Antenna Array Configuration in Air-to-Ground Communications Scenario

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***Abstract*—In this paper, focusing on the air-to-ground (ATG) communication, the coverage requirement of a ground station is briefly investigated. Established on the given ATG communication model, an antenna array configuration is proposed. The simulation results and numerical results are provided in this paper showing that it is a good candidate deployment for ATG communications.**

***Keywords*—Air-to-ground (ATG) communications; uniform linear arrays (ULA); antenna configuration.**

I. INTRODUCTION

Air-to-ground (ATG) communications have been developed for nearly 30 years [1] and their developments always follow the mobile wireless communications. Also, the technologies in mobile wireless communications are usually employed in ATG communications. Yet, there are still many differences between them. For example, the space of signal coverage is the upper half-space in ATG communications, and the ATG communication environment is comparatively simple, although it also exists multipath effect [2]-[6]. Usually, ATG channels have a much higher line-of-sight (LOS) probability [5]. However, for a low altitude, multipath propagation exists in ATG channels, and the probability for appearance of multipath components is getting higher with decreasing of aircraft's altitude [6]. Accordingly, it is necessary to study the antenna deployment of the ground station (GS) in ATG communications.

Besides, the applications of the ATG communications are mainly centered in Europe, North America and Japan. There are still no airlines employing the ATG communication systems in their flights in China. Most recently, several Chinese airlines declared allowing the passengers using mobile phones in the plane, and the homegrown passenger jet has been successfully tested. These will prompt the applications of ATG communications in China. Unfortunately, the related research is not too much in China.

Motivated by these facts, the antenna deployment of GS is investigated for the straight-and-level flight under a given ATG communications. The required capability of the GS coverage is simply analyzed at first. According to the requirement and adopting the idea of beam diversity (or angle diversity), an antenna configuration is proposed for ATG communication, which equips the antennas in three different faces and the antennas on each face covers a determined spatial area. What is more, an antenna example is given to show the validity of the proposed antenna deployment.

The rest of this paper is organized as follows. In section II, ATG communication scenario is described, and the coverage capability of GS antenna is analyzed briefly. Section III presents

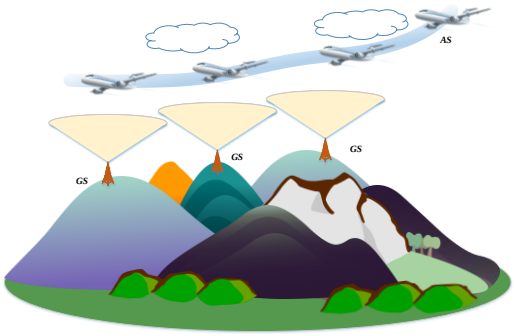


Fig.1 Illustration of GS deployment in ATG scenario.

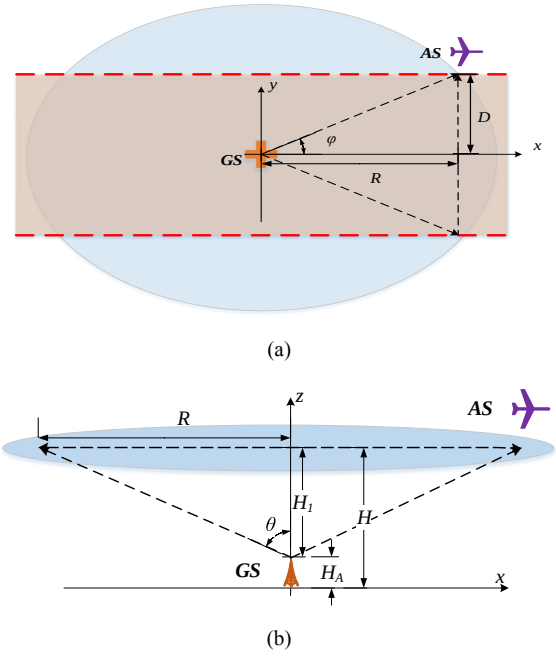
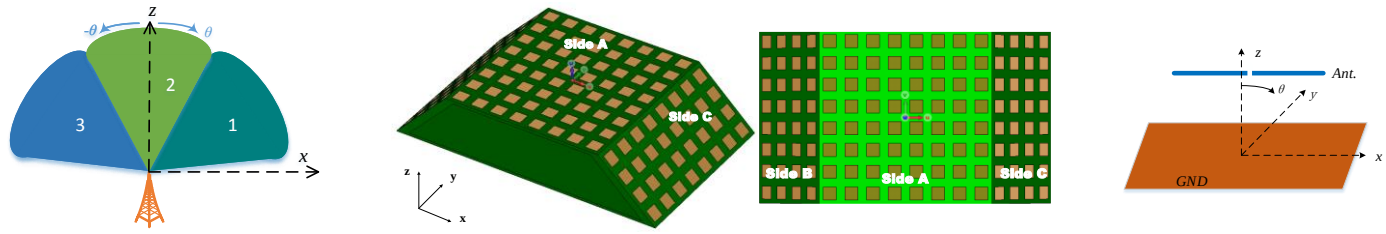


Fig.2 Illustration of GS coverage in ATG scenario, (a) horizontal plane and (b) vertical plane.



(a) (b) (c)

Fig.3 Illustraion of beam diversity of GS and antenna configuration, (a) beam diversity, (b) antenna configuration, (c) antenna element.

the proposed antenna configuration. Besides, the simulation results also provided in this section. Last, summary is made in section IV.

II. Scenario Description and GS Antenna Coverage Analysis

In this paper, we consider an ATG communication scenario in which GS is deployed along the air route, illustrated in Fig.1. The radius of signal coverage for GS is given by 75 km. For the sake of simplicity, only the straight-and-level flight is considered in this paper. Besides, assume that the cruise height is 8 km~12 km and the maximum deviation in direction is ±12.5 km.

Based on the coverage requirement of GS, the beam coverage capability of GS antennas can be approximately determined. The coverage analysis of GS is depicted in Fig.2 where $R = 75$, $D = 12.5$, $H \in [8,12]$, φ, θ, H_A and H_1 are coverage radius, maximum deviation in direction, the height of air station (AS), deviation angle in direction, elevation angle of the AS at the edge of signal coverage, GS antenna height, and the vertical distance between GS antennas and AS respectively. According to Fig.2 (a) and (b), φ and θ are easily obtained by

$$\begin{aligned} \varphi &= \tan^{-1}\frac{D}{R} \\ \theta &= \tan^{-1}\frac{R}{H_1} \end{aligned} \tag{1}$$

Assuming that the height of GS antenna is 50 m, namely $H_A = 0.05$, $H_1 = H - 0.05$ is obtained, which can be approximated as $H_1 \approx H$. When the AS is flying above GS under the maximum deviation in its desired direction and the lower limit of the height for level flight, φ reaches its maximum

$$\begin{aligned} \varphi &= \tan^{-1}\frac{D}{H} \approx 57.38^\circ \\ \theta &= 0^\circ \end{aligned} \tag{2}$$

When the AS is flying to the edge of signal coverage under the lower limit of the height for level flight, θ reaches its maximum and can be obtained from (1), that is,

$$\begin{aligned} \varphi &= 0^\circ \\ \theta &= 83.91^\circ \end{aligned} \tag{3}$$

Accordingly, the beam coverage of GS antennas can be determined by φ in (2) and θ in (3), namely

$$\begin{aligned} \varphi_A &\approx 115^\circ \\ \theta_A &\approx 168^\circ \end{aligned} \tag{4}$$

III. Proposed Antenna Configuration

From the last section, it is clear that the required coverage of GS antennas in both φ and θ directions are too large to be available by a single antenna or an array. In order to meet the GS coverage requirement in (4), we proposed an antenna configuration for ATG communications based on the idea of beam diversity.

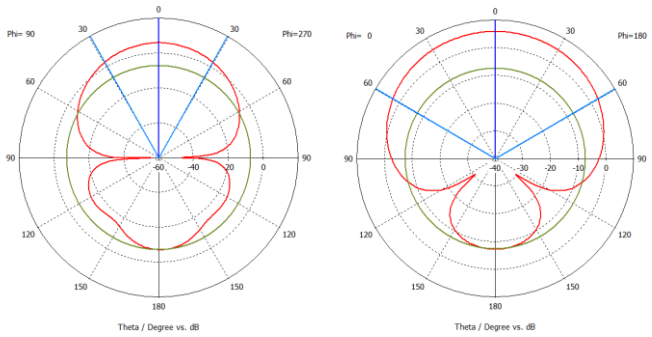
In our proposed configuration, GS coverage in θ direction is split into 3 fields and each of them is covered by corresponding antenna beam. An illustration is depicted in Fig.3 (a), and the proposed antenna configuration is illustrated in Fig.3 (b) and (c) where the angles between side A and side B, side A and side C are 120°. Hence each side of antennas cover ±30° referred to their outer-pointing normal. In terms to φ direction, it can be covered by an antenna with 120° beam width. An illustration of a simple dipole antenna element with ground is depicted in Fig.3 (c) and the corresponding radiation patterns are shown in Fig.4. The results show that the given example fully satisfies the required coverage capability of GS. This example implies the possibility of the proposed antenna configuration from the angle of antenna design.

Moreover, for each side, the antennas can be formed an ULA in *x*-axis direction. This not only allows the antennas have the beam scan ability in *x*-axis direction, but also keeps a wide coverage in *y*-axis direction. Consequently, the proposed antenna configuration can be regarded as a combination of multiple-input multiple-output (MIMO) and ULA, which can obtain the benefits from both MIMO and ULA.

According to antenna theory [7], for a given ULA, the radiation pattern usually suffers a distortion with the increasing of scanning angle. A beam scanning example for a 6-element ULA is presented in Fig.5 where the pattern begins to suffer a distortion when the scan angle goes up, especially when the scanning angle is greater than 60° in this example. In our proposed configuration scheme, the scanning angle in θ direction is limited in ±30°. Apparently, the proposed antenna configuration in which the beam diversity is considered, to some extent, limits the pattern distortion at a small value for ULA scanning.

IV. Summary

In this paper, the coverage of GS is briefly discussed for ATG communications. Based on the determined coverage



(a) (b)

Fig.4 Radiation patterns in (a) xz plane and (b) yz plane.

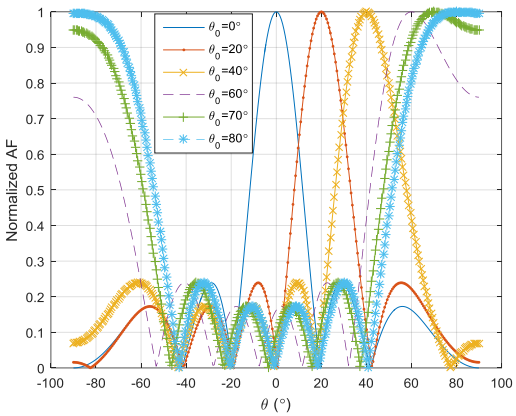


Fig.5 ULA beam scan in *x*-axis direction

requirement, with idea of beam diversity, we proposed a GS antenna deployment for the straight-and-level flight situation in ATG communications. The simulation results indicate that the proposed configuration can totally satisfy the coverage requirement. Therefore, the proposed antenna configuration in this paper provides a reference and a candidate scheme for ATG communications.

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