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# Improvement in Reflectarray Antenna Bandwidth with Changing the Geometrical Shape

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## Abstract

**The method of this paper is based on change in the geometrical shape of the reflectarray plane which is similar to a concave shape and with this changing, it is tried to make the incident waves orthogonal as much as possible in order to remove the phase error caused by incident wave variation. The other benefit of this work is omitting frequency change error caused by path difference between reflectarray antenna bandwidth. Two types of reflectarray antennas operating at X-band frequency with a linear polarization are considered in this design: concave and flat reflectarray antennas with the diameter of 135 mm. elements which are used in this paper are variable-size patches. The proposed reflectarray antenna (concave) approximately has 25% 3-dB bandwidth which shows an increment in bandwidth about 18% compared to flat reflectarray antenna.**

## Keywords

**Increasing of Reflectarray Antenna Bandwidth, Non-Flat Reflectarray Antenna**

## 1. Introduction

Reflectarray antennas are the new generation of traditional parabolic reflectors. They are combination of both printed phased arrays and parabolic reflectors [1]. They are light and easy to fabricate and occupy less space than parabolic reflectors. Reflectarrays have the advantage of high gain and low cost; therefore they have been used in development activities [1]-[3]. A reflectarray consists of array of elements to create a focused beam in a desired direction. Usually, there are three different ways to determine printed reflectarrays. The first one is the usage of identical microstrip patches connected to variable-length delay lines [4]. The second is to use variable-size printed elements [5]. The third way is utilization of elements with different angular rotations and is only usable for circular polarization antennas [6] [7].

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Design and analysis of reflectarray antennas is based on reflection phase versus elements size. In this method it is supposed that the phase response is independent of incident field, this technique is valid for those elements which are located in the center of the reflectarray plane and with a center-fed situation. The technique of orthogonal incident field can have suitable estimation for reflectarray antennas with center-fed when an enormous amount of reflection fields reflected from the center region of the antenna. For variable size patches with 40˚ incident wave, phase will change about 25˚ beside the orthogonal incident wave. When the incident wave is about 60˚, this variation in phase reaches to 50˚ [8]. Therefore, this technique is not suitable for the elements near the edges of the reflectarray and a new technique is needed. The technique which is used in this paper is based on making the ground plane in form of a concave in order to cause the incident waves become orthogonal to the patches and also reducing the frequency change error for increasing the bandwidth.

## 2. Design of the Non-Flat Reflectarray Antenna (Concave)

Beside the reflection waves from the reflectarray patches, specular reflection is also considered. Two specular reflections occur from reflectarray plane: reflection from the ground plane and reflection from the resonating patches. Because of the reflection from the resonating patches are negligible, only the reflection from the ground plane of the reflectarray is considered. Specular reflections from the ground plane in the regions near to the center of the reflectarray are approximately in the direction of reradiated waves but as the becomes bigger, specular reflections more apart from the reradiation waves and it causes increase in side lobes in radiation pattern of the antenna (**Figure 1**). **Figure 2** indicates the new structure of the ground plane which has a concave shape.

For the first part of design a suitable degree ($\alpha$) is required in which the maximum of reflection waves are situated in the main beam direction. In this design, the reflectarray shape is considered as a square in which each side is 135 mm. as can be seen in **Figure 3**, the ground plane of the reflectarray is divided in two parts: center part and other corner parts in which the center part is a square which has L side and the corner parts with trapezoid shape which are connected to the four sides of center part.

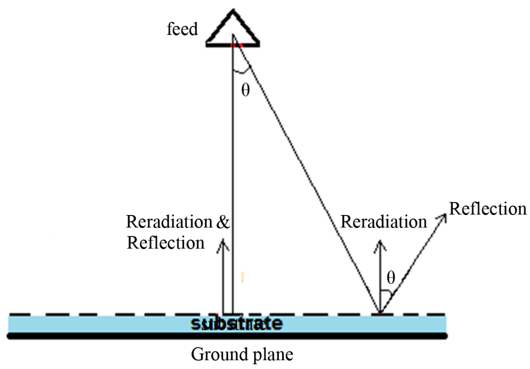


**Figure 1.** Flat reflectarray antenna.

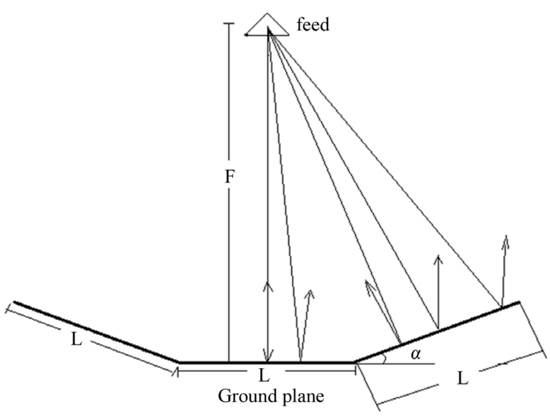


**Figure 2.** Side view of proposed ground plane.

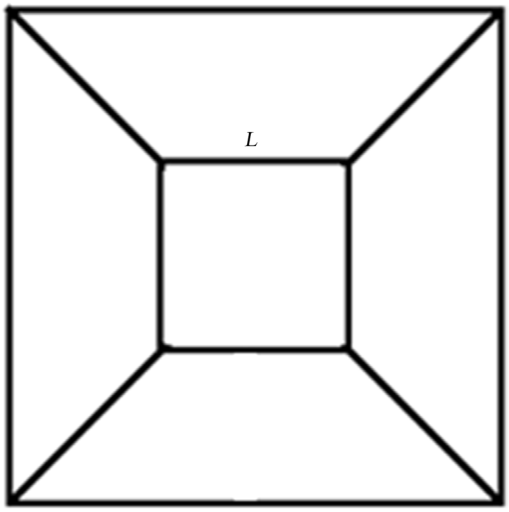


**Figure 3.** Front view of proposed ground plane.

The small side and altitude of the trapezoid are equaled to L. Also trapezoidal planes are located angular with the Z axis in which the angle between the normal (orthogonal) vector of trapezoidal planes and Z axis is $\alpha$.

With considering the ground plane size (135 mm) and with considering f/D to 1, we locate the phase center of the horn antenna in the 135 mm distance from the center of concave plane and examine the directivity according to the variation in $\alpha$ degree. With considering **Figure 4**, with changing $\alpha$ from 0˚ to 20˚, it can be seen that the maximum directivity is in $\alpha$ = 10˚. Here, the maximum directivity indicates the maximum reflection waves in the main beam direction.

## 2.1. Reflectarray Elements Design

This part is based on situating dielectric layer on the ground plane and also designing patches on the dielectric. Because the ground plane shape of this antenna is not like the conventional reflectarrays, a suitable solution is needed. For calculation of phase difference for every patches in order to control main beam in $(\theta_b, \phi_b)$ direction, equation $\phi_R(x_i, y_i) = k_0\left[d_i - (x_i \cos\phi_b - y_i \sin\phi_b)\sin\theta_b\right]$ is useable but this equation is valid only for a flat reflectarray planes.

The main issue in this design is making all elements of the proposed reflectarray inphase. In flat reflectarray with using previous equation, we can make the elements of the center plane and trapezoidal planes inphase but the major problem is making these elements inphase together. This issue is illustrated in **Figure 5**.

## 2.2. Novel Formula for Calculating Elements Phase of a Non-Flat Reflectarray

In this section, a novel formula for making all elements of a non-flat reflectarray plane is presented. First of all, an important point exists in designing patches which is when a constant value $(\phi_0 = 2n\pi,\ n = 0, \pm 1, \pm 2, \cdots)$ adds to the computing phase, inphase condition of the patches will keep [9]-[11]. **Figure 6** verifies this point. In **Figure 6**, $D, \theta_b, x_0, k_0$ are antenna diameter, angle between antenna main beam and Z axis, constant value as shown in **Figure 6**, propagation constant, respectively.

Based on these values, it can be concluded that $\phi_0 = k_0(D + x_0)\sin\theta_b$ is constant because all parameters in this formula have a constant value and also these parameters should be choose in order to make $\phi_0$ equals $2n\pi$ in which $n$ is integer as a result $k_0(D + x_0)\sin\theta_b = 2n\pi$.

As mentioned in previous sentence, with adding this constant ($\phi_0$) to $\phi_R(x_i, y_i) = k_0\left[d_i - (x_i \cos\phi_b - y_i \sin\phi)_b \sin\theta_b\right]$, inphase situation of element will keep. If we assume $\phi_b = 0$, equations of this examination are presented below:

$$\phi_R(x_i, y_i) = k_0\left[d_i - x_i \times \sin(\theta_b)\right] + \phi_0, \quad \phi_0 = 2n\pi,\ n = 0, \pm 1, \pm 2, \cdots \tag{1}$$

$$\phi_R(x_i, y_i) = k_0\left[d_i - x_i \times \sin(\theta_b)\right] + k_0(D + x_0)\sin(\theta_b) \tag{2}$$

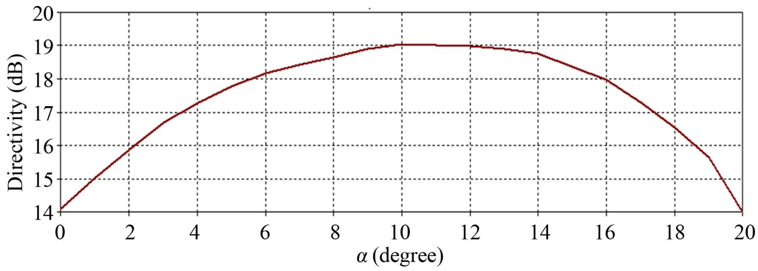


**Figure 4.** Directivity of the proposed ground plane.

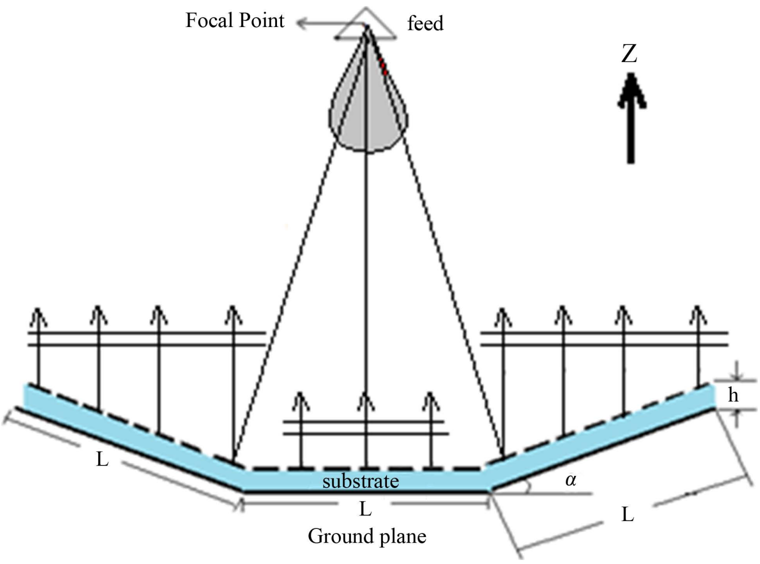


**Figure 5.** The antenna which is designed by conventional formula.

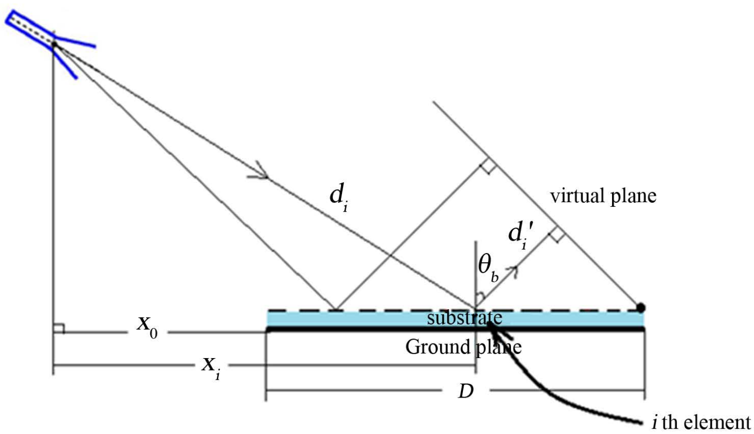


**Figure 6.** The reflectarray coordination and virtual plane.

$$\phi_R(x_i, y_i) = k_0\left[d_i - x_i \sin(\theta_b) + x_0 \sin(\theta_b) + D\sin(\theta_b)\right] \tag{3}$$

$$\phi_R(x_i, y_i) = k_0(d_i) + k_0(D + x_0 - x_i)\sin(\theta_b) \tag{4}$$

By substituting $\left[(D + x_0 - x_i)\sin\theta_b\right]$ with $d_i'$, the Equation (4) will become:

$$\phi_R(x_i, y_i) = k_0(d_i + d')_i \tag{5}$$

As can be seen in **Figure 6**, $d_i$ is the elements distance from the horn phase center and $d_i'$ is the elements distance from the virtual plane in which the orthogonal vector of the virtual plane ids located in the main beam direction of the antenna. It should be noticed that the virtual plane should be parallel with the reradiation wave plane from the patches and also one side of the virtual plane should have connection with end of reflectarray plane (connection point in **Figure 6**).

## 2.3. Computation of Reflectarray Element Phase

In this section, we obtain (calculate) phase of elements which are located on the non-flat reflectarray by using the equation $\phi_R(x_i, y_i) = k_0(d_i + d_i')$. In order to use this technique firstly we should consider a suitable virtual plane. Considering that the maximum of specular reflections in the proposed antenna (**Figure 4**) is in the Z axis direction, the antenna main beam (caused by resonating patches) is also will design in that direction. As the main beam direction of the antenna of **Figure 4** is in the Z axis direction, therefore, orthogonal vector of virtual plane should be paralleled with the Z axis.

Concerning **Figure 7**, we consider the virtual plane in a special height from the ground plane and also in front of it. In order to obtain the phase of each element, it is required to calculate $d_i$, $d_i'$ parameter for each element.

In this antenna, the variable sized patches are used. For computing elements phase, firstly size of each unit cell should be calculated. Here, size of each element (unit cell) is $\lambda/2$ and center frequency of this design is 10 GHz as a result of which each side of every unit cell is 15 mm. Dielectric constant which is used in this antenna equals to 2.2 ($\varepsilon_r = 2.2$) and also dielectric height is 1 mm (h = 1 mm). Phase-element of microstrip patches with L side is shown in **Figure 8**.

## 2.4. Radiation Pattern and Bandwidth of Non-Flat Reflectarray

A horn antenna is used as feed in which the phase center distance from the reflectarray plane is 135 mm. Radiation pattern of the antenna are shown in **Figure 9** and **Figure 10**.

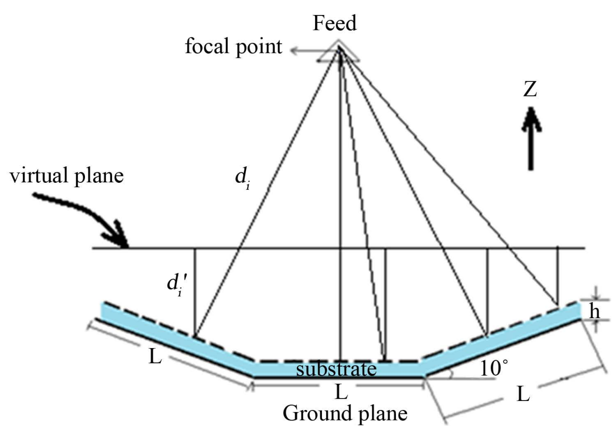


**Figure 7.** Reradiation waves for designed reflectarray with proposed formula.

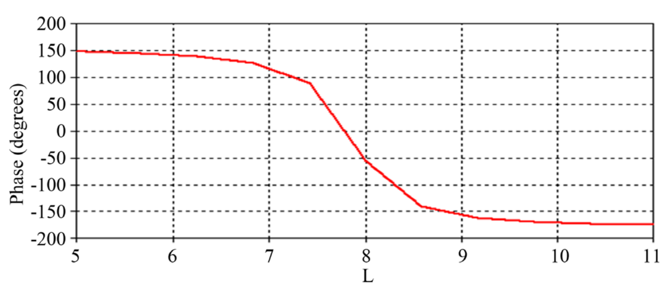


**Figure 8.** Reflectarray element phase versus size of the patch.

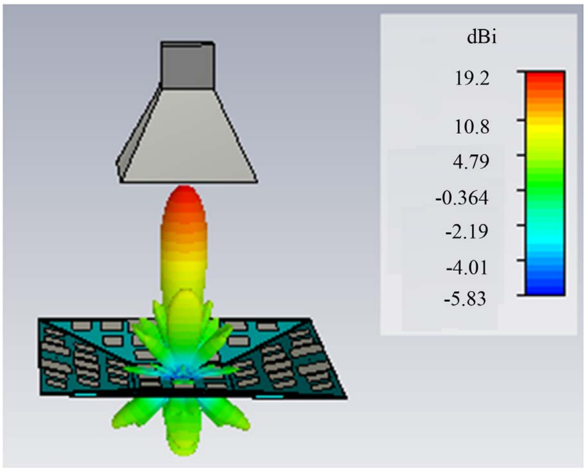


**Figure 9.** Radiation pattern of non-flat reflectarray antenna.

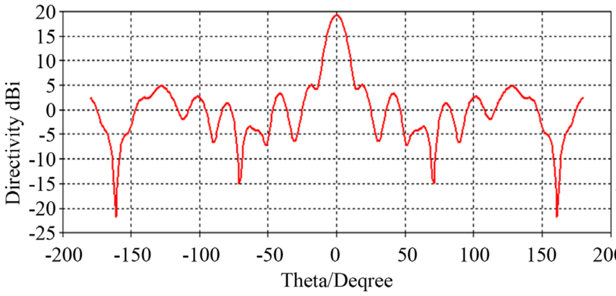


**Figure 10.** Two dimensional radiation pattern of non-flat reflectarray antenna in E-plane.

As can be seen in **Figure 10**, directivity of antenna in 10 GHz is about 19.2 dB. **Figure 11** indicates the antenna directivity in the frequency range from 9 GHz to 14 GHz. −3 dB bandwidth obtained from this figure is about 25%.

## 3. Design of a Flat Reflectarray Antenna with the Same Scale of Non-Flat Proposed Reflectarray in Order to Compare Their Bandwidth

In this design, ground plane has some condition of ground plane of **Figure 2**, with the difference in $\alpha$ which here equals to zero. With this value the antenna has the conventional shape as other reflectarrays. In other words, ground plane is a square with 135 mm side. Dielectric constant is same as non-flat reflectarray and also same thickness ( $\varepsilon_r = 2.2$, $h = 1\text{ mm}$ ).

Feed for this antenna is same as non-flat reflectarray which is a horn and have phase center distance from the ground plane which is radiation pattern of this antenna in center frequency of 10 GHz is shown in **Figure 12**. As can be seen in **Figure 13**, directivity of antenna in 10 GHz is about 21.6 dB. From **Figure 10** and **Figure 13**, it is considerable that the side lobe level of the proposed ground plane is lower than flat one which shows an improvement in this parameter.

**Figure 14** shows directivity of this antenna for frequency range from 9 GHz to 11 GHz. −3 dB bandwidth in center frequency is about 6.3%. As can be understood from the results, the non-flat reflectarray has increment in bandwidth about 18%.

Another important parameter in antenna is cross-polarization which should be decreased in design. Radiation pattern with cross-polarization for non-flat and flat reflectarray antenna are shown in **Figure 15**. By considering the **Figure 15**, an improvement in cross-polarization for non-flat reflectarray exists.

## 4. Conclusion

Two major results obtained in this part, first of all, Equation (5) can be used for calculation of elements phase of

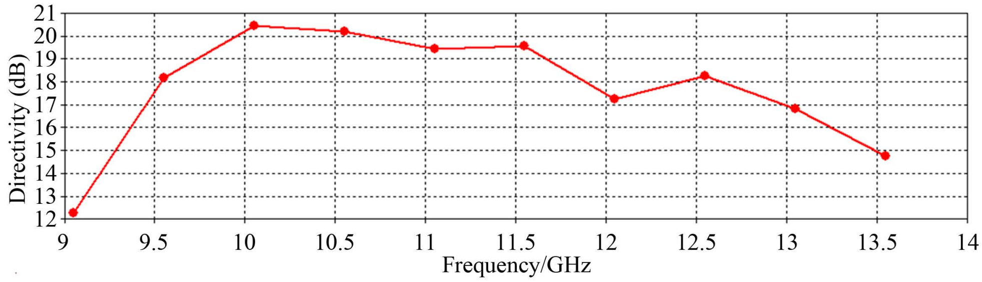


Figure 11. Frequency response of non-flat reflectarray antenna with the diameter of 135 mm.

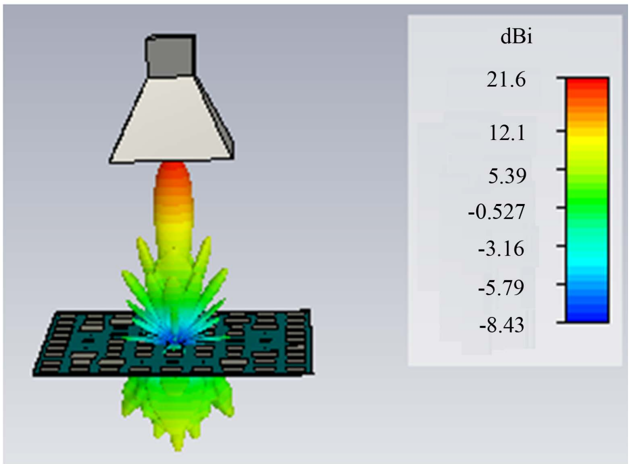


Figure 12. Radiation pattern of flat reflectarray antenna.

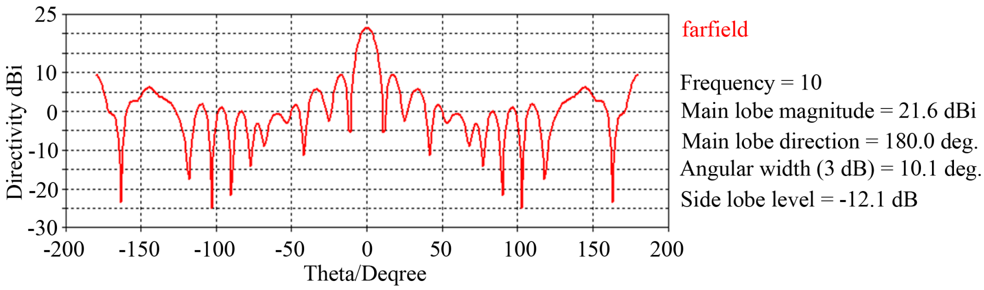


Figure 13. Two dimensional radiation pattern of flat reflectarray antenna in E-plane.

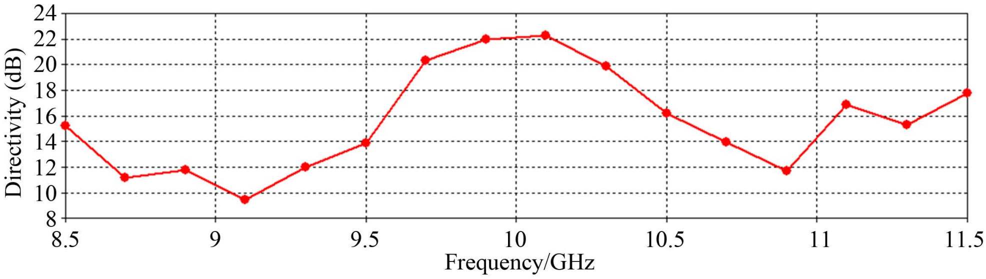


Figure 14. Frequency response of flat reflectarray antenna with the diameter of 135 mm.

a non-flat reflectarray. Another important result is improvement in incident angle of horn antenna to elements which are located in the edges of a reflectarray by changing the geometrical of the antenna and also an improvement in bandwidth is attainable.

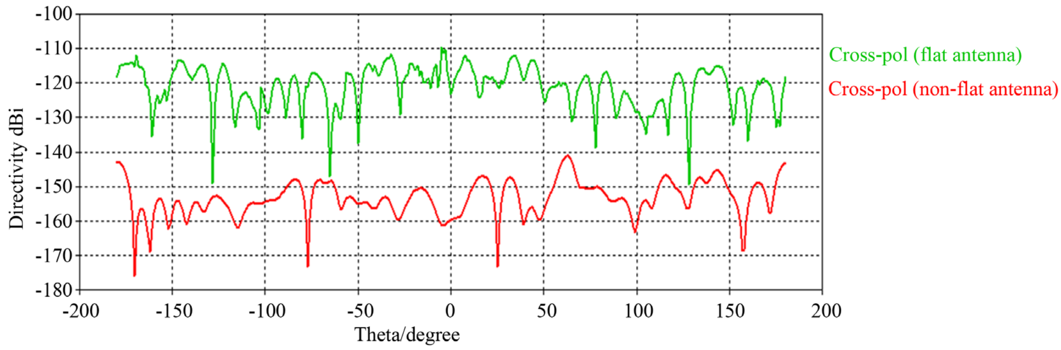


**Figure 15.** Cross polarization for flat and non-flat reflectarray antennas in center frequency of 10 GH.

Obtained bandwidth for a non-flat reflectarray (proposed antenna) with 135 mm diameter is about 25% which has improvement about 18% compared to flat reflectarray with same size.

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