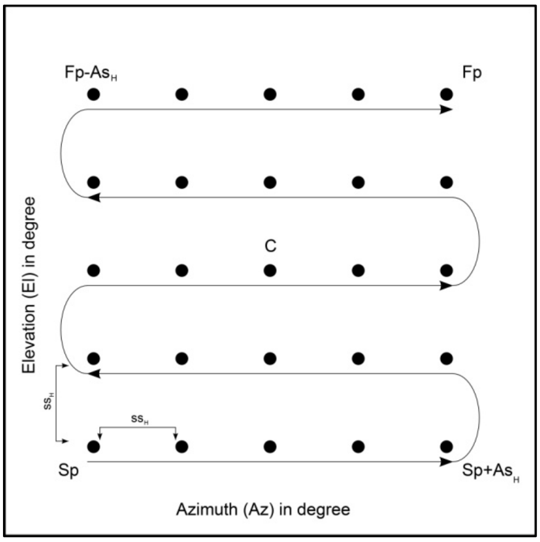


**Figure 1** Raster scanning for Baghdad University Radio Telescope (BURT) in horizontal coordinates.

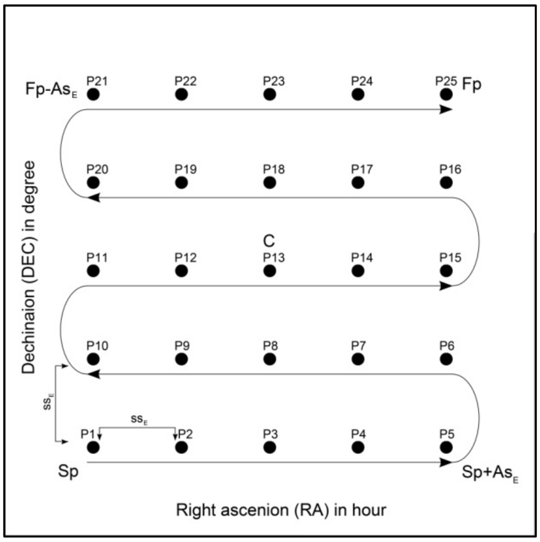


**Figure 2** Area scan technique in Equatorial coordinates (Raster scan).

Figure 2 illustrates the scanning process in equatorial coordinates, where the number of points in the equatorial coordinates is equal to the number of points (NO.) in the horizontal coordinates. The $SS_E$ and $AS_E$ in the equatorial coordinates can be calculated using the equations:

$$AS_E = Fp - Sp \quad (2)$$

Where: $AS_E$ is area size in Equatorial coordinates, Fp finish point and Sp start point.

$SS_E$ is the distance between two points and can be calculated by finding the difference between each two points.

$$SS_E = P2 - P1 \quad (3)$$

Where: $SS_E$ is step size in equatorial coordinates, P2 and P1 represent any two adjacent points.

## 2. HORIZONTAL TO EQUATORIAL COORDINATES CONVERT EQUATION

Conversion from horizontal coordinates (Az, El) to equatorial coordinates (RA, DEC) is done by using the following equations [7-14]:

$$\sin DEC = \sin El \sin \emptyset + \cos El \cos \emptyset \cos Az \qquad (4)$$

$$\cos H = \frac{\sin El - \sin \emptyset \sin DEC}{\cos \emptyset \cos DEC} \qquad (5)$$

$$H = LST - RA \qquad (6)$$

Where DEC is declination in degree, El is represents elevation in degree, Ø the observer's geographical latitude (Ø = 33.275°), Az is the azimuth in degree, H is the hour angle, LST is the Local Sidereal Time, RA is the right ascension. Both H and RA expressed in degrees or hour.

## 3. DATA OBSERVATION

The data in this paper is obtained from four files obtained from the BURT archives for sun observation, which contain the values of Az and El at different dates and times. File 1 is observed at (2019-1-7 at 10:50 AM), File 2 is observed at (2019-4-16 at 10:35 AM), File 3 is observed at (2019-4-20 at 11:45 AM), and File 4 is observed at (2019-4-30 at 9:22 AM).

**Table 1** Sun data observations file 1.

| From BURT archives | | Calculated by equations | | |
|---|---|---|---|---|
| Az(degree) | El(degree) | RA(hour) | DEC(degree) | $SS_E$(degree) |
| 152.99 | 28.19 | 19.6225 | -23.4109 | 0.5273 |
| 154 | 28.01 | 19.5686 | -23.9382 | 0.3389 |
| 155 | 28.02 | 19.509 | -24.2771 | 0.3455 |
| 156 | 28.01 | 19.4495 | -24.6226 | 0.3087 |
| 157.01 | 28.03 | 19.3881 | -24.9313 | 0.9614 |
| 157.01 | 29.06 | 19.361 | -23.9699 | 0.3342 |
| 155.99 | 29.07 | 19.4213 | -23.6357 | 0.3271 |
| 155 | 29.07 | 19.4795 | -23.3086 | 0.3386 |
| 154.01 | 29.07 | 19.5372 | -22.97 | 0.4063 |
| 152.99 | 29.12 | 19.5947 | -22.5637 | 0.9122 |
| 152.99 | 30.12 | 19.5652 | -21.6515 | 0.397 |
| 154 | 30.07 | 19.5092 | -22.0485 | 0.3365 |
| 155 | 30.07 | 19.4517 | -22.385 | 0.3281 |
| 156.01 | 30.07 | 19.3933 | -22.7131 | 0.313 |
| 157.01 | 30.07 | 19.3349 | -23.0261 | 0.9354 |
| 157.01 | 31.07 | 19.3094 | -22.0907 | 0.314 |
| 155.99 | 31.07 | 19.368 | -21.7767 | 0.3131 |
| 155.01 | 31.07 | 19.4238 | -21.4636 | 0.3341 |
| 154 | 31.07 | 19.4809 | -21.1295 | 0.4005 |
| 152.99 | 31.13 | 19.5358 | -20.729 | 0.9052 |
| 152.99 | 32.12 | 19.5073 | -19.8238 | 0.3856 |
| 154 | 32.07 | 19.453 | -20.2094 | 0.3161 |
| 155 | 32.08 | 19.3971 | -20.5255 | 0.3202 |
| 155.99 | 32.07 | 19.3418 | -20.8457 | 0.3087 |
| 157.01 | 32.07 | 19.2842 | -21.1544 | |

**Table 2** Sun data observations file 2.

| From BURT archives | | Calculated by equations | | |
|---|---|---|---|---|
| Az(degree) | El(degree) | RA(hour) | DEC(degree) | $SS_E$(degree) |
| 126.56 | 55.04 | 2.0072 | 9.4563 | 0.4697 |
| 127.62 | 54.96 | 1.9806 | 8.9866 | 0.416 |
| 128.63 | 54.92 | 1.9532 | 8.5706 | 0.3312 |
| 129.63 | 54.98 | 1.9213 | 8.2394 | 0.4165 |
| 130.63 | 54.92 | 1.8944 | 7.8229 | 0.8022 |
| 130.64 | 55.97 | 1.8488 | 8.6251 | 0.4027 |
| 129.57 | 55.99 | 1.8787 | 9.0278 | 0.349 |
| 128.56 | 55.96 | 1.9088 | 9.3768 | 0.3811 |
| 127.56 | 55.97 | 1.9365 | 9.7579 | 0.4229 |
| 126.56 | 56.03 | 1.9616 | 10.1808 | 0.7341 |
| 126.55 | 57.03 | 1.9155 | 10.9149 | 0.4433 |
| 127.63 | 56.97 | 1.8890 | 10.4716 | 0.3754 |
| 128.64 | 56.96 | 1.8617 | 10.0962 | 0.3327 |
| 129.63 | 56.99 | 1.8329 | 9.7635 | 0.3719 |
| 130.64 | 56.97 | 1.8054 | 9.3916 | 0.7665 |
| 130.64 | 57.97 | 1.7619 | 10.1568 | 0.3874 |
| 129.56 | 57.99 | 1.7905 | 10.5442 | 0.3279 |
| 128.56 | 57.96 | 1.8188 | 10.8721 | 0.3632 |
| 127.56 | 57.97 | 1.8451 | 11.2353 | 0.4082 |
| 126.55 | 58.03 | 1.8690 | 11.6435 | 0.727 |
| 126.55 | 59.03 | 1.8222 | 12.3705 | 0.4198 |
| 127.62 | 58.97 | 1.7975 | 11.9507 | 0.3573 |
| 128.63 | 58.96 | 1.7717 | 11.5934 | 0.3185 |
| 129.63 | 58.99 | 1.7440 | 11.2749 | 0.3542 |
| 130.64 | 58.97 | 1.7181 | 10.9207 | |

**Table 3** Sun data observations file 3.

| From BURT archives | | Calculated by equations | | |
|---|---|---|---|---|
| Az(degree) | El(degree) | RA(hour) | DEC(degree) | $SS_E$(degree) |
| 153.49 | 64.27 | 2.3417 | 9.7568 | 0.2763 |
| 154.51 | 64.15 | 2.3168 | 9.4805 | 0.1483 |
| 155.52 | 64.16 | 2.2888 | 9.3322 | 0.158 |
| 156.51 | 64.15 | 2.2617 | 9.1742 | 0.1361 |
| 157.52 | 64.16 | 2.2334 | 9.0381 | 0.1856 |
| 158.52 | 64.11 | 2.2065 | 8.8525 | 1.0159 |
| 158.53 | 65.18 | 2.2838 | 9.8684 | 0.1306 |
| 157.48 | 65.17 | 2.2123 | 9.9990 | 0.1489 |
| 156.48 | 65.18 | 2.2389 | 10.1479 | 0.1372 |
| 155.47 | 65.17 | 2.2661 | 10.2851 | 0.151 |
| 154.47 | 65.17 | 2.2927 | 10.4361 | 0.2075 |
| 153.50 | 65.23 | 2.3167 | 10.6436 | 0.9249 |
| 153.50 | 66.23 | 2.2909 | 11.5685 | 0.2125 |
| 154.54 | 66.17 | 2.2660 | 11.3560 | 0.1411 |
| 155.51 | 66.17 | 2.2411 | 11.2149 | 0.1319 |
| 156.52 | 66.18 | 2.2149 | 11.0830 | 0.1438 |
| 157.52 | 66.17 | 2.1892 | 10.9392 | 0.1179 |
| 158.51 | 66.18 | 2.1633 | 10.8213 | 0.9594 |
| 158.51 | 67.19 | 2.1418 | 11.7807 | 0.1089 |
| 157.48 | 67.17 | 2.1680 | 11.8896 | 0.1391 |
| 156.48 | 67.18 | 2.1927 | 12.0287 | 0.1284 |
| 155.46 | 67.17 | 2.2182 | 12.1571 | 0.1376 |
| 154.48 | 67.17 | 2.2424 | 12.2947 | 0.1997 |
| 153.49 | 67.23 | 2.2652 | 12.4944 | 0.9252 |
| 153.48 | 68.23 | 2.2392 | 13.4196 | 0.2038 |
| 154.54 | 68.17 | 2.2158 | 13.2158 | 0.1321 |
| 155.52 | 68.17 | 2.1925 | 13.0837 | 0.1203 |
| 156.52 | 68.18 | 2.1684 | 12.9634 | 0.1245 |
| 157.52 | 68.18 | 2.1445 | 12.8389 | 0.1192 |
| 158.52 | 68.18 | 2.1204 | 12.7197 | 0.9599 |
| 158.51 | 69.19 | 2.0989 | 13.6796 | 0.0991 |
| 157.48 | 69.17 | 2.1231 | 13.7787 | 0.1197 |
| 156.48 | 69.17 | 2.1461 | 13.8984 | 0.126 |
| 155.47 | 69.17 | 2.1692 | 14.0244 | 0.1284 |
| 154.48 | 69.17 | 2.1917 | 14.1528 | 0.1885 |
| 153.49 | 69.23 | 2.2126 | 14.3413 | |

**Table 4** Sun data observations file 4.

| From BURT archives | | Calculated by equations | | |
|---|---|---|---|---|
| Az(degree) | El(degree) | RA(hour) | DEC(degree) | $SS_E$(degree) |
| 100.95 | 43.09 | 3.0480 | 15.0012 | 1.9385 |
| 103.96 | 42.93 | 2.9755 | 13.0627 | 1.799 |
| 106.97 | 42.96 | 2.8888 | 11.2637 | 1.7705 |
| 109.94 | 42.93 | 2.8032 | 9.4932 | 1.7779 |
| 110.04 | 45.98 | 2.6352 | 11.2711 | 1.6843 |
| 107.04 | 45.97 | 2.7190 | 12.9554 | 1.7116 |
| 104.08 | 45.98 | 2.7973 | 14.6670 | 1.7907 |
| 101.09 | 46.04 | 2.8702 | 16.4577 | 1.615 |
| 100.95 | 49.04 | 2.6936 | 18.0727 | 1.6961 |
| 103.92 | 48.98 | 2.6266 | 16.3766 | 1.6473 |
| 106.91 | 48.97 | 2.5528 | 14.7293 | 1.6617 |
| 110.02 | 48.98 | 2.4713 | 13.0676 | 1.7515 |
| 110.04 | 51.98 | 2.3040 | 14.8191 | 1.4995 |
| 107.07 | 51.97 | 2.3766 | 16.3186 | 1.5467 |
| 104.1 | 51.98 | 2.4447 | 17.8653 | 1.6957 |
| 100.96 | 52.04 | 2.5101 | 19.5610 | |

## 4. RESULTS AND ANALYSIS

**Table 5** Boundary scan area in Equatorial coordinates (DEC) corresponding to Horizontal coordinates (El).

| Number of file | Sp (degree) | | Sp+AS (degree) | | Fp-AS (degree) | | Fp (degree) | |
|---|---|---|---|---|---|---|---|---|
| | El | DEC | El | DEC | El | DEC | El | DEC |
| 1 | 28.19 | -23.4109 | 28.03 | -24.9313 | 32.12 | -19.8238 | 32.07 | -21.1544 |
| 2 | 55.04 | 9.4563 | 54.92 | 7.8229 | 59.03 | 12.3705 | 58.97 | 10.9207 |
| 3 | 64.27 | 9.7568 | 64.11 | 8.8525 | 69.23 | 14.3413 | 69.19 | 13.6796 |
| 4 | 43.09 | 15.0012 | 42.93 | 9.4932 | 52.04 | 19.5610 | 51.98 | 14.8191 |

**Table 6** Resultant for four files.

| Number Of file | Horizontal coordinates (Az & El) | | Equatorial coordinates (DEC) | | | |
|---|---|---|---|---|---|---|
| | $SS_H$ (degree) | $AS_H$ (degree$^2$) | $SS_E$ (degree) | $AS_E$ (degree$^2$) | $AS_E$ Ideal (degree$^2$) | Area scan Error |
| 1 | 1 | 4 | 0.3087≤SS≤0.9614 | 5.1075 | 5.0191 | 1.7612% |
| 2 | 1 | 4 | 0.3185≤SS≤0.8022 | 4.5476 | 4.4344 | 2.5527% |
| 3 | 1 | 5 | 0.0991≤SS≤1.0159 | 5.4888 | 5.377 | 2.0792% |
| 4 | 3 | 9 | 1.4995≤SS≤1.9385 | 10.0678 | 10.0193 | 0.484% |

Table 5 shows area scan boundaries for four files in horizontal coordinates (El) and equatorial coordinates (DEC) and Table 6 shows the step size (SS) and area size (AS) in horizontal and equatorial coordinates. The $SS_H$ and $AS_H$ in horizontal coordinates are given as values entered when the scanning process starts. In equatorial coordinates, we find that the distance between points ($SS_E$) is not constant, i.e. it ranges between two values. This is due to the mechanical movement of the telescope. The $AS_E$ column is the actual value of the area size in equatorial coordinates obtained from the values of Az and El. The $AS_E$ ideal column is the ideal area expected to be obtained when taking only the integer values of Az and El. The last column shows us the result of the error percentage between the ideal values and the resulting values of the area size. This percentage is calculated through eq. (7). We find that the percentage does not exceed 3% of the real values.

$$Error\ ratio = \left| \frac{AS_E - AS_E\ Ideal}{AS_E\ Ideal} \right| * 100\% \quad (7)$$

## 4. CONCLUSIONS

1. It turns out that the area size ($AS_E$) in the equatorial coordinates (DEC) is larger than the $AS_H$ in the horizontal coordinates.
2. The $AS_E$ in the equatorial coordinates DEC changes with the limits of El, so if El is close to the horizon, the area is larger, and this is proven by the results of 1 and 2 in Table 6.
3. When comparing the DEC area size calculations by using the values of El as an integer, we find that they represent the correct representation of this area. The percentage error in area was found to be approximately 3% or less, and this percentage occurs due to the mechanical movement of the telescope.

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