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A Patterning Method of Polarization Grids on a Reflector Using Reflector Surface Developing Technique

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1 Introduction

Gridded reflector antennas are often applied to on-board antennas for communications satellites owing to their excellent cross polarization suppression characteristics and to their frequency reuse capabilities using dual overlapped reflector configurations[1][2]. Polarization grids are arranged on a curved reflector surface to form a parallel-line pattern projected on an antenna aperture plane. Such grids have been manufactured by several methods. One method is sticking thin conducting wires on a reflector surface. Another method is direct photo-etching on a reflector surface using a NC-driven laser system[2]. These methods require special expense for complex patterning equipments. On the other hand, one of simple grid patterning methods is transcribing a grid pattern etched on a plane onto a curved reflector surface. A grid pattern on a plane is easily etched by conventional photo-etching technique. A key technology for this method is pattern design on a plane to obtain a desired pattern on a curved reflector surface. This paper proposes a pattern design method on a plane using reflector surface developing technique, and presents a grid patterning method of transcribing a plane pattern onto a curved reflector surface.

2 A grid patterning method using reflector surface developing technique

2.1 A developable surface contacting with an arbitrary reflector surface at an arbitrary curved line

A developable surface is mapped isometrically to a plane. As described in this section, an appropriate developable surface can be found to approximate an arbitrary reflector surface. The arbitrary reflector surface $\boldsymbol{p}_0$ and the developable surface $\boldsymbol{p}$ are illustrated in Figure 1. The necessary and sufficient condition for a developable surface is, as described in geometry textbooks, that a ruled surface

$$\boldsymbol{p}(u,v) = \boldsymbol{q}(u) + v\boldsymbol{t}(u) \tag{1}$$

has a fixed normal direction against variation of the parameter v, where $\boldsymbol{t}$ is unit vector, and u, v are parameters representing arc lengths. When the ruled surface $\boldsymbol{p}(u,v)$ represented by equation (1) contacts with an arbitrary reflector surface $\boldsymbol{p}_0$ at an arbitrary curved line $\boldsymbol{q}(u)$ on $\boldsymbol{p}_0$, unit vector $\boldsymbol{t}(u)$ is given by

$$\boldsymbol{t}(u) = \sin\varepsilon(u)\{\hat{\boldsymbol{n}}(u) \times \boldsymbol{q}'(u)\} + \cos\varepsilon(u)\boldsymbol{q}'(u) \tag{2}$$

where $\hat{\boldsymbol{n}}(u)$ is a unit normal of the surface $\boldsymbol{p}_0$ at the curved line $\boldsymbol{q}(u)$, and $\varepsilon(u)$ is the angle between $\boldsymbol{t}(u)$ and $\boldsymbol{q}'(u)$. The ruled surface $\boldsymbol{p}$ represented by equations (1) and (2) is derived to become a developable surface when $\varepsilon(u)$ is given by the following equation:

$$\tan\varepsilon(u) = -\frac{q''(u)\cdot\hat{n}(u)}{\{\hat{\boldsymbol{n}}'(u) \times \boldsymbol{q}'(u)\}\cdot\hat{\boldsymbol{n}}(u)} \tag{3}$$

2.2 Developing a pattern on a developable surface onto a plane

Let a plane $\bar{\boldsymbol{p}}(u,v)$ be defined by the following equations:

$$\bar{\boldsymbol{p}}(u,v) = \bar{\boldsymbol{q}}(u) + v\bar{\boldsymbol{t}}(u) \tag{4}$$

$$\bar{\boldsymbol{q}}''(u) = \kappa_g(u)\{\bar{\boldsymbol{n}}(u) \times \bar{\boldsymbol{q}}'(u)\} \tag{5}$$

$$\bar{\boldsymbol{t}}(u) = \sin\varepsilon(u)\{\bar{\boldsymbol{n}} \times \bar{\boldsymbol{q}}'(u)\} + \cos\varepsilon(u)\bar{\boldsymbol{q}}'(u) \tag{6}$$

where $\bar{\boldsymbol{q}}(u)$ is a curved line on the plane $\bar{\boldsymbol{p}}(u,v)$, $\bar{\boldsymbol{n}}$ is unit normal vector of the plane $\bar{\boldsymbol{p}}(u,v)$. κ_g is a geodesic curvature of the curved line $\boldsymbol{q}(u)$ on the developable surface $\boldsymbol{p}(u,v)$ and given by:

$$\boldsymbol{q}''(u) = \kappa_n(u)\hat{\boldsymbol{n}}(u) + \kappa_g(u)\{\hat{\boldsymbol{n}}(u) \times \boldsymbol{q}'(u)\} \tag{7}$$

where κ_n is a normal curvature of the curved line $\boldsymbol{q}(u)$. The first fundamental quantities of the plane $\bar{\boldsymbol{p}}(u,v)$; $\bar{E}, \bar{F}, \bar{G}$ are as follows:

$$\bar{E} = (\partial\bar{\boldsymbol{p}}/\partial u)^2 = 1 - 2v(\kappa_g + \varepsilon')\sin\varepsilon + v^2(\kappa_g + \varepsilon')^2 \tag{8}$$

$$\bar{F} = \partial\bar{\boldsymbol{p}}/\partial u \cdot \partial\bar{\boldsymbol{p}}/\partial v = \cos\varepsilon \tag{9}$$

$$\bar{G} = (\partial\bar{\boldsymbol{p}}/\partial v)^2 = 1. \tag{10}$$

Furthermore, each of the first fundamental quantities of the developable surface $\boldsymbol{p}(u,v)$ are found to be equal to each of those of the plane $\bar{\boldsymbol{p}}(u,v)$, respectively. This means that, as described in geometry textbooks, the plane $\bar{\boldsymbol{p}}(u,v)$ is the developed plane of the developable surface $\boldsymbol{p}(u,v)$. and a point $\boldsymbol{p}(u,v)$ on the developable surface is mapped to a point $\bar{\boldsymbol{p}}(u,v)$ on the developed plane.

2.3 Grid patterning procedure

Based on the above results, the proposed grid patterning procedure is presented as follows.

1. Determine the developable surface p approximating the curved reflector surface p_0 according to equations (1)-(3). An appropriate grid line on p_0 may be selected as the curved line q.

2. Map a desired grid pattern on the curved reflector surface p_0 onto the developable surface p. Indicate a point on a grid line on p_0 using u and v, where u is a parameter of the curved line $q(u)$, v is a geodesic distance from a point on $q(u)$ to a point on the grid line along the geodesic line with the $t(u)$-direction at the point on $q(u)$. The point $p_0(u, v)$ is mapped to the point $p(u, v)$.

3. Develop the mapped pattern on the developable surface $p(u, v)$ to the plane $\bar{p}(u, v)$ according to equations (4)-(6).

4. Transcribe the pattern on the plane $\bar{p}$ onto the curved reflector surface p_0. When transcribing, the curved line $\bar{q}(u)$ on the plane $\bar{p}$ should be adjusted to the curved line $q(u)$ on the reflector surface p_0.

Relationships among grid patterns on a reflector surface p_0, on a developable surface p, and on a developed plane $\bar{p}$ are illustrated in Figure 2.

3 Conclusion

A patterning method of polarization grids on a curved reflector surface using reflector surface developing technique is proposed. This method is efficient for manufacturing polarization grids on a curved reflector surface by simple and conventional equipments.

References

[1] K. K. Chan and F. Hyjazie, "Design of overlapped gridded reflectors for frequency reuse," AP-S International Symposium digest, APS5-2, 1985.

[2] S. Makino, H. Shigemasa, T. Noguchi, T. Ebisui, M. Kobayashi, and S.Mano, "Radiation characteristics of dual overlapped gridded reflector antennas," 1988 Autumn Nat. Conv. Rec. IEICE, B-61, Sept. 1988 (in Japanese).

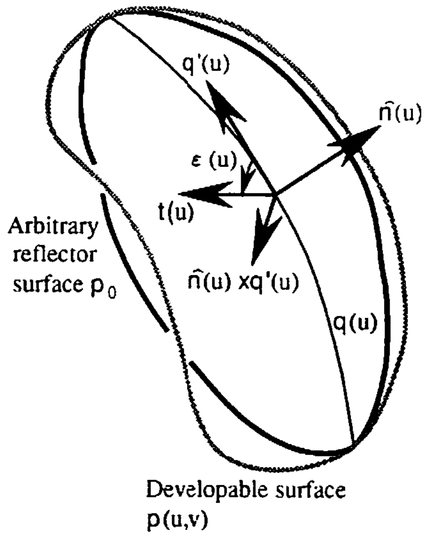

Figure 1: A developable surface p contacting with an arbitrary reflector surface p_0 at an arbitrary curved line q.

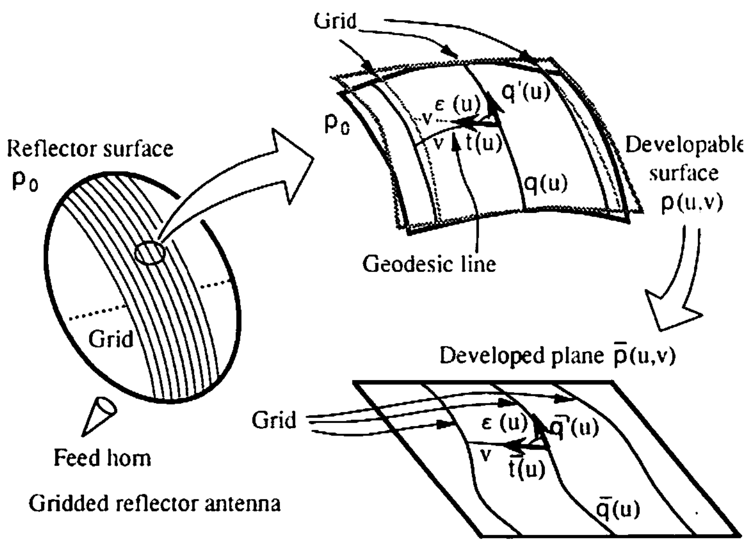

Figure 2: Relationships among grid patterns on a reflector surface p_0, on a developable surface p, and on a developed plane $\bar{p}$.