Degradation Analysis of User Terminal EIRP and G/T due to Station-Keeping Variation of Stratospheric Platform

Bon-Jun Ku[a], Do-Seob Ahn, Dong-Cheol Baek, Kwang-Ryang Park, and Seong-Pal Lee

Wireless communication systems using airship have been proposed in worldwide. The airship will be located at the stratosphere about 20 ~ 23 km above the sea level. The position of airship will vary within the station keeping range with time due to the drag of the wind in the stratosphere. When the earth station antenna has a high gain without the tracking function, the antenna performance may be degraded by a small variation of the airship. This means that variation of airship location could result in serious degradation of the system performance. In this paper, degradation in earth station's Equivalent Isotropic Radiated Power (EIRP) and Gain to noise Temperature ratio (G/T) due to the stratospheric platform movements has been derived by calculating the deviation angle of the main beam directions between the earth station and the platform antenna. In this case, the antenna of the earth station has been assumed circular and/or patch array antennas.

I. INTRODUCTION

To solve limited orbits and frequency resources problems in the satellite communication system and to satisfy the increasing worldwide demand for inexpensive high speed multimedia, Internet, and mobile communication services, USA, Japan, and Europe, etc. are now developing a new technology that utilize airship located at fixed point in the stratosphere [1], [2], [6]. The stratospheric platform can obtain high capacity by employing a multi-beam antenna system and incorporating the frequency reuse. As the frequencies are in a mm-wave band, terminals with a small antenna are feasible. The stratosphere has a stable weather conditions at about 20 ~ 80 km between the troposphere and the mesosphere. The airship is often called stratospheric platform, and the platform loads wireless communication transponders. Because platforms do not require a launch vehicle, they can move by using their own power throughout the world or remain stationary, and they can be brought down to earth, refurbished and re-deployed. The stratospheric platform is a helium-filled airship and maintains its position by propellers with electrical motors that contrast wind drugs. The solar panel placed on the airship surface provides power during the daytime and fuel cell does during the nighttime. In the World Radio-communications Conference 1997 (WRC-97), it was announced that the bands of 47.2 ~ 47.5 GHz and 47.9 ~ 48.2 GHz are allowed to be used by the stratospheric wireless communications system. In addition to these, many countries are also under consideration of using other frequency bands such as Ka and IMT-2000 band.

The airship will be located at a fixed point in the stratosphere about 20 ~ 23 km above sea level. But, the position of airship will be varied within station keeping range by time because of

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Manuscript received September 29, 1999; revised January 19, 2000.

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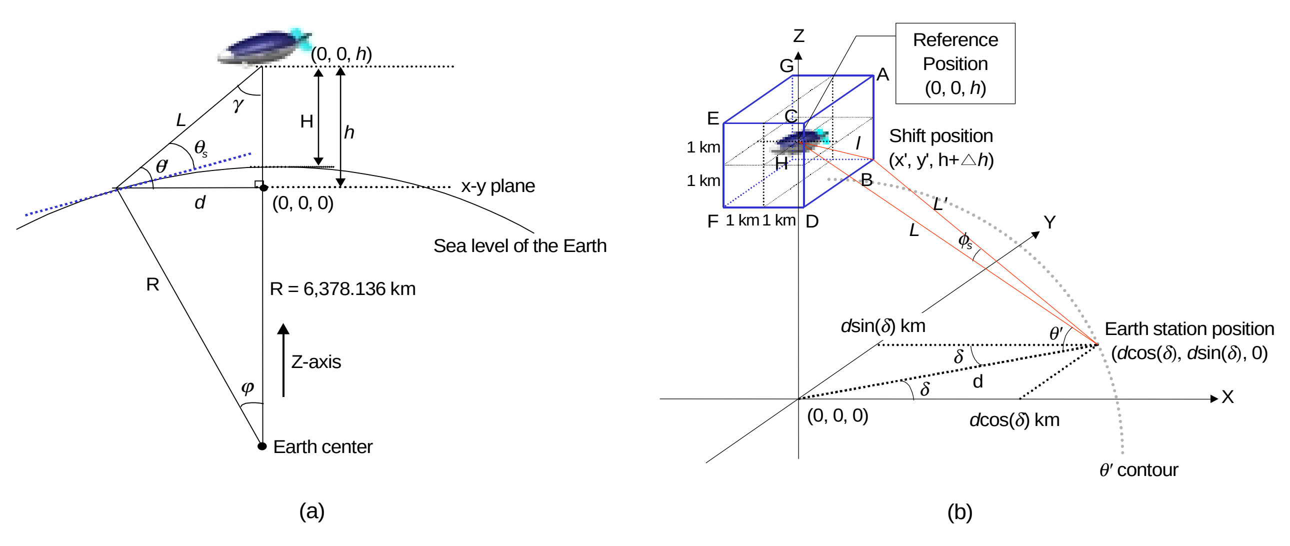

Fig. 1. Coordinates of a platform and earth station.

the wind in stratosphere [7], [8]. If earth station antenna doesn't have a tracking function, even though the airship location has a little variation, disagreement of main beam directions between the airship antenna and the earth station (terminal) antenna would be occurred. This can provide degradation of antenna gain and results in the performance degradation of system.

This paper investigates the degradations of earth station's EIRP and G/T due to movement of the platform within station keeping range. Firstly, the basic assumptions are set up and the deviation angle of the main beam directions between the platform and the earth station antenna is calculated in Section II. The degradation of earth station's EIRP and G/T for circular and patch array antennas, is estimated from the deviation angle in Section III. Finally conclusions are drawn in Section IV.

II. ANALYSIS

1. Basic Assumptions

Figure 1 shows the coordinates between a platform and earth station. In Fig. 1, H represents the altitude of a platform above sea level and h is the distance between the origin (0, 0, 0) and a platform. θ_s is the elevation angle and θ' is the angle between line L and d. The stratospheric platform is located at 20.6 km above sea level within the station keeping range of a few km. The station keeping range means the inside of a cube which its side length is $(2 \cdot \Delta h)$ km. Although some other models of the surface shape of the station keeping range, such as circular cylinder or sphere can be used, they were not considered because they would be included within a cube model (That is, it is desirable to apply a cube model to the surface of station keeping range in order to obtain the deviation angle in the worst case). Earth station or user terminal antenna (its height is set up to 0 km) is assumed to point toward the reference point (0, 0, h) of a platform. It is assumed that the main beam of on-board antenna of the platform always points to earth station position whenever a platform position is changed. The position of earth station is expressed as elevation angle θ_s and azimuth angle δ which is the angle of from x-axis to earth station on the x-y plane. For points A ~ H, the variation of G/T and EIRP is calculated from the deviation angle of main beam directions between a platform and earth station antenna. The summary about assumptions is as follows;

- Altitude of a platform H: 20.6 km
- Station keeping range : ±0.1 km ~ ±1.0 km
- Height of earth station antenna: 0 km
- Reference point of a platform: (0, 0, h)
- The main beam direction of earth station antenna points to reference point of a platform (0, 0, h).
- The main beam of onboard antenna in a platform always points to earth station antenna position.
- Earth station antenna uses patch array antenna with air gap and/or circular aperture antenna.
- Maximum range of airship's movement: A(Δh, Δh, $h+\Delta h$), B(Δh, Δh, $h-\Delta h$), C(Δh, $-\Delta h$, $h+\Delta h$), D(Δh, $-\Delta h$, $h-\Delta h$), E($-\Delta h$, $-\Delta h$, $h+\Delta h$), F($-\Delta h$, $-\Delta h$, $h-\Delta h$), G($-\Delta h$, Δh, $h+\Delta h$), H($-\Delta h$, Δh, $h-\Delta h$) (Δh : station-keeping range)
- The position of earth station (user terminal) is expressed as elevation angle θ_s and azimuth angle δ.
- The deviation angle of main beam directions between a platform and earth station antenna is calculated for 8 points

(A ~ H).

- Considering the earth curvature and earth radius R is the same in all regions.

2. Calculation of the Deviation Angle

In Fig. 1, the distance L between earth station and a platform reference point (0, 0, h) is expressed as earth radius R, a platform altitude H, and elevation angle θ_s.

$$L = (R+H)\frac{\sin\varphi}{\sin(\pi/2+\theta_s)}, \qquad (1)$$

where the angle φ between a platform and earth station position in earth's center is given by

$$\varphi = \frac{\pi}{2} - \theta_s - \gamma, \qquad (2)$$

and the angle γ between earth's center and earth station position in a platform is given by

$$\gamma = \sin^{-1}\left[\frac{R}{R+H}\sin(\pi/2+\theta_s)\right]. \qquad (3)$$

The distance L' between the Earth station position ($d\cos\delta$, $d\sin\delta$, 0) and the platform's shift position $(x', y', h+\Delta h)$ is expressed as

$$L' = \sqrt{(d\cos\delta - x')^2 + (d\sin\delta - y')^2 + (h+\Delta h)^2}, \qquad (4)$$

where d and h represent the distance from the origin $(0,0,0)$ to earth station position and to a platform respectively.

$$d = L\cos\theta' \qquad (5)$$

$$h = L\sin\theta' \qquad (6)$$

And the angle θ' between the distance L and d is defined as

$$\theta' = \frac{\pi}{2} - \gamma \qquad (7)$$

and γ is given by eq. (3).

The distance l between a platform reference position $(0,0,h)$ and shift position $(x', y', h+\Delta h)$ is given by

$$l = \sqrt{(x')^2 + (y')^2 + (\Delta h)^2}, \qquad (8)$$

where Δh means a platform shift distance along z-axis, i.e. platform altitude variation.

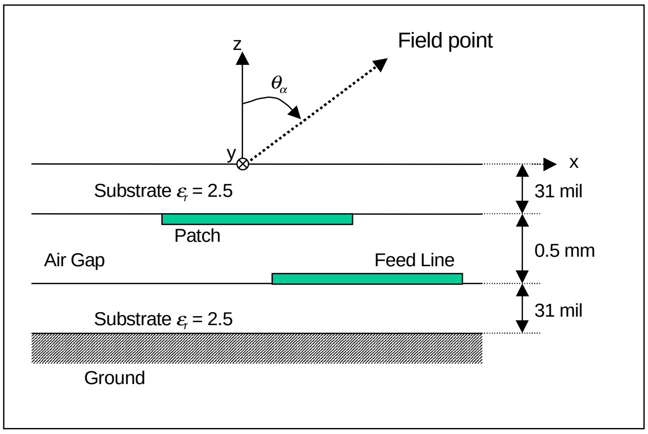

Fig. 2. Geometry of single patch antenna.

The distance l between a platform reference position $(0, 0, h)$ and shift position $(x', y', h+\Delta h)$ can be obtained as a function of deviation angle ϕ_s between the distance L and L' for the case of $L > L'$ and $L < L'$,

$$l = \sqrt{L^2 + (L')^2 - 2LL'\cos\phi_s} \qquad (9)$$

and from eq.(1), (4), and (8), the deviation angle ϕ_s can be obtained as eq. (10) and is a function of user terminal and platform shift position.

$$\phi_s = \cos^{-1}\left(\frac{L^2 + (L')^2 - l^2}{2LL'}\right) \qquad (10)$$

3. Earth Station or User Terminal Antenna

Earth station or user terminal antenna is considered for two kinds of antenna, patch array and circular aperture antenna.

A. Patch Array Antenna

The structure of a single patch antenna is shown in Fig. 2. It consists of two layers of which the relative dielectric constant ε_r is 2.5 and one layer with air gap. Figure 3 shows the radiation pattern for a single patch antenna. As shown in Fig. 3, the shape of its beam pattern is assumed to be symmetrical in the range of $\pm 5^\circ$ since normalized radiation pattern intensity of E-plane and H-plane is much the same in the range of $\pm 5^\circ$.

The radiation pattern of the patch array antenna is obtained from that of a single patch antenna by using the planar array factor [3], [4]. That is

$$E(total) = [E(\textit{one element at reference point})] \times [\textit{array factor}] \qquad (11)$$

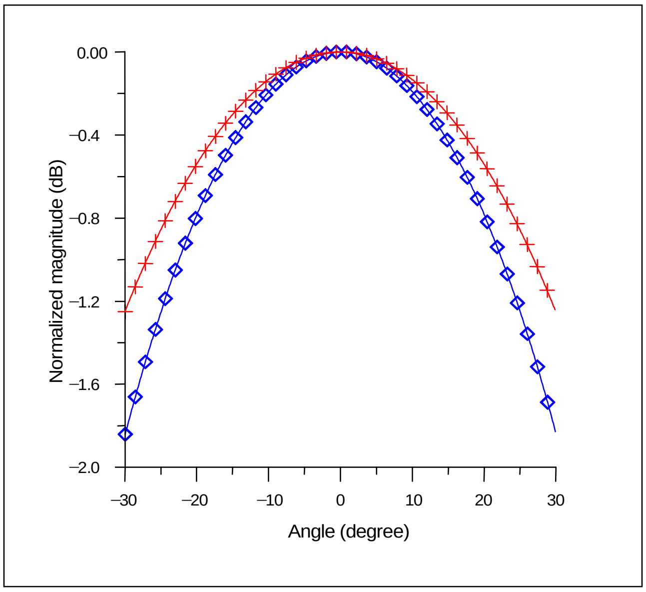

Fig. 3. Radiation pattern of single patch antenna, E-plane(+)and H-plane(◇).

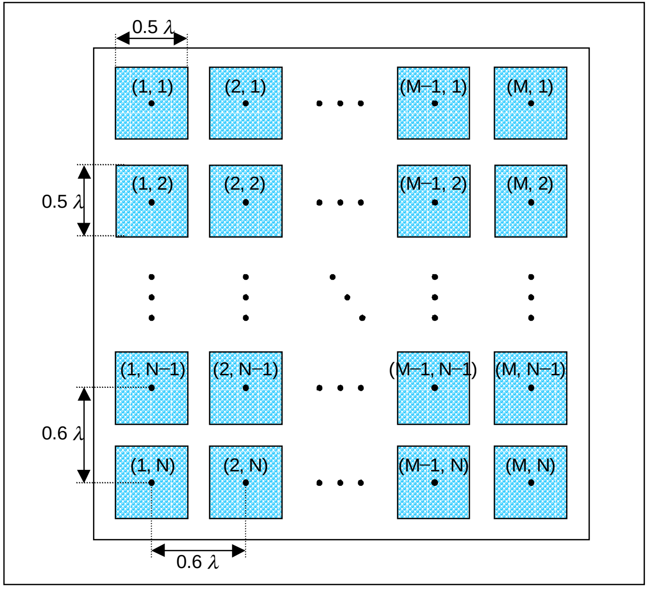

Fig. 4. Geometry of M × N patch array antenna.

and the array factor of a uniform rectangular array cophasal in the (θ_0, ϕ_0) direction is given by

$$AF_n = \frac{1}{M}\frac{\sin(M\psi_x/2)}{\sin(\psi_x/2)}\frac{1}{N}\frac{\sin(N\psi_y/2)}{\sin(\psi_y/2)}, \tag{12}$$

where M and N are the number of elements along the x and y axes, respectively, and

$$\psi_x = 2\pi d_x(\sin\theta_a \cos\phi_a - \sin\theta_0 \cos\phi_0) \tag{13}$$

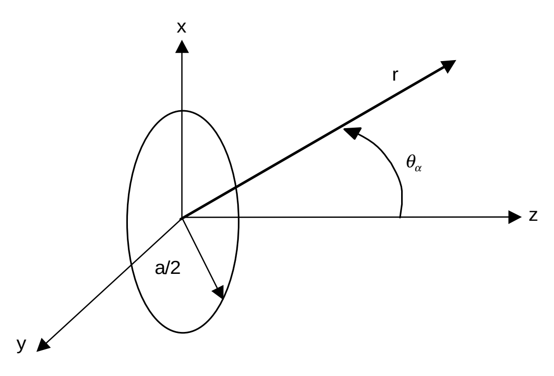

Fig. 5. Coordinates of a circular aperture antenna.

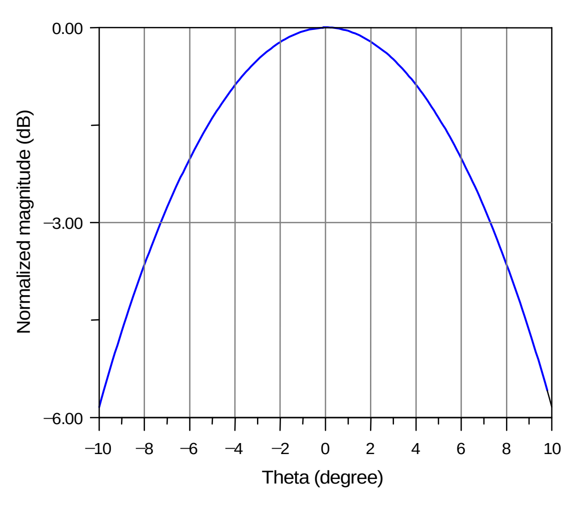

Fig. 6. Radiation pattern of a circular aperture antenna (f=47 GHz, a=5 cm).

$$\psi_y = 2\pi d_y(\sin\theta_a \sin\phi_a - \sin\theta_0 \sin\phi_0) \tag{14}$$

and d_x and d_y are interelement spacing (in wavelengths) along the x and y axes, respectively.

The geometry of M × N patch array antenna is shown in Fig. 4.

B. Circular Aperture Antenna

For a circular aperture of diameter a in Fig. 5 the normalized pattern of a parabolic taper on a pedestal distribution for $n = 2$ and $C = 0.15$ is plotted in Fig. 6 [5].

The pattern function is

$$f(\theta_a, n, C) = \frac{Cf(\theta, n=0) + \dfrac{1-C}{n+1} f(\theta_a, n)}{C + \dfrac{1-C}{n+1}}, \tag{15}$$

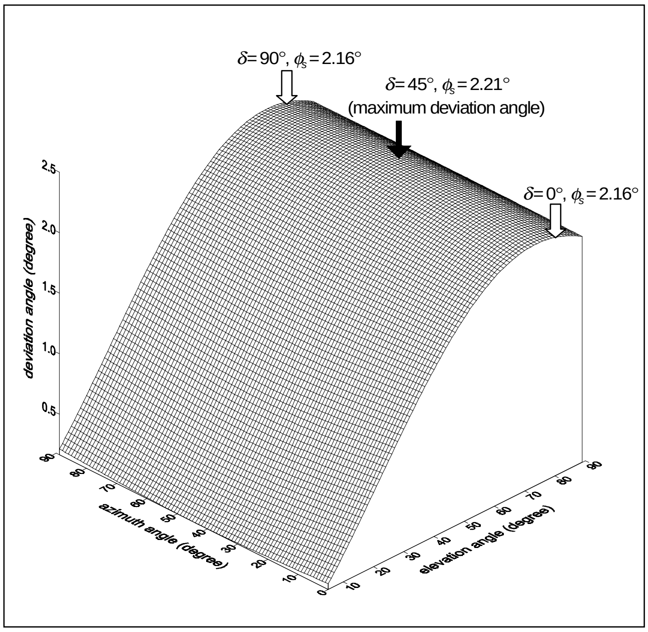

Fig. 7. Deviation angle for elevation and azimuth angle of user terminal (station-keeping range ±0.5 km, θ_s = 73.4°).

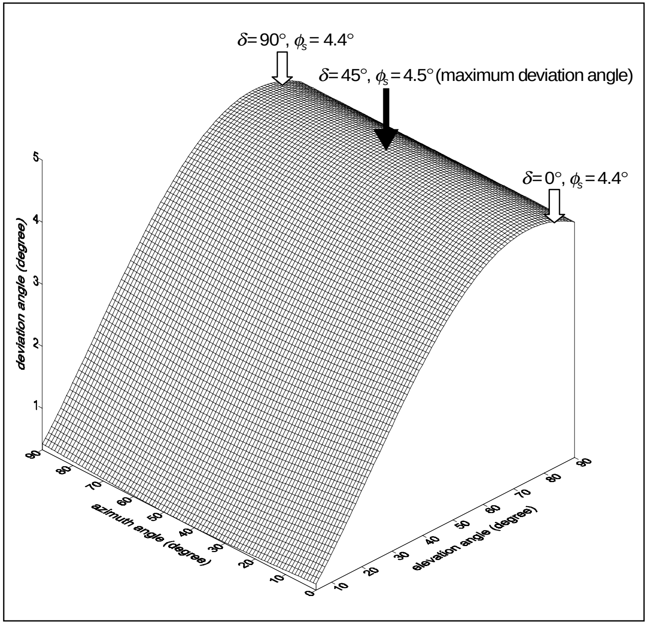

Fig. 8. Deviation angle for elevation and azimuth angle of user terminal (station-keeping range ±1.0 km, θ_s = 74.6°).

where

$$f(\theta_a, n) = \frac{2^{n+1}(n+1)!\,J_{n+1}(\beta a \sin\theta_a)}{(\beta a \sin\theta_a)^{n+1}}. \tag{16}$$

III. VARIATION OF EIRP AND G/T FOR STATION KEEPING RANGE

The maximum deviation angle of main beam directions between the platform antenna and earth station (or user terminal) antenna, is shown in Tables 1 and 2 for station-keeping range 0.1 ~ 1.0 km. The maximum deviation angle can be calculated from eq. (10) in Section II. Figures 7 and 8 show the variations of the deviation angle for user terminal position when the station-keeping range is ±0.5 km and ±1.0 km respectively. As shown in Fig. 7, the maximum deviation angle is about 2.21° when user terminal elevation angle is 73.4° and azimuth angle 45.0°, for station-keeping range ±0.5 km. For the station-keeping range ±1.0 km, when user terminal position is elevation angle 74.6° and azimuth angle 45.0°, the deviation angle is a maximum as shown in Fig. 8. As shown in Figs. 7 and 8, when the station-keeping range is increased, user terminal elevation angle, which deviation angle is a maximum, is also increased. The azimuth angle of user terminal is from 0° to 360° but the maximum deviation angle is the same every 90°. So only azimuth angle from 0° to 90° is considered.

To calculate EIRP and G/T variation of the user terminal, a patch antenna and a circular aperture antenna are considered. Firstly, the radiation patterns for a variety of antenna sizes are obtained from Section II.

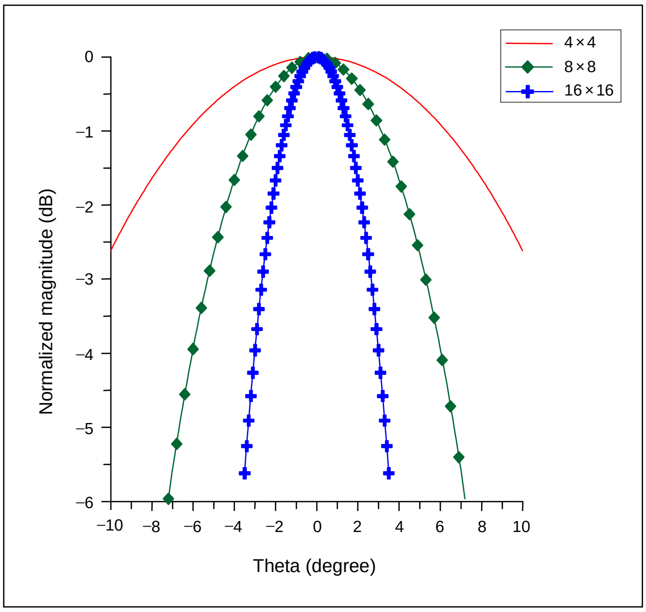

Fig. 9. Comparison of radiation pattern for 4 × 4, 8 × 8, 16 × 16 array of patch antenna.

The variation of gain due to its pointing error can be calculated from the radiation patterns of a patch array and a circular aperture antenna at a given deviation angle. The radiation patterns are compared in Fig. 9 for 4 × 4, 8 × 8, and 16 × 16 array of patch antenna respectively and those for 5 λ, 10 λ, 15 λ, and 20 λ in a circular aperture diameter are compared in Fig. 10 respectively.

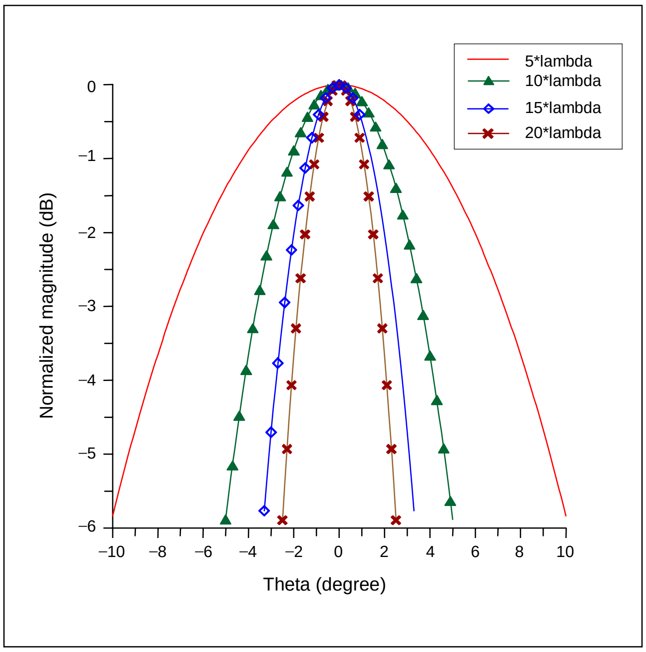

Fig. 10. Comparison of radiation pattern for aperture diameter 5 λ, 10 λ, 15 λ, and 20 λ.

By using Figs. 9 and 10, gain variation for user terminal's position can be obtained as Figs. 11 and 12. User terminal's position is represented by elevation angle and azimuth angle defined by Section II. Figures 11 and 12 shows the gain variations of 8 × 8 patch array antenna and a circular aperture antenna with diameter 5 λ respectively for user terminal's position when the platform position is $F(-1, -1, h-1)$, that is, the station-keeping range ±1.0 km.

From these, for a circular aperture antenna, the degradation of antenna gain due to pointing error can be obtained as Table 1 and for a patch array antenna, Table 2. G/T can be expressed in terms of receiving antenna gain and receiving noise temperature, and EIRP transmitting power, transmitting loss and transmitting antenna gain. That is

$$G/T\,[dB] = [\textit{receiving antenna gain}] - [\textit{receiving noise temperature}] \quad (17)$$

$$EIRP\,[dBW] = [\textit{transmitting power}] - [\textit{transmitting loss}] + [\textit{transmitting antenna gain}] \quad (18)$$

Assuming the receiving noise temperature, transmitting power and transmitting loss constant, the variation of G/T and EIRP for a patch array and/or a circular aperture antenna can be obtained directly from that of antenna gain in Tables 1 and 2.

Figures 13 and 14 show the variations of G/T and EIRP for patch array antenna and a circular aperture antenna respectively. They are determined, mainly, by the size of the antenna aperture, a wavelength and an amplitude distribution in the antenna aperture.

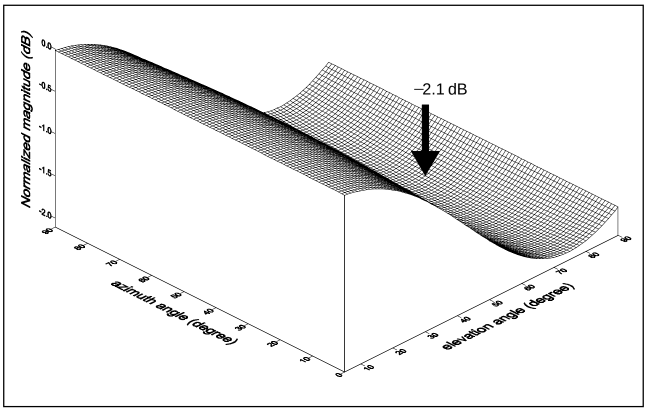

Fig. 11. Gain variation for elevation and azimuth angle of 8 × 8 patch array antenna (platform position F(–1, –1, *h*–1) and station-keeping range ±1.0 km).

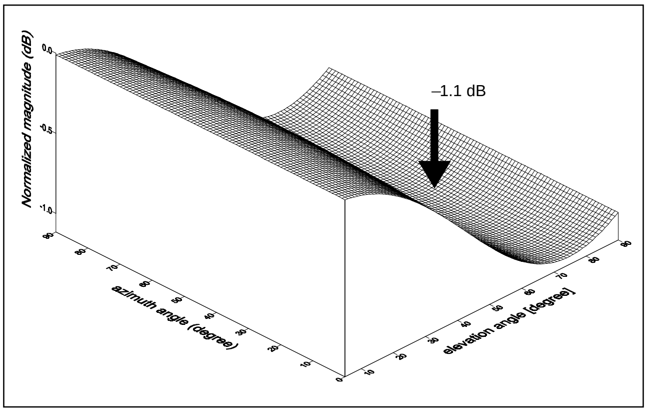

Fig. 12. Gain variation for elevation and azimuth angle of a circular aperture (5 λ) antenna (platform position F(–1, –1, *h*–1) and station-keeping range ±1.0 km).

As shown in Figs. 13 and 14, if user terminal use a low gain antenna (below 20 dBi), for example, for user terminal antenna with below diameter 5 λ or 8 × 8 patch array, the variation of G/T and EIRP is below 1.0 dB. It is a negligible amount compared to other link parameter variations. However, if user terminal antenna without tracking function has a high gain (above 20 dBi), for example, for antenna with diameter of 20 λ or 16 × 16 patch array, it can't be ignored. That is, for high gain antenna (above 20 dBi) without tracking function, the variation of G/T and EIRP can not be ignored if the system does not have a sufficient link margin or the station-keeping range of platform is above ±0.4 km. So the use of user terminal antenna with mechanical tracking function and/or a settable phased array antenna is more proper to compensate for a pointing error for above station-keeping range ±0.4 km and high gain antenna proper to high speed services for fixed terminals.

Table 1. Gain degradation at maximum deviation angle for a circular aperture.

Station-keeping range (km)		±0.2	±0.4	±0.6	±0.8	±1.0
Earth station position (elevation angle, azimuth angle)		$\theta_s = 72.8°$ $\delta_s = 45.0°$	$\theta_s = 73.2°$ $\delta_s = 45.0°$	$\theta_s = 73.7°$ $\delta_s = 45.0°$	$\theta_s = 74.1°$ $\delta_s = 45.0°$	$\theta_s = 74.6°$ $\delta_s = 45.0°$
Deviation angle		0.9°	1.8°	2.7°	3.6°	4.5°
Maximum gain degradation (dB)	D = 5 λ (22 dBi)	−0.04	−0.17	−0.39	−0.70	−1.12
	D = 10 λ (27.7 dBi)	−0.17	−0.69	−1.59	−2.89	−4.66
	D = 15 λ (31.3 dBi)	−0.38	−1.57	−3.66	−6.83	−11.45
	D = 20 λ (33.8 dBi)	−0.17	−2.84	−6.76	−13.24	−25.03

Table 2. Gain degradation at maximum deviation angle for a patch array antenna.

Station-keeping range (km)		±0.2	±0.4	±0.6	±0.8	±1.0
Earth station position (elevation angle, azimuth angle)		$\theta_s = 72.8°$ $\delta_s = 45.0°$	$\theta_s = 73.2°$ $\delta_s = 45.0°$	$\theta_s = 73.7°$ $\delta_s = 45.0°$	$\theta_s = 74.1°$ $\delta_s = 45.0°$	$\theta_s = 74.6°$ $\delta_s = 45.0°$
Deviation angle		0.9°	1.8°	2.7°	3.6°	4.5°
Maximum gain degradation (dB)	4 × 4 (18 dBi)	−0.02	−0.08	−0.18	−0.32	−0.5
	8 × 8 (24 dBi)	−0.08	−0.31	−0.72	−1.31	−2.11
	16 × 16 (30.5 dBi)	−0.31	−1.29	−3.05	−5.88	−10.46

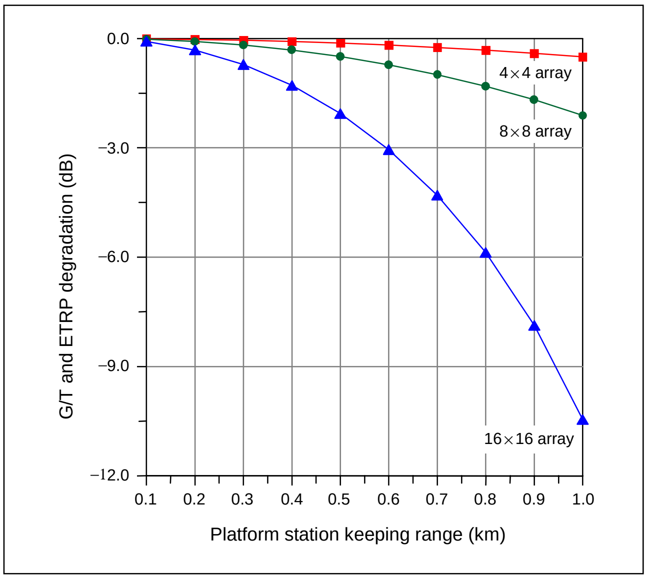

Fig.13. G/T and EIRP degradation for a patch array antenna.

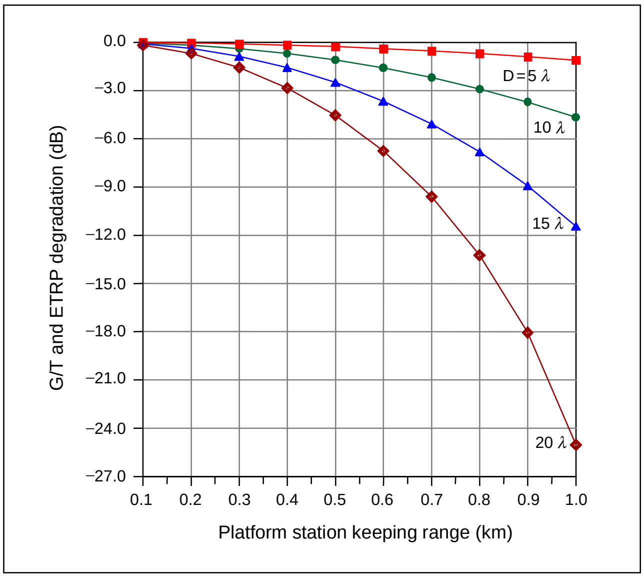

Fig. 14. G/T and EIRP degradation for a circular aperture antenna.

IV. CONCLUSIONS

The stratospheric platform is assumed to be at an altitude of 20.6 km above sea level, and will remain nominally stationary within station-keeping range. The position of platform will be varied within station keeping range by time because of wind in stratosphere. In this case, degradation of system performance is occurred due to the antenna pointing error between a platform and user terminal. In this paper, it is assumed that the height of user terminal (or earth station) antenna is 0 km and the main beam direction of onboard antenna in a platform always points to user terminal antenna position. The main beam direction of user terminal antenna that doesn't have the function of a pointing error adjustment is assumed to point to the center of the station-keeping range. From these assumptions, the pointing error according to station-keeping range can be calculated. The variation of G/T and EIRP for Earth station (or user terminal) can be obtained directly from that of antenna gain due to the deviation angle of the main beam directions between a platform and the earth station antenna. In this paper, the EIRP and G/T variation of user terminal according to antenna gain and station-keeping range are examined. If the user terminal uses a low gain antenna, the degradation of EIRP and G/T has a negligible amount compared to other link parameter variations. But if the earth station (or user terminal) antenna has a high gain, it can't be ignored. Therefore, for high gain antenna without tracking function, the variation of antenna gain can not be ignored if the system does not have a sufficient link margin. In general, for the portable and/or semi-fixed service, the user terminal antenna is pointed to the current position of the stratospheric airship at the call set-up, and the platform position does not shift instantaneously because the stratosphere has a stable weather condition compared to the atmosphere. Therefore degradation of system performance due to change of the platform position may not occur during the calling. Nevertheless, the use of a circular aperture antenna with mechanical tracking function and/or a steerable phased array antenna is more proper to compensate the pointing error for fixed services.

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