Theoretical Analysis of Polarization Rotation angle in Dual Reflector Antenna

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***Abstract*- Because of special structure, a dual reflector antenna has beam rotation capability in azimuth and elevation directions. In this structure, the antenna beam can be placed in any point in the space by mechanical movement of twist reflector which it is the most important ability of the antenna. Due to the antenna structure, if the polarization of incident wave is linear, it is expected that the polarization of propagated wave is linear and in the direction of desired design. In this paper, for the first time, a nonlinear relation is extracted that it shows the propagated beam polarization has a polarization rotation. This formula is a mathematic closed form relation. These structures are very useful in airborne radar systems.**

Index Terms- Antenna, beam, dual reflector, feed horn, polarization, trans-reflector, twist reflector.

I. INTRODUCTION

Airborne radar systems have many requirements such as small size, low weight, fast beam scanning, high efficiency and high gain. A reflector antenna is a good choice for low cost and high efficiency [1]-[4].

A dual reflector antenna is compact, like a Cassegrain reflector antenna; but, it delivers high efficiency, high gain and low sidelobe levels of a prime-focus reflector. The dual-reflector antenna, as a compact option for the Cassegrain, has performed more comparably to a prime-focus reflector antenna. These antennas can achieve gains in excess of 30 dB [5]-[11].

This antenna is composed of three parts: the main reflector (twist reflector), sub-reflector (trans-reflector) and feed horn.

Trans-reflector is a parabola structure which acts as both a reflector antenna and a radome. The trans-reflector is made of conductive-strip grating embedded in a shaped dielectric molding [12]. It is easy to see that a large subreflector blocks effective area of the main reflector (aperture blocking

Manuscript received 16-Nov-2014 and revised 28-Jan.-2015, *P-ISSN: 2322-4088*
Accepted on 26- Feb.-2015 *E-ISSN: 2322-3936*

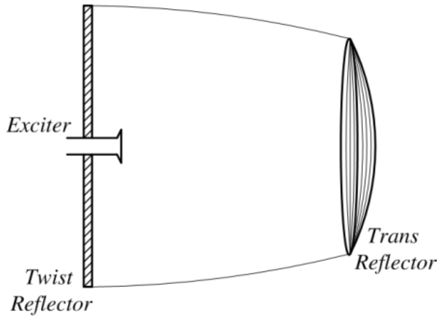


Fig. 1. Configuration of the proposed antenna.

phenomenon). However, if only one polarization is permissible, this adverse effect can be considerably decreased.

Consider the antenna in transmitting mode, as in Fig. 1. A feed horn antenna with linear polarization illuminates the trans-reflector that its electric field vector is aligned parallel to the conductive strip grating. The strips are arranged orderly beside each other so that the trans-reflector collects and then reflects the incident wave with considerable reduction in escaping waves to the space. While the twist-reflector receives the reflected radiation from the trans-reflector, the twist-reflector rotates field vector 90 degrees and then redirects it toward the trans-reflector. The electric field polarization is perpendicular to the trans-reflector's strips grating direction, and then it passes through the trans-reflector into the space with an inconsiderable loss.

The twist reflector may be gimbaled for two axes of tilt, as illustrated in Fig. 5, to perform two angles coordinate scan. Major advantages of the dual-reflector antenna include 1) the capability for beam scanning with no waveguide rotary joints for reliability and low loss operation, 2) the very wide angle scan capability with low scan loss, and 3) the ability of beam scanning with high acceleration and velocity because the only moving parts are the lightweight twist reflector and its actuators [13].

The most important ability of this antenna is beam rotation by twist-reflector mechanical movement. Due to the antenna structure, it is expect that the propagated wave polarization has 90 degrees rotation angle only because of the twist-reflector.

In this paper, it is shown that the propagated wave polarization has another polarization rotation in scanning mode which it is extracted. Also, polarization rotation angle for azimuth and elevation scan angle has been presented.

II. ANTENNA CONFIGURATION

The proposed antenna is divided to three parts: a feed horn, a trans-reflector, and a twist-reflector as revealed in Fig. 1. The design method of any part is discussed below.

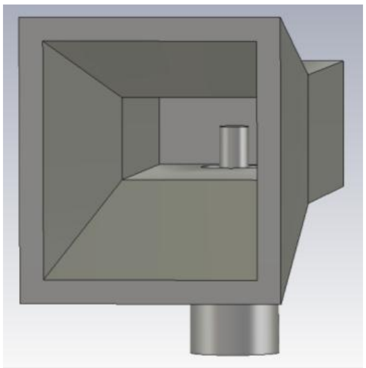
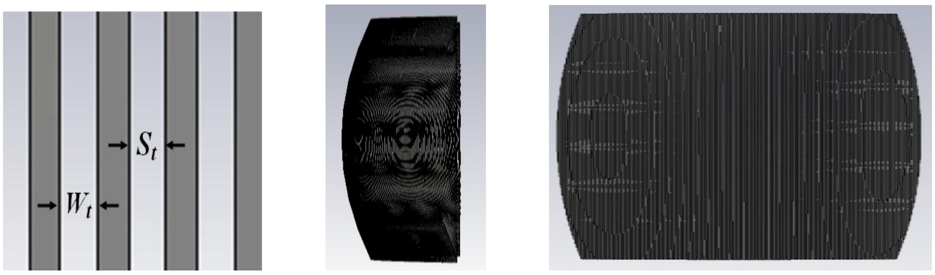


Fig. 2. Feed horn antenna.



a) Strip grating b) Side view c) Front view

Fig. 3. Trans-reflector structure.

A. Feed horn

This antenna illuminates the trans-reflector by propagated waves with vertical polarization. The electric field vector is parallel to trans-reflector conductive strips direction. Then, all of incident waves will reflect.

Since the horn antenna has a phase center, the best performance of dual-reflector antenna can be achieved when the phase center of horn antenna is located at the trans-reflector focal point.

B. Trans-reflector

The trans-reflector has a periodic structure which includes a set of embedded conductive strips grating inside a dielectric layer, as shown in Fig. 3. This structure does two functions: first, it acts as a reflector which collocates feed-horn radiation and second, it is a radome to collocate the returned energy from the twist-reflector. The function of the trans-reflector is almost dependent on the polarization of the incident electric field.

Whenever the electric field is parallel to the strips (as in Fig. 3) we call it a reflect-polarized because the field reflects; otherwise we call it a thru-polarized because the field passes through the strip grating. Since the grating has not a continuous conductive surface, there is some loss in the

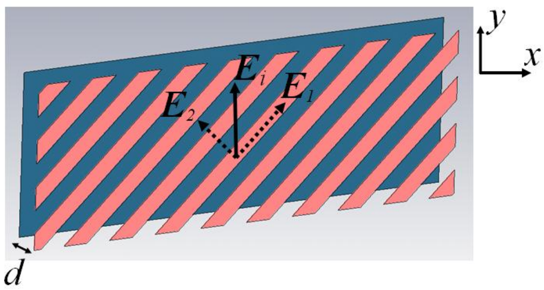


Fig. 4. Twist-reflector structure.

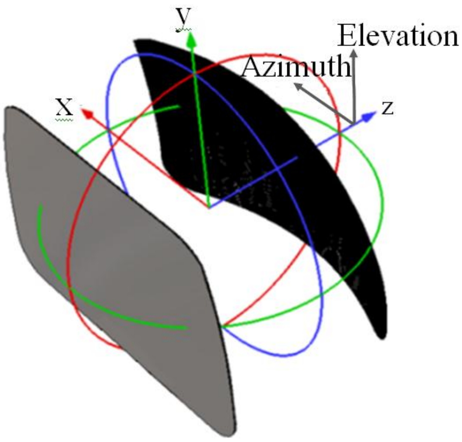


Fig. 5. Antenna coordination.

reflected polarization. For the thru-polarized signal, the trans-reflector acts like a radome. This structure has a parabolic shape.

C. Twist-reflector

A planar reflection structure has been used to rotate the incident electromagnetic wave. For economical reasons, a dielectric twist-reflector is used: a quarter-wave, ground-plane-backed and dielectric layer printed with conductive strip grating.

Fig. 4 shows the twist-reflector and a vertically polarized incident electric field on its conductive strips grating. The conductive strips and the incident electric field are making 45 degrees angle.

The incident electric field can be decomposed into parallel and perpendicular components with respect to the strips which will be reflected and transmitted, respectively. The transmitted perpendicular component travels through the dielectric substrate and will be reflected by the ground plane.

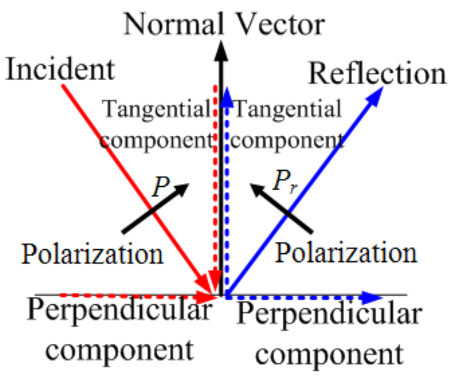


Fig. 6. Incident and reflection state.

III. THE RELATION BETWEEN THE TWIST-REFLECTOR MOVEMENT AND THE BEAM POLARIZATION ROTATION ANGLE

The antenna coordination is shown in Fig. 5. It is assumed that the polarization of incident wave is linear and vertical for twist-reflector antenna.

When –*z* and *y* are the propagation direction and polarization of the incident wave, respectively:

$$\hat{I} = -\hat{z} \tag{1}$$

$$\hat{P} = \hat{y} \tag{2}$$

where $\hat{I}$ and $\hat{P}$ are incident wave and polarization vectors, respectively.

The beam vector of antenna is:

$$\hat{r} = \cos(el_r)\sin(az_r)\hat{x} + \sin(el_r)\hat{y} + \cos(az_r)\cos(el_r)\hat{z} \tag{3}$$

where the az_r and el_r are beam rotation angles in azimuth and elevation directions, respectively.

Vectors of normal, incident and reflection wave are shown in Fig. 6. Using this figure, the normal vector is

$$\hat{n} = \frac{\hat{r} - \hat{I}}{\left|\hat{r} - \hat{I}\right|} \tag{4}$$

where $\hat{n}$ is normal vector.

Using the equations (1) and (3), the normal vector is:

$$\hat{n} = \frac{\sqrt{2}\cos(el_r)\sin(az_r)}{2\sqrt{\cos(az_r)\cos(el_r)+1}}\hat{x} + \frac{\sqrt{2}\sin(el_r)}{2\sqrt{\cos(az_r)\cos(el_r)+1}}\hat{y} + \frac{\sqrt{2\cos(az_r)\cos(el_r)+2}}{2}\hat{z} \tag{5}$$

The polarization of reflected beam is:

$$\hat{P}_r = 2(\hat{P} \cdot \hat{n})\hat{n} - \hat{P} \tag{6}$$

where $\hat{P}_r$ is polarization vector of reflected beam.

Using the equations (2) and (5), the polarization of the reflected beam is:

$$\hat{P}_r = \frac{\cos(el_r)\sin(az_r)\sin(el_r)}{\cos(az_r)\cos(el_r)+1}\hat{x} - \left(\frac{\cos(el_r)^2 - 1}{\cos(az_r)\cos(el_r)+1} + 1\right)\hat{y} + \frac{\sin(el_r)\sqrt{4\cos(az_r)\cos(el_r)+4}}{2\sqrt{\cos(az_r)\cos(el_r)+1}}\hat{z} \tag{7}$$

The polarization rotation angle is given by:

$$\cos(rot) = e\hat{l} \cdot \hat{P}_r \tag{8}$$

$$rot = \cos^{-1}\left(e\hat{l} \cdot \hat{P}_r\right) \tag{9}$$

where $e\hat{l}$ and *rot* are elevation vector and rotation angle of polarization, respectively. The elevation vector is:

$$e\hat{l} = -\sin(el_r)\sin(az_r)\hat{x} + \cos(el_r)\hat{y} - \cos(az_r)\sin(el_r)\hat{z} \tag{10}$$

$$rot = pi - \cos^{-1}\left(\frac{\cos(az_r)+\cos(el_r)}{\cos(az_r)\cos(el_r)+1}\right) \tag{11}$$

From Fig. 6, (*az*, *el*) are:

$$el = \sin^{-1}\left(\frac{\sqrt{2}\sin(el_r)}{2\sqrt{\cos(az_r)\cos(el_r)+1}}\right) \tag{12}$$

$$az = \tan^{-1}\left(\frac{\sqrt{2}\cos(el_r)}{\sqrt{\cos(az_r)\cos(el_r)+1}} \times \frac{\sin(az_r)}{\sqrt{2\cos(az_r)\cos(el_r)+2}}\right) \tag{13}$$

where *az* and *el* are azimuth and elevation rotation angle of the twist-reflector, respectively.

By use of equations (12) and (13) in the equation (11),

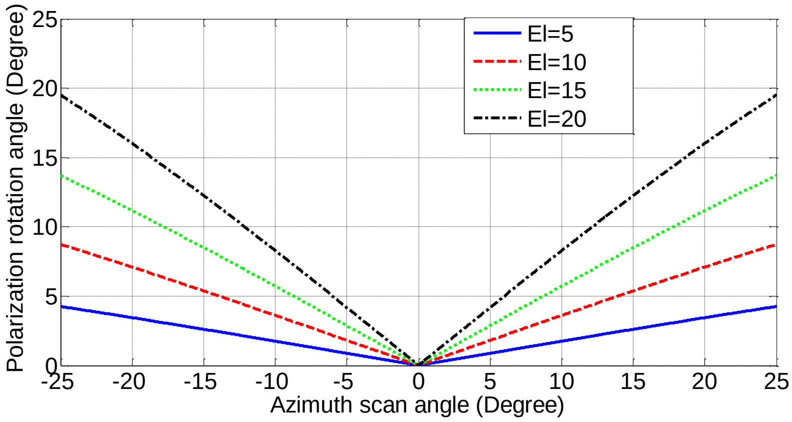


Fig. 7. The polarization rotation angle for the azimuth scan angle.

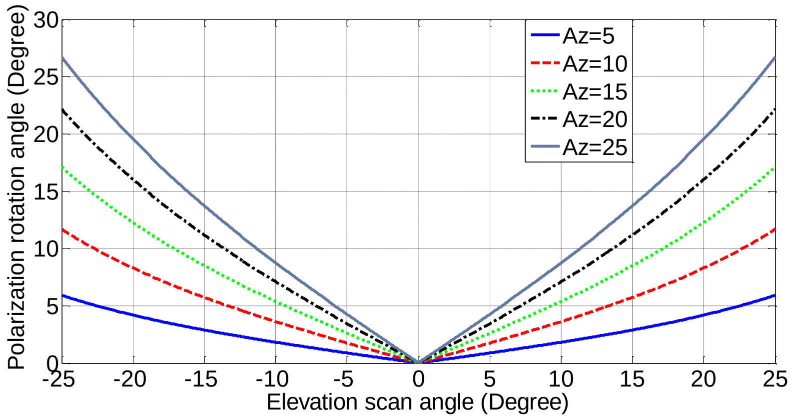


Fig. 8. The polarization rotation angle for the elevation scan angle.

$$rot=\cos^{-1}\left(\begin{array}{l}-\cos(2el)\sqrt{1-4\cos^{2}(az)\cos^{2}(el)\sin^{2}(el)}-\dfrac{4\cos^{2}(az)\cos^{2}(el)\sin^{2}(el)}{\sqrt{\dfrac{\sin^{2}(2az)\cos^{4}(el)}{\left(2\cos^{2}(az)\cos^{2}(el)-1\right)^{2}}+1}}-\\ \dfrac{4\sin(2az)\cos(az)\cos^{4}(el)\sin(az)\sin^{2}(el)}{\left(2\cos^{2}(az)\cos^{2}(el)-1\right)\sqrt{\dfrac{\sin^{2}(2az)\cos^{4}(el)}{\left(2\cos^{2}(az)\cos^{2}(el)-1\right)^{2}}+1}}\end{array}\right) \tag{14}$$

IV. RESULTS AND DISCUSSION

By use of equation (14), the polarization rotation angle for different azimuth and elevation scan angles are shown in figures 7 and 8. In the Fig. 7, the polarization rotation versus the azimuth scan angle for various elevation angles (*el*= 5°, 10°, 15° and 20°) is presented. When the azimuth or elevation scan angle is zero, the polarization rotation angle will be zero. Otherwise, if the azimuth and elevation scan angle are not zero simultaneously, the polarization rotation will be appear.

In the Fig. 8, the polarization rotation versus the elevation scan angle for various azimuth angles (*az*= 5°, 10°, 15°, 20° and 25°) is presented. Regarding to the simulation results, the rotation for small scan angle is negligible. Due to this rotation, a small loss will produce in antenna gain.

V. CONCLUSION

In this paper, the rotation angle of polarization in a dual-reflector antenna has been extracted. This antenna is a type of cassegrain which equipped with two reflectors: a flat (twist-reflector) and a parabola (trans-reflector). A new formula is extracted in the relation between the twist-reflector mechanical movement and the polarization rotation angle of propagated beam. This relation shows that the polarization of propagated beam has another rotation in the scanning mode. Without this formula the polarization of the propagated beam is not correct. These antennas can be useful for airborne radar systems and millimeter wave applications.

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