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A LOW SIDELOBE SHAPED OFFSET GREGORIAN ANTENNA FOR 14/11 GHz BAND VSATS

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1. Introduction

The advancement of satellite technologies makes it possible to provide various satellite communications services by installing VSATs (very small aperture terminals). In communication systems using a large number of VSATs, the reduction of interference to and from the other satellite systems or terrestrial radio systems is of primary technical importance. Since sidelobes of earth-station antennas are one of the dominant factors in the inter-network interference level, the development of small-aperture antennas with minimum possible sidelobes is considered to be essential to the construction of such systems.

This paper describes the performance of a 1.2 m shaped offset Gregorian antenna for 14/11 GHz band earth-stations. In order to achieve low sidelobe characteristics, a new design method based on physical optics is applied to the shaped reflectors. The antenna exhibits a high efficiency of more than 72 % and extremely low sidelobes of below $25 - 25\cdot\log(\psi)$ dBi.

2. Importance of sidelobe suppression

In order to clarify the importance of sidelobe suppression, the relationship between the off-axis e.i.r.p. density limit and the sidelobe level is discussed as an example. The maximum permissible levels of off-axis e.i.r.p. density from earth-stations transmitting in the 14 GHz band drafted by CCIR were as follows [1]:

$$2.5^\circ \le \psi \le 7.0^\circ : \quad 39 - 25\cdot\log(\psi) \text{ dB(W/40kHz)}. \qquad (1)$$

The design objective of the radiation diagram of a small earth-station antenna with D/λ between 35 and 100 was also decided as follows [2]:

$$(100\lambda/D)^\circ \le \psi \le (D/5\lambda)^\circ : \quad G = 52 - 10\cdot\log(D/\lambda) - 25\cdot\log(\psi) \text{ dBi}. \qquad (2)$$

In the case of an FM-TV carrier, the relationship between power density and total power is determined by the peak-to-peak frequency deviation factor of the video signal. Table 1 shows the maximum permissible e.i.r.p. level as a function of the size and the sidelobe envelope of an antenna. The necessary e.i.r.p. of an FM-TV transmitting terminal depends on the required uplink C/N and satellite G/T. However, 70 dBW can be assumed as a nominal value of required e.i.r.p. for SNG (satellite news gathering) service, which is one of the typical applications of small earth stations [3]. Table 1 shows that TV transmission would violate the off-axis e.i.r.p. density limit, even though the sidelobe envelope of the earth-station antenna satisfied the diagram (2). A low sidelobe characteristic of at least $G = 29 - 25\cdot\log(\psi)$ dBi is required in order to transmit a 70 dBW TV carrier from an antenna with $D/\lambda = 50$. In view of the above properties, it is very important to reduce the sidelobes of small antennas.

3. Antenna design

A shaped offset Gregorian antenna is designed. The effective aperture diameter is 1.2 m and the frequency bands are 10.95 - 11.7 GHz for reception and 14.0 - 14.5 GHz for transmission. The design objectives are as follows:

(a) the sidelobe envelope must be lower than $25 - 25\cdot\log(\psi)$ dBi,
(b) the aperture efficiency should be as high as possible,

(c) the cross-polarization level must be less than -27 dB within the beamwidth,
(d) the structure should be resistant to snow adhesion.

Regarding the most important item (a), an overall design optimization with particular attention to VSATs application is performed. The sidelobe level is minimized in the angle up to 10° from the boresight within ±45° of the horizontal plane, since the inclination of the geostationary satellite orbit observed from major cities in Europe, Japan and USA tends to be within 45°.

In shaping reflectors for high-performance reflector antennas, geometrical optics (GO) approximation is generally used [4]. When the GO shaping method is applied to antennas with small D/λ values, the difference between the desired or designed radiation pattern and that realized due to diffraction and scattering effects becomes an important problem. In particular, in the case of an offset antenna, these effects cause the sidelobe characteristics to be asymmetrical and stand in the way of sidelobe suppression [5].

In order to overcome the limit of GO shaping in achieving low sidelobe characteristics, we have proposed a new reflector shaping method through physical optics (PO) with the direct optimization of a far-field pattern [5]. Both surfaces of the reflectors are determined by a nonlinear optimization procedure. The objective of the optimization problem is minimizing the maximum value of sidelobe peaks which are calculated by PO and normalized by the gradient of $-25 \cdot \log(\psi)$ dB. The required minimum gain is imposed upon the procedure as a constraint. The aperture distribution calculated by PO has no phase error at a designed frequency.

An offset Gregorian geometry which satisfies the condition of no cross-polarized component [6] is used as an initial geometry in order to obtain good cross-polar performance. The present design is carried out at a point frequency of 11.7 GHz. The calculated minimum sidelobe envelope is $22.4 - 25 \cdot \log(\psi)$ dBi under an aperture efficiency constraint of 75%. The maximum deviation of the PO-shaped main reflector from the initial surface is approximately 6 mm.

4. Measured data

Figure 1 shows the 1.2 m shaped offset Gregorian antenna. Since the offset angle of the main reflector is about 73°, the antenna is very thin, less than 1000 mm in depth. The elevation angle of the main beam axis is 36° when the main reflector is vertically installed. The upright reflector surfaces prevent raindrops and snow adherence. The following requirements are necessary to realize the low sidelobe characteristic:

(a)The reflector surfaces must maintain a high accuracy. The surface accuracy of the main reflector is typically 0.3 mm r.m.s.
(b)The reflectors and the feed horn should be aligned accurately. A typical alignment error is 1 mm.
(c)It is better to remove a flange of the reflector. If necessary, a curved flange is better than a flat one.

In the reflector manufacturing process, we have tried three materials; pressed aluminum, sandwiched FRP with an aluminous honeycomb, and resin-injected FRP. It is concluded that all of the materials satisfy the required accuracy and are suitable for low sidelobe antennas.

Table 2 shows the measured gain of the antenna. The antenna exhibits high efficiency over 72% in the designed frequency range. Figure 2 shows measured radiation patterns near the main beam axis. The antenna produces extremely low sidelobes and excellent polarization purity over a wide frequency range. The peak envelope of the near-axis sidelobes is below $25-25 \cdot \log(\psi)$ dBi, which is superior to that of the CCIR recommendation [2] by 7 to 10 dB. The cross-polarization level is below -27 dB within the 3 dB beamwidth. One of the wide-angle radiation patterns measured in the azimuth plane is shown in Figure 3. Figure 4 shows one measured in the horizontal plane when the elevation angle of the main beam is 30°. Almost all of the sidelobe peaks measured are better than -10 dBi.

It is important to develop an economical method of deicing for VSATs. It is confirmed that a sheet radome made of glass fiber-reinforced Teflon of 0.5 mm thick does not affect the low sidelobe characteristics. From the results of field tests receiving a satellite beacon in Sapporo during the winter of 1988, it is concluded that an air heater of 1.5 kVA within the sheet radome is sufficient to prevent icing and snow adhesion.

5. Conclusions

The design technique and the measured performance of a 1.2 m shaped offset Gregorian antenna for 14/11 GHz band VSATs are presented. The antenna features extremely low sidelobes, better than $25-25\cdot\log(\psi)$, and is now used in satellite communication systems.

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Reference

[1] Draft Recommendation 524-2 (MOD I), Interim booklet of SG-4, CCIR, 1988.
[2] Recommendation 580-1, CCIR SG-4, 1986.
[3] Draft Report AK/CMTT, JIWP CMTT-4-10-11, CCIR, 1988.
[4] B. S. Westcott,"Shaped reflector antenna design," Research Studies Press, Hertfordshire, 1983.
[5] S. Nomoto and F. Watanabe,"Shaped reflector design for small-size offset dual reflector antennas," Trans. IEICE Japan, vol. J71-B, 11, pp. 1338-1344, Nov. 1988.
[6] Y. Mizuguchi, M. Akagawa, and H. Yokoi,"Offset dual reflector antenna," IEEE AP-S International Symp., Mass., U.S.A., Oct. 1976.

Table 1 The maximum permissible e. i. r. p. (dBW) for an FM-TV carrier.
- 2 MHz peak to peak dispersal
- 70 % antenna efficiency

diameter	gain	sidelobe envelope (dBi)			
		$35-25\log\psi$	$32-25\log\psi$	$29-25\log\psi$	$25-25\log\psi$
100λ	48.4dBi	69.4	72.4	75.4	79.4
75λ	45.9dBi	66.9	69.9	72.9	76.9
50λ	42.4dBi	63.4	66.4	69.4	73.4
35λ	39.3dBi	60.3	63.3	66.3	70.3

Table 2 Measured gain and efficiency.

Frequency	gain		efficiency	
	V-pol.	H-pol.	V-pol.	H-pol.
10.95 GHz	41.4 dBi	41.4 dBi	72.9%	72.9%
11.7 GHz	42.0 dBi	42.1 dBi	73.3%	75.0%
14.0 GHz	43.6 dBi	43.7 dBi	74.0%	75.7%
14.5 GHz	44.0 dBi	43.9dBi	75.7%	73.9%

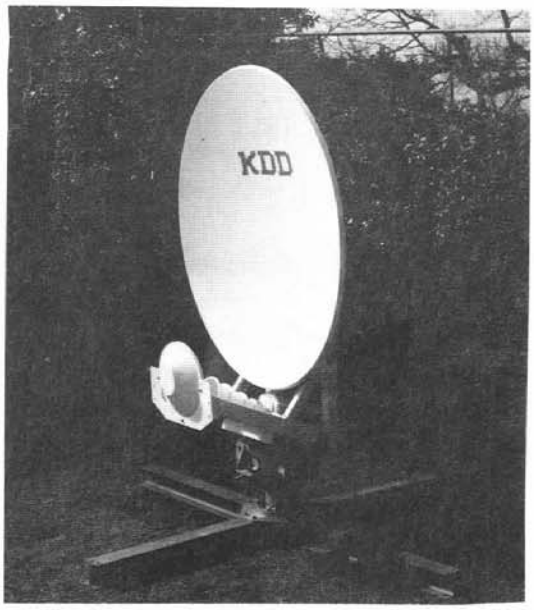

Figure 1 1.2 m Shaped offset Gregorian antenna.

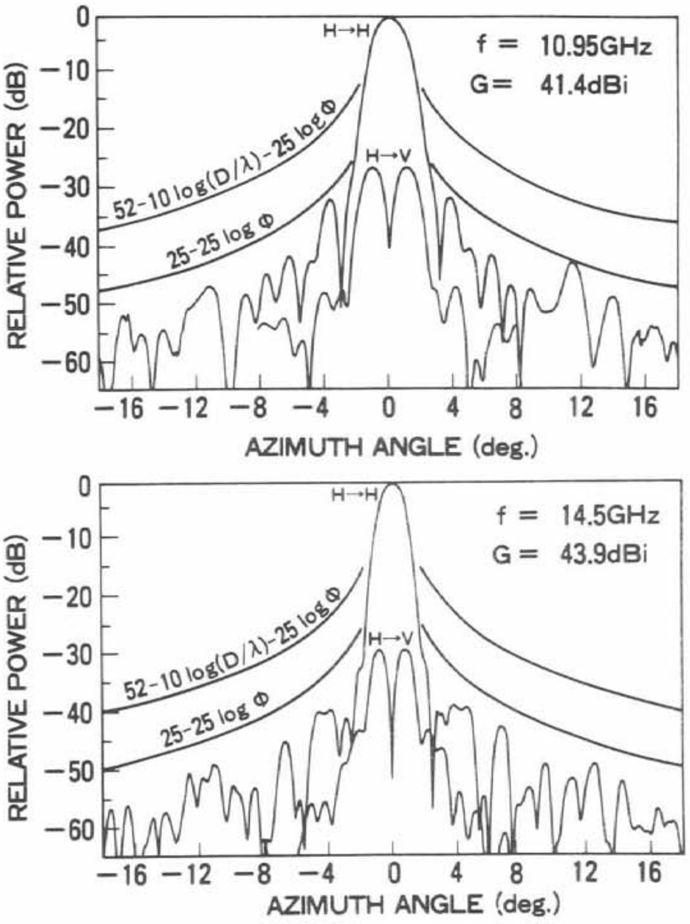

Figure 2 Measured near-axis radiation patterns.

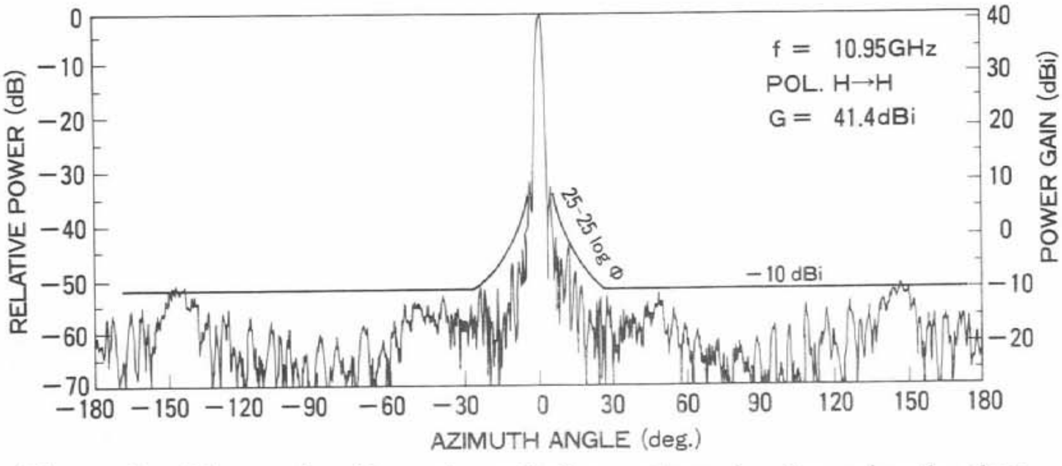

Figure 3 Measured wide-angle radiation pattern in the azimuth plane.

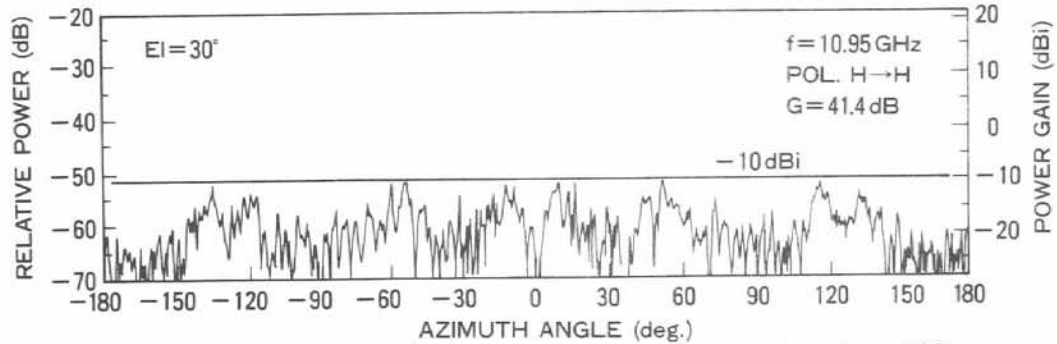

Figure 4 Measured horizontal pattern; beam elevation=30°.