3-2 Wireless Communications System Using Stratospheric Platforms

3-2-1 R&D Program on Telecom and Broadcasting System Using High Altitude Platform Stations

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Telecommunication and broadcasting systems using radio-relay/base stations on board the high altitude platforms are expected to create the largest business market among its possible applications. Telecommunications Advanced Organization (TAO) and Communications Research Laboratory (CRL) is conducting R&D on the telecom and broadcasting system to demonstrate its feasibility. Prototype onboard equipment and ground equipment are being developed on schedule in the fixed, mobile, and broadcasting services. The performance of them will be demonstrated and evaluated in the preliminary flight test planned in 2002 using a helicopter, a jet and a stratospheric unmanned solar plane, Pathfinder Plus, which was developed by NASA, before the flight test using the low-altitude powered test airship being developed by National Aerospace Laboratory.

Keywords

stratospheric platform, high altitude platform, airship, solar plane, multibeam antenna

1 Introduction

A stratospheric platform has been developed wherein a large-scale airship will stay at a predetermined position approximately at the altitude of 20 km in the stratosphere and will be used for telecommunications, broadcasting, and environmental measurements. The project has been promoted through the ministerial cooperation of the Ministry of Education, Culture, Sports, Science and Technology and the Ministry of Public Management, Home Affairs, Posts and Telecommunications[1]~[5]. Of the airship's various applications, a telecommunication and broadcasting system using the stratospheric platform as a radio relay or a base station is expected to demonstrate the largest economic impact for the future. For research and development of a telecommunications and broadcasting system aiming to demonstrate the feasibility of this aspect of the project, the Communications Research Laboratory (CRL) and the Yokosuka Research Center of the Telecommunications Advancement Organization of Japan (TAO) are playing a central role in developing onboard equipment and ground equipment for evaluation testing, centering on the three fields of fixed communications, mobile communications, and broadcasting. The relevant equipment is to be installed on an alternate aerial vehicle to conduct a preliminary flight test and to evaluate its performance, prior to installation on board the airship. On the other hand, the National Aerospace Laboratory (NAL) has taken the initiative in developing the airship itself, and the Mitaka Research Center of TAO is developing a TT&C (telemetry, tracking, and command) system. The structure of the research and development system in Japan is shown in Fig.1. Among the technologies depicted, this article introduces the progress of the development of the telecommunications and broadcasting system.

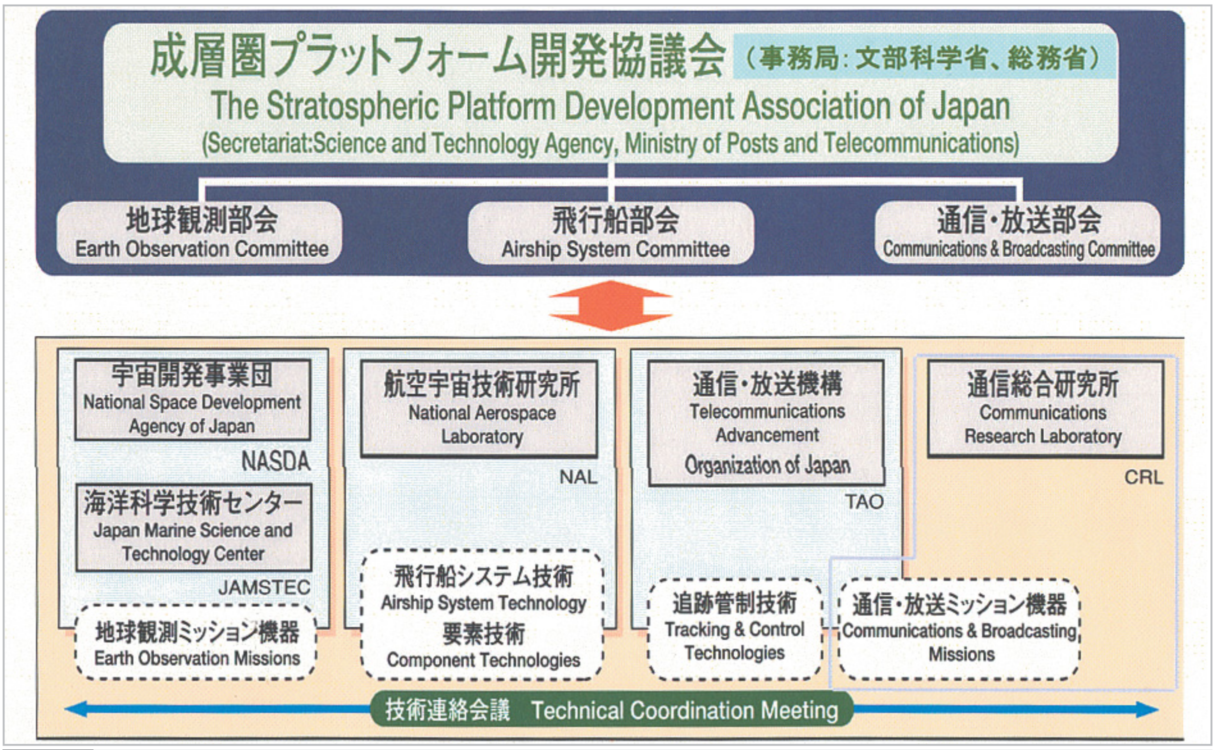


Fig. 1 *Research and development system*

2 Candidate for the third telecommunication infrastructure equivalent to terrestrial and satellite infrastructures

A terrestrial radio link faces a great deal of obstacles in its path: Hence, the electromagnetic wave cannot travel great distances, while a satellite link features an extremely long transmission path, which weakens the wave and demands additional cost, although less obstacles obstruct the signal. Thus, the current focus is on the use of an undeveloped space, the stratosphere, that is located between the terrestrial and the satellite domains. The idea has existed for some time of an airship, a balloon, or the like which would be kept in the stratosphere, where the air stream is relatively steady, and used for telecommunication systems relay purposes. However, to make the airship remain stably in the stratosphere, where the atmospheric pressure is approximately 1/20 times that of the ground, and where wind velocity is occasionally as high as 30 m/s or more, it is necessary to circumvent problems relating to the supply of electric power, flight control, launching and recovery, membrane materials, security, and so on; there is so far no precedent of successful implementation of such a system. On the other hand, the demand for an economical “broadband” wireless access system is increasing, due to rapid popularization of mobile communication (such as mobile phones) and of the Internet, and it is expected that the stratospheric platform may be the infrastructure that will allow these services to be offered economically to business users as well as personal users. A conceptual drawing of the service is shown in Fig.2.

Features of the radio communications system offered by the stratospheric platform are summarized as follows.

(1) High line-of-sight probability and small propagation delay time: The stratospheric platform can be considered an ultra-high-altitude tower, with a height of 20,000 meters (60 times the height of the Tokyo Tower or more). That is, since the stratospheric platform can easily provide line-of-sight paths with a high elevation angle, whereby the lines are relatively free of the influence of obstacles, a single platform can cover a large area with a radius of 50-200 km, depending upon the frequency. Because the electric power required for transmission can be decreased, the antenna and the radio equipment can be made smaller. Further, there is minimal voice delay when used for voice telephone or the like, because the stratospheric platform is much closer to the ground than satellites, and hence the propagation delay time is less.

(2) Electromagnetic environment: Today, the demand for radio communication is rapidly increasing, and an analysis of the electromagnetic environment, including such details as such as the sharing of frequencies between different systems and the influence of electromagnetic waves on the human body, becomes important. Since mobile communication links, broadcasting links, and the like of the terrestrial systems are built based on the propagation of electric waves traveling very close to the ground, these lines are susceptible to the interference of buildings, trees, terrain features, and the like; therefore, the electromagnetic waves are transmitted with an extremely large transmission power, to maintain line quality. For example, although the transmission power of a VHF broadcasting electromagnetic wave from the Tokyo Tower can be as high as 50 kW, the electromagnetic wave will not necessarily reach as far as 100 km. Further, there is an attenuation of electric power as high as 40 dB (10,000 times) between the neighborhood of a transmitting station and more distant areas of reception. If the electric wave is transmitted from the stratosphere, the transmission power can be as low as a few tens of watts – sufficient to cover the same area – as surplus electromagnetic waves are minimally irradiated to the surroundings, and the attenuation in electric power over one service area can be mitigated to approximately 10 dB (a few tens of times).

(3) Economic efficiency and low risk: If an area with a 100-km radius is intended to be covered thoroughly with ground stations such as steel towers, more than 1,500 stations must be installed, whereas in the case of the stratospheric platform, the whole area could be covered with one or two platforms. That is, in the terrestrial radio communication network, an area that is covered by means of installation of a great many number of base stations – steel towers and the like – can be covered by a small number of stratospheric platforms at once, and consequently an extremely economical network could be constructed. As an example, a deployment plan for stratospheric platforms that could cover the entire country of Japan is shown in Fig.3. When the lowest service elevation angle is assumed to be 10 degrees, the number of necessary platforms

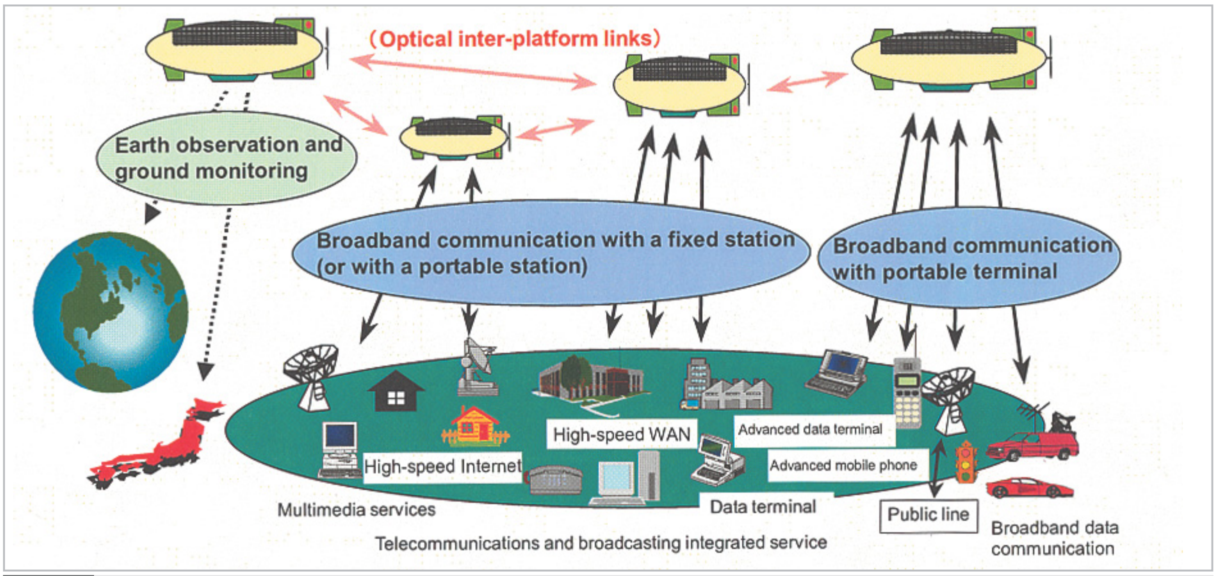


Fig.2 *Conceptual drawing of service provided by the stratospheric platform*

becomes 16. Further, unlike a satellite system suited to global service, the stratospheric platform is suited to local services, each centering on an area where demand exists. High efficiency can thus be expected, compared to the low earth-orbiting satellite systems and the like that have little choice but to cover service areas including the sea and virtually unpopulated regions. That is, it can be said that the height of the stratosphere is a naturally suitable height from which users of a specific area may be covered extensively and precisely.

(4) Flexibility: The system can provide flexibility in allocation of platforms and provision of communication links according to need, responding to disasters and other such extraordinary events. It is also expected that in the event the onboard equipment malfunctions or when upgrades become necessary, the onboard equipment can be temporarily retrieved on the ground, therefore providing greater flexibility than a satellite system.

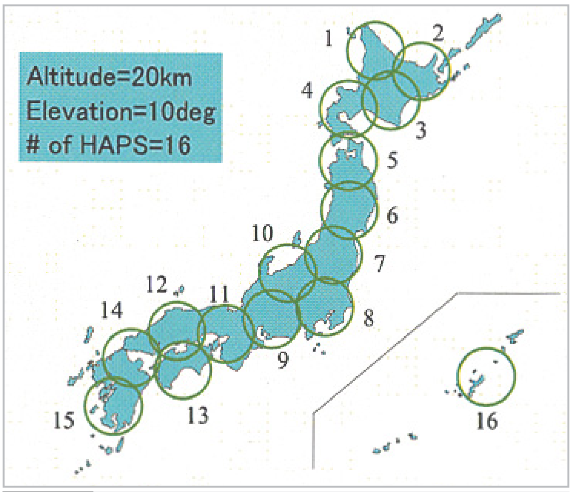


Fig.3 Example of an area deployment plan in Japan

The telecommunication and broadcasting concept using the stratospheric platform provides that a number of stratospheric platforms will be arranged in the sky in a mesh manner, with a spacing of a few tens to a few hundreds of kilometers, set to serve as relay stations or a base station. With this concept, there can be envisioned a variety of applications, not only for fixed communications but also for mobile communications, broadcasting, global environment measurements, radio monitoring, and so on. Among others, a broadband access network that uses high frequencies (in the millimeter wave band, for example) and provides transmission speed of 20 Mbps or more in a single channel, aimed at personal users, is considered to be one of the applications that will make the most of the features of the stratospheric platform. It raises the possibility that high-quality digital services, such as a high-speed Internet and a high-quality digital broadcasting (whereby motion pictures and a large volume of contents can be exchanged without taxing the user's system) may be realized without relying on satellites or on the terrestrial infrastructure, such as optical fibers. Further, by connecting the platforms with optical wireless links, it will be possible to establish links by wireless only over a wide area.

3 Comparison of platforms suitable for telecommunications and broadcasting applications

The following can be listed as requirements for a stratospheric platform with onboard radio equipment for telecommunications and broadcasting applications.

(1) Capable of reaching the stratosphere (an altitude of 20 km or so) and staying at a fixed point within a prescribed range.

(2) Capable of round-the-clock continuous operation for a long duration.

(3) Capable of bearing large weights, so as to accommodate numerous types of application apparatuses and at the same time supply sufficient power to these apparatuses.

(4) Onboard radio equipment may be retrieved on the ground or on the sea, as necessary.

(5) Is environmentally friendly in terms of the stratosphere.

As candidates that fulfill these requirements, three categories of aircraft are considered, classified broadly as: an unmanned airship with a propulsion system[1][6], a solar plane (solar cell-powered unmanned aircraft)

Table 1 *Comparison between main candidates for the stratospheric platform*

	Large-scale airship (unmanned)[*1]	***Solar plane (unmanned)***	***Jet (manned)***
Total length	~200m	~70m	~30m
All-in weight	~30ton	~1ton	~2.5ton
Propulsion energy source	Solar cell	Solar cell	Fossil fuel
Flight duration time	About 3 years	Unknown	8 hours
Station keeping range(radius)	~1km	~1.5km	~10km
Mission equipment weight	~1000kg	~100kg	~1000kg
Mission allowable electric power	~10kW	~1kW	~20kW
System example	Japan, Korea, China, Sky Station and other companies in the U.S.	Helios, Pathfinder Plus (AeroVironment Inc., in the U.S.)	HALO (Angel Technology Corporation, in the U.S.)

(*1) from NAL feasibility study [1][3] (1999)

(a) Large-scale airship (designed by NAL)   (b) Solar plane (Helios)   (c) Stratosphere jet (HALO)

Fig.4 *Candidates for the stratospheric platform*

[7], and a manned aircraft (a jet)[8](Fig.4). Table 1 shows a rough comparison of these aerial vehicles. Considering the mission equipment weight, influence on the environment, and the like, the airship system is the candidate with the most potential, as expected. However, the airship must be very large in order to be capable of fulfilling these requirements and at the same time reach the stratosphere. Although the challenges are being addressed one by one, various technological problems still remain. Therefore, although we are aiming at installing radio equipment on an airship as a final goal, we feel that it is not absolutely necessary to insist upon a large-sized airship, nor to require that the airship fulfill all of the above-mentioned requirements, in the context of a partial preliminary demonstration test representing the prior stage to full development. There is also possibility that the solar plane, the manned aircraft, or even a small-size airship may be suitably applied.

A conceptual drawing of the stratospheric airship that was created in the feasibility study carried out by NAL in 1999 is shown in Fig.5 [1][3]. The body of the airship is equipped with a number of helium gas bags, a solar cell panel on its top face, and three propulsion engines. A regenerative fuel cell is installed on the platform for operation at night. Analysis indicated that the length of the airship would be 245 m, the weight would be 32.4 tons, and the power required to propel it would be approximately 200 kW. At this time, it was calculated that the equipment load capacity (mission payload) was about 1 ton and the allowable power for maximum dissi-

Table 2 *Steps of present airship development and testing in Japan (Organization in charge: NAL; support: domestic heavy-industry manufacturers)*

Development completion time	Name	Target altitude	Feature	Test item
Year 2002-2003	Stratosphere fight testing aerial vehicle (presently under development)	15km	45-m class, non-powered, payload 40kg	Acquisition of basic data relating to materials, heat control, and the like, as well as terrestrial environment measurements in the stratosphere
2003-2004	Low-altitude station keeping flight	4km	65-m class, powered, payload 250kg	Acquisition of basic data relating to aerial vehicle control, and basic operations and telecommunications experimentation at low altitude
In and after 2006	Technology demonstration aerial vehicle	20km	150-m class, powered, payload 500-1,000kg?	Acquisition of general data concerning aerial vehicles in the stratosphere and telecommunication experimentation in the stratosphere

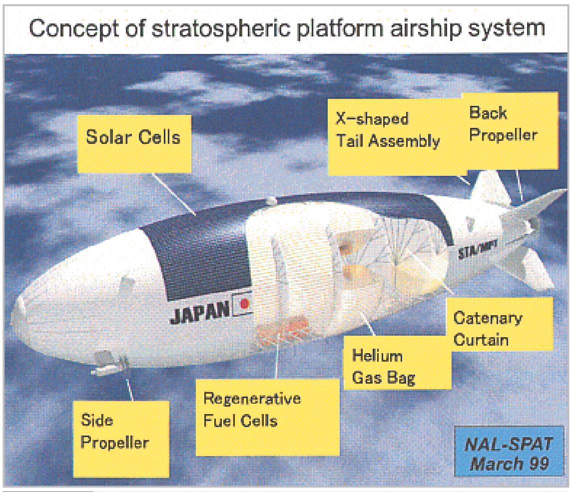


Fig.5 *Results of airship feasibility study (conducted by NAL in 1999)*

pation was 10 kW. Note that these parameters are continually being revised, according to the actual state of technological development.

Initially as the energy source for such an airship, the feasibility of transmitting electric power using a high- powered microwave output from the ground was investigated, and development and experimentation were conducted in the CRL[10], but the problem of disturbances in the electromagnetic environment became a stumbling block, and consequently the strategy has been changed, focusing on a combination of the solar cell and the fuel cell. Table 2 shows the status of the present airship development in Japan.

4 Research and development to date and preliminary demonstration plan with CRL/TAO

The target of development of a government-run telecommunications and broadcasting mission is to demonstrate the concept behind it. Basic component technologies are in line with the technology developed for satellite and terrestrial radio systems. However, especially in the high frequencies, there is no operational experience relating to environmental conditions and link requirements peculiar to the stratosphere, nor are there specific available technologies, and no system has been implemented that could demonstrate the benefits that may actually be provided to telecommunication users. Therefore, the most important problem at present is to demonstrate these features as soon as possible, and to establish the system's future potential and directionality in terms of technology, business, and society. If these problems are achieved and a market appears in sight, the task will then pass to those responsible for project execution and manufacture.

The development of the telecommunications and broadcasting project by CRL/TAO began in 1998, and since then conceptual design, development of onboard equipment, and development of ground equipment have been carried out in the three fields of fixed communications, mobile communications, and broadcasting[1][2][4][5]. To make the status of the project available to the public, we have published these achievements broadly in domestic and foreign academic conferences, newspapers, etc., and have applied for various related patents, as part of our business strategy for the future. In addition to these activities, execution of an evaluation test to check the performance of the stratospheric platform when being used for radio monitoring of illegal radio stations on the ground is scheduled in fiscal year 2001. The outline of the onboard equipment for testing the applications is as follows.

(1) Broadband fixed access: This is for providing broadband access links of 2-150 Mbps or so to users at fixed locations by means of small-sized antennas and radio equipment, to effect the economical provision of moving pictures and a broadband Internet environment. The use of a 48/47 GHz band and a 31/28 GHz band has already been accepted by the ITU (International Telecommunication Union) for fixed access[16][17]. As a prototype antenna to be mounted for this purpose, two potential multibeam antennas have been developed to date (as described below). With these antennas, the functions of space division multiple access (SDMA) systems (where a plurality of users share the same frequency without interference), compensation for a platform's oscillation, automatic acquisition of ground users, high-speed transmission of motion pictures, etc., may be evaluated.

(2) Next-generation mobile access: This is intended to allow a small number of stratospheric platforms to take over the functions of a number of base stations on the ground for W-CDMA, one of the third-generation portable telephone standards (IMT-2000). In cases where infrastructure must be built up from a nearly-zero state, this will be effective in curtailing the cost to a great extent and in decreasing "dead spots," where the strength of electromagnetic wave is weak. ITU has approved that part of the band for the terrestrial IMT-2000 service may be used for the IMT-2000 service using the stratospheric platform [16]. Two kinds of antennas have been developed: a switching planar antenna and a multi-helical antenna, together with a test onboard repeater of a through-repeater system. The ground user side will be able to access the stratospheric platform at 384 kbps using a commercially available third-generation portable phone terminal.

(3) Digital broadcasting: With conventional terrestrial broadcasting, a transmitting station sends a broadcast wave of large electric power, and a number of relay stations are installed in various places to compensate for attenuation of the electromagnetic wave caused by buildings and terrain features, in order to decrease the area where reception is poor. With the stratospheric platform, one platform alone can provide a broad area of coverage, with a significantly lower transmission power. Naturally the area of platform coverage is smaller than that of the satellite broadcasting, but precisely for this reason, the platform is well-suited to broadcasting to a certain focused area. Although the frequencies of a broadcasting service using the stratospheric platform has not yet been established by the ITU, we have developed an onboard repeater for testing through-repeater system digital broadcasting that uses UHF in a 400-500 MHz band. For the antenna, the drooping dipole antenna is used. Through this arrangement, performance of high-definition TV broadcasting by an orthogonal frequency division multiplex (OFDM) scheme may be evaluated.

(4) Radio monitoring: The observation and radio monitoring of illegal electromagnetic waves represent applications that could benefit from the strong line-of-sight capability of the stratospheric platform. Conventionally, radio monitoring is conducted using monitoring antennas on the ground. When the antenna is elevated to the altitude of the stratosphere, the influence of multipath and shielding can be reduced; therefore, it is expected that high-accuracy and wide-area radio monitoring of electromagnetic wave sources may be realized. To demonstrate this fundamental concept, we are developing a data-acquisition apparatus with the use of mutually-orthogonalized two eight-element linear array antennas (2 GHz) to permit radio positioning of an electromagnetic wave on the ground by using a super-resolution DOA (direction-of-arrival) estimating algorithm and the ray-tracing method.

The components of the radio equipment for relay testing in the stratosphere described above need to be tested in the context of an environment as similar to that of the stratosphere as possible, so that the results may be used to pave the way for conceptual demonstration of a stratospheric platform-based telecommunications and broadcasting system. Therefore, CRL/TAO has devised a plan for a preliminary demonstration test, prior to installation on board the airship in fiscal year 2002 [2]. The aerial vehicles to be used in the preliminary demonstration test are expected to be of the following three types.

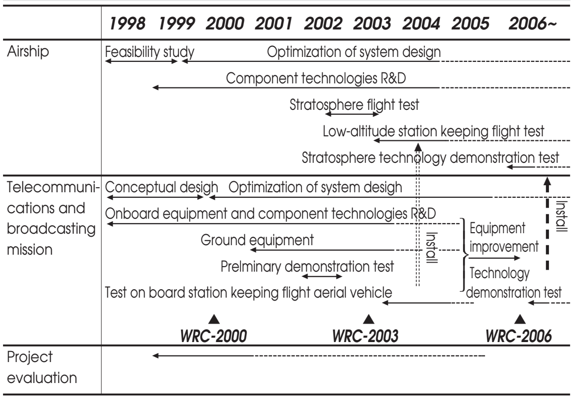
(1) Helicopter (Kawasaki Vertol): This has an excellent hovering ability and surpasses other flying vehicles in the station keeping performance (within a radius of 150 m). On the other hand, it cannot reach the altitude of the stratosphere; the highest attainable altitude is 3-4 km or so. Therefore, this will carry multibeam antennas developed for fixed access, an application requiring relatively high station keeping performance, and an access test is to be conducted using a millimeter-wave band of 30 GHz or more, with a high elevation angle. To confirm whether or not this vehicle can actually obtain flight permission over the Yokosuka YRP, where the experiment is scheduled, the vehicle flew to the YRP and executed a hovering test at a height of 3,000 m, and it was ascertained that there was no problem (Fig.6). Note that for the basic radio-monitoring experiment, a smaller-sized helicopter will be used to conduct the actual test of the radio positioning of electromagnetic wave sources.

(2) Small-sized jet (Gulfstream II): This is inferior to the helicopter in the station keeping performance (turning radius of 10 km or more) and a bank angle of nearly 30 degrees is generated when turning, but the jet can fly at an altitude of approximately 14 km, which enables tests to be conducted in an environment close to that of the stratosphere. Therefore, this machine is used to conduct a digital broadcasting test using low frequencies (such as UHF frequencies) that do not require a directional antenna for the onboard equipment.

Fig.6 *Kawasaki Vertol flown to Yokosuka YRP (March 2001)*

(3) Solar plane (Pathfinder Plus): This was developed by NASA, in the United States. Present models are the Helios (wingspan of 75 m) and the Pathfinder Plus (wingspan of 37 m), owned by AeroVironment Inc. in the U.S. These have the ability of soaring up to the stratosphere with electricity supplied only by the solar cell. The Helios has successfully reached an altitude of 30 km (August 2001) and the Pathfinder Plus has reached an altitude of 24 km (August 1998) in Hawaii[7]. The station keeping performance can be attained within a few kilometers, although it depends upon the air stream. However, the mission payload is limited, at 50-100 kg or so. The solar plane itself is assumed to be among the candidates for the stratospheric platform, and it is said that NASA supports the use of the solar plane for the platform. As the Helios cannot be used because of modifications and the like scheduled in fiscal year 2002, we will use the Pathfinder Plus to conduct tests of the W-CDMA signal relay (using a lightweight

Table 3 *Research and development schedule*



repeater), and of UHF digital broadcasting.

Regarding the roles of CRL and TAO, TAO executes the conceptual design of an entire system and develops the onboard repeater and the ground equipment, and CRL takes charge of the development of the component technologies (centering on the antenna to be mounted) in respect of which research remains to be conducted. Table 3 shows the present research and development schedule. After the preliminary demonstration test, we are going to install the telecommunication equipment on the test airship currently being built by NAL, followed by an actual demonstration test of the technology using the airship, as we push ahead with our plan to demonstrate the feasibility of the stratospheric platform.

5 Overseas trends

Outside Japan, the movement toward commercialization of the stratospheric platform has been active in recent years as well.

This movement has taken place against the backdrop of the expansion of available frequencies at the World Radiocommunication Conference (WRC-2000), as discussed below, which expansion was expected to trigger sudden business development of the platform.

The main developments are as follows.

(1) Sky Station International Inc. (United States)

The first of its kind worldwide, this is a venture company that aims at developing communication business using a stratospheric airship. The company successfully lobbied the ITU, for ITU permission to use frequencies in the 47/48 GHz band and in the 2 GHz band. The company is preparing to offer a broadband fixed access link (2-10 Mbps) in the 47/48 GHz band and an IMT-2000 mobile communication link in the 2 GHz band, through the use of a 150-m class airship[6]. It was announced that a first test flight was to be executed at the end of 2000, but no publication has yet been made. However, the company designated United States Lockheed Martin Global Telecommunications as a system integrator (according to a latest news, this contract has been cancelled), and the company has reportedly been recently working on the design of a new airship. Thus, it will be necessary to keep an eye on developments in this area in the meantime.

(2) NASA/AeroVironment Inc. (United States)

NASA has proposed that a lightweight unmanned solar plane (with the above-mentioned solar cell fixed on the upper-front portion of its main wing) be operated at an altitude of 17-30 km[7], and has invested over 80 million dollars to date to develop the body of the airplane (Helios, and others) with a view to use these mainly for earth observations. The AeroVironment Inc., a venture company that deals in solar cars and the like, has suggested that this solar plane be used as a telecommunication base. This aerial vehicle is environmentally friendly and is nearing practical use, but has problems, such as limitation of the mission weight at 100 kg and a limited area of flight at present (due to susceptibility to wind damage). Note that SkyTower Inc., a communication business proposing to use this aerial vehicle, has already been established, with an agency in Japan (Japan Stratosphere Communications Inc.).

(3) Angel Technologies Corporation/Raytheon Company (United States)

The company has planned for a small-size manned jet to be operated at an altitude of 17-20 km[8]. The pilots will be on duty, for example, over three shifts of eight hours each. This system offers a means for realizing the stratospheric platform almost solely based on existing technologies, and at the lowest cost. A special aircraft called the HALO-Proteus has already been developed, and succeeded in conducting an initial demonstration flight at an altitude of 15 km, in 1998. Angel Technologies is in charge of the aerial vehicle and Raytheon Co. is in charge of the telecommunications equipment.

(4) European Space Agency (ESA)/Lindstrand Balloons Ltd. (U.K.)

By contract with ESA, the balloon maker Lindstrand carried out a feasibility study on a stratospheric platform in the form of an airship in 1998, but subsequently no contract was concluded.

(5) Advanced Technologies Groups Inc. (U.K.)

This company has demonstrated actual results in developing a variety of low-altitude airships, such as the SkyCat series for transportation, sightseeing, monitoring, and AT-10 for pilot training[1][9]. For the stratosphere (altitude of 20 km), the company has started development of an airship called the StratSat (Fig.7). They had a contract with SkyStation temporarily but there is no contract at present. The company aims at creating an airship of a length of 200 m, with resistance to wind damage of 35 m/s, and a payload of 2 tons. For a power source, a combination of the solar cell and an additional diesel engine is proposed, where the latter is in preparation for the strong wind environments that may occur. The company seems to manufacture a scale model approximately 120 m long and to conduct a test flight at an altitude of 10 km, with the combined use of the solar cell and the diesel engine or the diesel engine's alternative, microwave transmission of electrical energy in 2003.

In addition, research activities have begun in Korea (Korea Aerospace Research Institute and Electronics and Telecommunications Research Institute) and in China (Shanghai Jiao Tong University and Beijing Tsinghua University)and elsewhere; countries in Southeast Asia, South America, Africa, and elsewhere are carefully following such research.

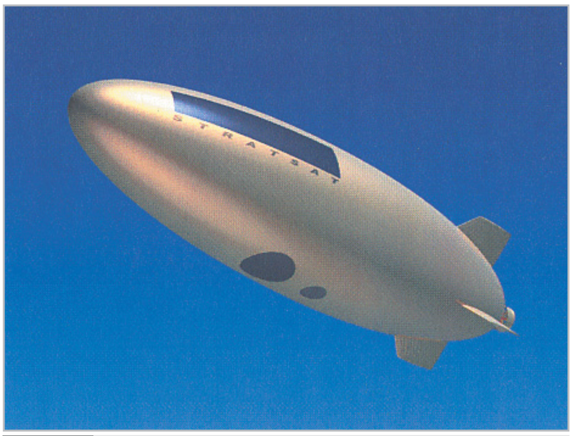


Fig.7 Conceptual drawing of StratSat™, made by Advanced Technologies Groups Inc

Further, interest is growing from all sides with respect to individual research plans for the stratospheric platform: there is the "Spacebird" plan at Cranfield University, the "Helinet" plan at the University of York, and the "Sirius" plan at the University of Surrey, all in the UK.; the U.S. Army has begun a high-altitude airship program, which Lockheed Martin Naval Electronics & Surveillance Systems was quick to apply for participation with; etc. However, it is thought that Japan continues to lead the world at present in the development of the applicable telecommunications equipment.

6 Prototype of multibeam antenna to be mounted

In fiscal year 1998, CRL began development of an antenna for broadband access that involves the development of many difficult technological elements, necessitating the allocation of development time for the various components. For the broadband access antenna to be mounted on the stratospheric platform, the following functions are required.

(i) Use of a high radio frequency (e.g., 10 GHz or more) to secure a sufficient bandwidth for a broadband link.

(ii) When using high frequencies, communication quality is governed by thermal noise, and hence a directional antenna with a high gain is necessary.

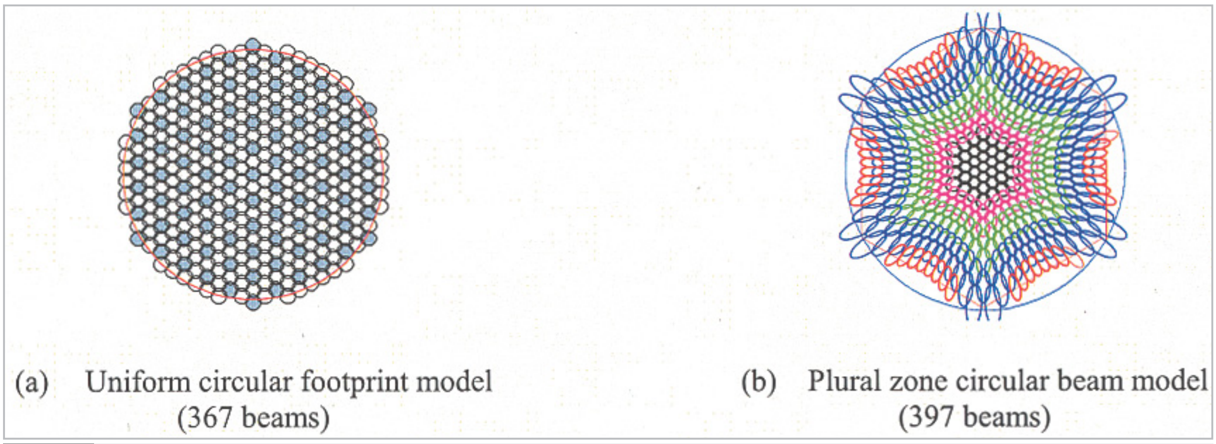


Fig.8 *Typical examples of multibeam footprints under consideration for formulation into an ITU-R recommendation*

(iii) Since the angle of view over the service area on the ground when viewed from the stratosphere may be as wide as 120 degrees or more, a multibeam antenna that accommodates 100 beams or more is necessary, both for transmission and for reception, in order to reconcile the wide angle of view and the high gain required, as well as to achieve effective use of the frequencies involved.

(iv) Since the position and attitude of the platform vary due to variations in the air stream and in atmospheric pressure, the platform must cancel out the influences of attitude variation on the footprint on the ground by means of beam control.

Especially regarding (iii), note that at ITU-R, where frequency allocation to the stratospheric platform is being discussed, multibeam footprint patterns for broadband access were presented, each of which would generate 300-400 cells in the Ka band, as shown in Fig.8. These patterns are required for the purpose of mitigating the effect of the above-mentioned frequency allocation on services already using the same frequency band (e.g., terrestrial fixed-communication service, satellite communication service, and the like)[17][18]. Fig.8 (a) represents a model where footprints of the beams on the ground form a circular pattern of the same size, regardless of the direction and the elevation angle relative to the ground, while the cross-sections of the beams generated by the antenna are made to be elliptical. Further, Fig. 8 (b) represents a model where a service area is divided into several zones, according to the elevation angle from the ground, so that beam gain in each zone is the same among the footprints and the footprints on the ground necessarily become elliptical.

For a multibeam antenna that can respond to these requirements, two types have been developed to date: a multibeam horn (MBH) antenna of the mechanical-drive type, and a digital beamforming (DBF) antenna of the electronic-scanning type[11]. Basic configurations of the antennas (in reception) are shown in Fig.9, basic specifications of the respective antennas are shown in Table 4, and photographs of the antennas may be seen in Fig.10. We have developed a prototype antenna as a limited-function model, equipped with minimum functions, which permitted demonstration of the concept. This prototype featured a reduced number of antenna elements, due to restrictions of development time and budget, and was developed assuming it would be used for an onboard test on a 150-200 m class demonstrator model. Although the stratosphere presents a harsh environment (the atmospheric pressure is 1/20th that present on the ground, and the temperature drops to -50 degrees centigrade or lower), the temperature and pressure inside the enclosure in which the equipment is installed are controlled, so that as many pieces of ground equipment as possi-

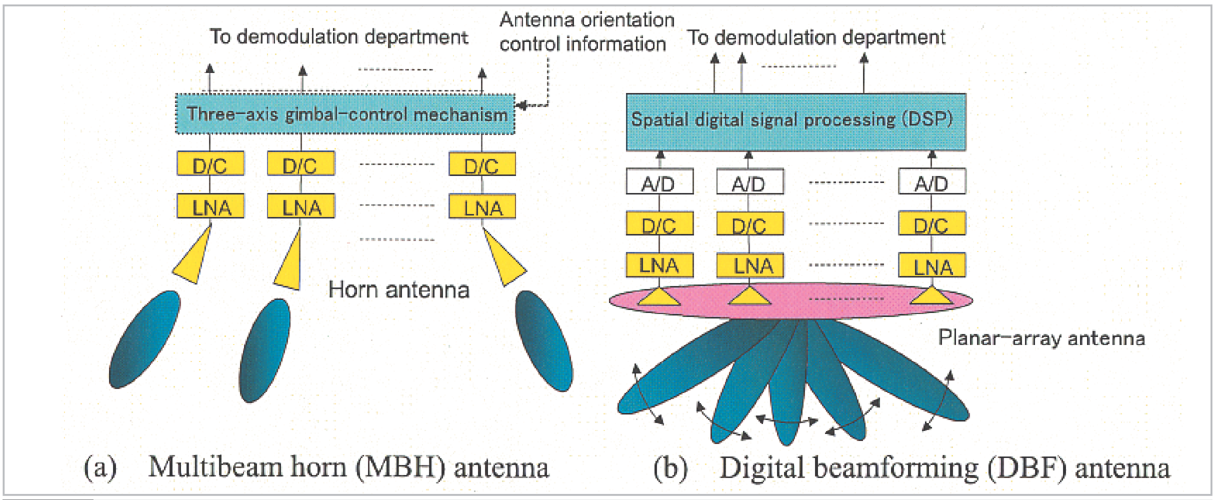


Fig.8 *Basic configuration of multibeam antenna to be mounted on demonstrator model under development*

Table 4 *Main specifications of the multibeam antenna prototype*

Item	Multibeam horn antenna	Digital beamforming antenna
Frequency band	Transmission: 47.2-47.5 GHz Reception: 47.9-49.2 GHz	Transmission: 28.5-27.35 GHz Reception: 31.0-31.3 GHz
Antenna type	7-element corrugated horn	16-element (4 x 4) patch array
Spot beam width	12 degrees	10-13 degrees
Number of multibeams	Fixed beams:7	Fixed beams: 9, adaptive beams: 3
Bandwidth	300 MHz or more	3MHz or more
Ttansmission EIRP	6.3 dBW or more	11-15 dBW
Recepion G/T	-15.4 dB/K or more	-13 to -17 dB/K
Compensation for platform oscillation	Attitude sensor and three-axis gimbal mechanical drive control	Adaptive beamforming via digital signal processing of received signal
Maximum transmission rate	25Mbps or more	2-4 Mbps
Power consumption	1.0 kW or less	1.6 kW or less
Weight	150 kg or less	74.2 kg
Other	Number of frequencies reused:7 or less Isolation between the same frequency beams: 30 dB or more	Sampling rete: 32 MHz Resolution: 12 bits Signal-processing device: FPGA (RX: 100k gates x 61, TX: 100k gates x 31)

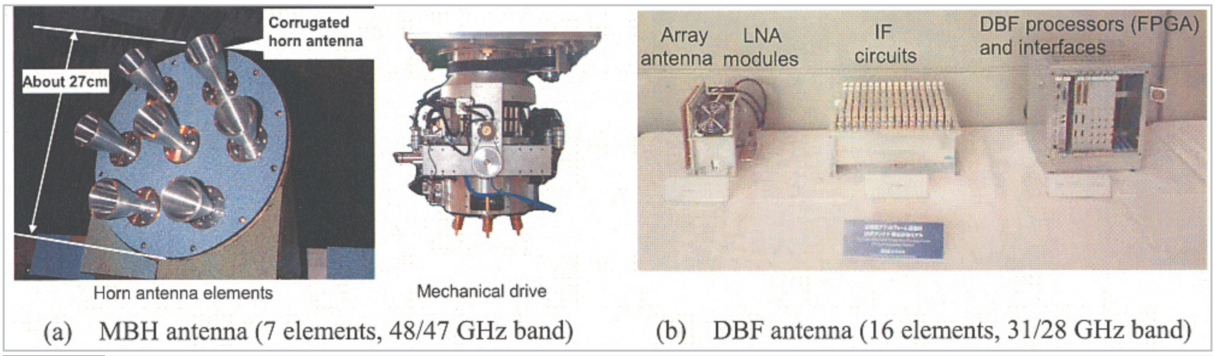


Fig.10 *Prototype of multibeam antenna to be mounted*

ble may be used, thus reducing costs.

Features of each antenna are described as follows.

(1) Mechanical drive multibeam horn (MBH) antenna

This is part of a multibeam system where a number of horn antennas are fixed to a base that is gimbal-controlled by a three-axis mechanical drive, and each of the horn antennas forms a relatively fixed footprint on the ground. The MBH antenna is specified to use a frequency in the 48/47 GHz band and features seven antenna elements. It is intended to be used mainly for broadband feeder links, high-quality business links, and the like. The main features of this antenna are as follows.

(a) A broadband antenna can be produced almost exclusively relying on existing technologies.

(b) The antenna has excellent wide-angle characteristics of gain, axial ratio, and the like.

(c) Development expense is comparatively low.

Since the footprints created by this antenna become fixed cells, it is mandatory to use a different frequency for each beam in such a manner that, for example, four or seven frequencies, are reused in the spatial domain; therefore this antenna lacks flexibility, relative to the DBF antenna discussed below. Further, the antenna must feature a sufficiently low side-lobe level. Moreover, when a ground user stations moved or when the platform itself drifts in a vertical direction due to variation in the atmospheric pressure or the like, a handover action becomes necessary between the beams. With this antenna, each element requires an aperture, as each element acts as a directional antenna; when the antenna is composed of a few dozen or hundreds of elements, the antenna becomes oversized, and the number of cables connecting the repeater and the respective antenna must also increase, making the gimbal difficult to rotate. Therefore, this antenna is considered not to be particularly suitable to a large-scale multibeam antenna application.

(2) Digital beamforming (DBF) antenna

This represents a system where a beam is formed by a combination of the active array antenna and spatial digital signal processing; it is an “intelligent” next-generation antenna, referred to as a “smart antenna” or a “software antenna.” The antenna effects automatic acquisition, tracking, interference separation, and the like by performing spatial parallel processing of signals received from the ground-user stations, thereby forming an antenna pattern. Further, the transmitting side forms a beam based on information on the direction of arrival of the signal obtained by the reception side, to effect spatial power combining. Since there is no mechanical drive component, this antenna is considered to be suitable for multi-element, large-scale, multibeam formation. Recently, the DBF antenna has been adopted for cellular base station antennas because it significantly improves the capacity and quality of mobile-communication systems, although there are few examples of its use in a multi-element array antenna at high frequencies (10 GHz or more). However, since the DBF antenna involves a number of parts untested in the field and features a large number of components relative to the MBH system, the development cost is large, and it also consumes a great deal of electric power, in the current configuration. Given this situation, for the demonstrator model antenna, we focused on improved beamforming functions, rather than on broadband characteristics, and specified the antenna as an array antenna with a limited number of elements (16, in a 4-by-4 square arrangement), in light of our desire to acquire basic data for the realization of a multi-element DBF antenna in the future. As for frequency, the newly allocated 31/28 GHz band was specified. It was assumed that a great number of individual users will be densely distributed on the ground and that this antenna will be used in the access links by those users. The main features of this antenna are as follows.

(a) Flexible, accurate transmit/receive beam steering (or beam pointing), accommodating a number of ground-user station communication requests, which can be effected individually (i.e., “beam on-demand,” with an adaptive multibeam).

No fixed cell exists in the footprints, and the handover frequency is less than that of the MBH antenna.

(b) To a specific ground user, the onboard antenna can always provide its maximum gain, and since the side lobe level is controllable, the link quality is stabilized; therefore it is possible to utilize the frequency effectively by space-division multiple access (SDMA), thus increasing the communication capacity.

(c) The antenna has the capability of removing undesired in-coming interfering waves, reducing the interference on other systems (such as satellite systems) that share the same band, and also can estimate, based on direction of arrival, the location of sources of communication signals and unauthorized electromagnetic waves.

(d) The antenna is robust against failure of a number of components.

(e) High-speed calibration of the transmit-receive array antenna is possible via signal processing.

For a digital signal-processing device for the DBF antenna, a FPGA (Field Programmable Gate Array, suited for high-speed parallel processing and featuring a reconfigurable algorithm), and a general-purpose high-speed MPU (Micro Processing Unit, allowing for easy program development) were adopted, with the aim of combining high-speed parallel processing performance with ease of program development. As remaining challenges, enhanced broadband characteristics are sought through improvements in the processing speed of the digital devices, the problem of heat-dissipation must be overcome when active elements are integrated in a large-scale array, and gain and axial ratio must be improved for cases of large scan angles, among others.

In the development of the beamforming algorithm for the DBF antenna, it is necessary to consider a multi-element array, power-limited types of links, burst signals, SDMA, and so on, in the context of a practical future aerial vehicle. Therefore, the algorithm needs to be designed so as to allow a reduced number of operations, parallel-processing adaptability, stable operations in a low-CNR environment, high-speed acquisition of the desired wave, sufficient suppression of interference, and so on.

A maximal ratio combining system [12][13], assisted by known reference sequences, was examined and implemented in the prototype antenna. With this system, the maximum ratio combining previously used (within one of the existing diversity systems) was developed into a multi-user-compliant algorithm, based on non-blind processing, and was implemented within a simple arithmetical system, so as to be applicable to the multi-element DBF antenna. Further, to accommodate the low CNR signal, a beam-space processing method was adopted, whereby a spatial DFT forming a fixed multibeam in advance is assigned as a preprocessor. According to a simulation study, this method makes it possible to conduct automatic acquisition of a desired wave with 10 symbols or so, even within a low-CNR environment (not more than 0 dB per antenna element), and also to perform separate reception for different user stations with a given degree of isolation between them, by instructing them to use different reference sequences when their directions of arrival are different (Fig.11). Further, it is also easy to convert weight coefficients of a reception array into weight coefficients of a transmitting array on a different frequency. Although this method does not obtain the optimum solution in an environment where an interference wave exists (in which case the Wiener solution is preferable), this method can decrease the quantity of operations by one or two orders of magnitude, relative to methods that use complicated matrix operations or the like (i.e., optimization methods such as the recursive least square method, or “RLS,” and the direct matrix inversion, or “DMI”), precisely because it does not employ such operations. Further, since this method enables parallel processing, it can be easily and effectively implemented in devices that utilize spatially distributed circuit resources, such as the FPGA and the ASIC. We are also developing

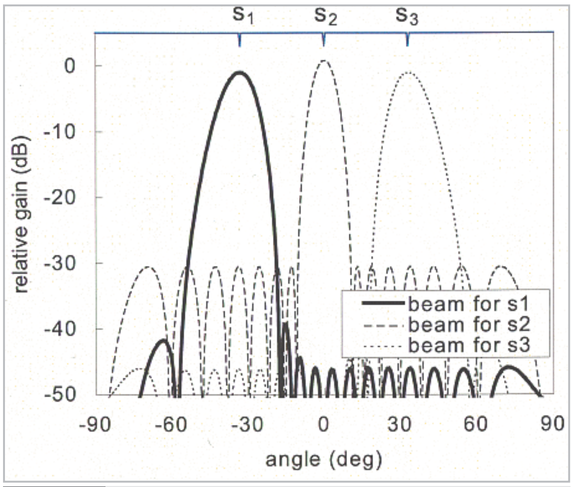


Fig.11 *Example of a simulation in which the DBF antenna pattern is formed by maximal ratio combining, with the aid of already-known reference sequences (separate reception of three waves with a 16-element linear array)*

a high-speed calibration technique for the transmit-receive array antenna, in which this principle of beamforming is applied[14][15].

7 Summary

Here we have presented an outline of research and development status of a stratospheric platform, with the Ministry of Public Management, Home Affairs, Posts and the Telecommunications and the Ministry of Education, Culture, Sports, Science and Technology both playing central roles. In CRL, the Wireless Innovation Systems Group is producing an analysis in conjunction with other groups, such as the Broadcasting Systems Group and the Optical Space Communications Group, with a view to making use of the research accumulated thus far. Further, this group is actively contributing technical support to the Ministry of Public Management, Home Affairs, Posts and Telecommunications in its attempt to obtain frequency allocation at the ITU, in cooperation with the Yokosuka Research Center of TAO. To date, we have submitted a number of technical contributions and obtained conditional approval for use of the 31/28 GHz band at the WRC (World Radiocommunication Conference) 2000 (in Istanbul), and in addition have formulated seven preliminary draft new Recommendations, continuing to refine these into actual Recommendations[19]. We can say that the telecommunication technology based on the stratospheric platform involves a number of problems that have not been addressed worldwide in the fields of hardware, software, networking, and protocols, and is one of very few technologies in which Japan can play a leading contributing role worldwide. For that purpose and others, we are making efforts to effect a demonstration test in the stratosphere as soon as possible; this will represent a key event that will serve as the impetus to shift the national initiative into the private sector.

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References

1 Proc. The 1st ~ 3rd Stratospheric Platform Workshop (SPSW'99~01), 1999~2001.
2 R&D Report on the Wireless System Using Stratospheric Platform in 2000, TAO, May 2001.
3 Web Site of NAL, http://www.nal.go.jp/Welcome-e.html/
4 Web Site of CRL, http://www2.crl.go.jp/mt/b181/research/sbf/index-e.html/

5 Web Site of TAO, http://www.yrp.tao.go.jp/

6 Web Site of Sky Station, http://www.skystation.com/

7 Web Site of AeroVironment, http://www.aerovironment.com/

8 Web Site of Angel Technologies, http://www.angelhalo.com/

9 Web Site of Advanced Technologies Group, http://www.airship.com/

10 Y. Fujino, M. Fujita, N. Gaya, M. Onda, S. Kunimi, and M. Ishii, "Wireless Power Receiving System for Microwave Propelled Airship Experiment," Space Technology, Vol. 17, No. 2, pp. 89-93, Dec. 1997.

11 R. Miura, M. Oodo, and Y. Hase, "Development of Multibeam Antennas in the Millimeter-Wave Band On Board Stratospheric Platform," Proc. AP-2000, Davos, Switzerland, Apr. 2000.

12 R. Miura, M. Oodo, A. Kanazawa, and Y. Koyama, "Maximal-Ratio-Combining Array Beamformer Assisted by a Training Sequence for Space Division Multiple Access In Power-Limited Channels, " IEICE Trans. Commun., Vol. E83-B, No. 2, pp. 394-405, Feb. 2000.

13 R. Miura, M. Oodo, Y. Hase, T. Inaba, T. Sakamoto, and M. Suzuki, "Digital Beamforming Array Antenna On-Board Stratospheric Platform for Quick-Response SDMA in the Band 31/28 GHz," Proc. WPMC'01, Aalborg, Denmark, Sep. 2001.

14 M. Oodo and R. Miura, "A Novel Calibration Method for DBF Transmitting Array Antennas, " Proc. AP-2000, Davos, Apr. 2000.

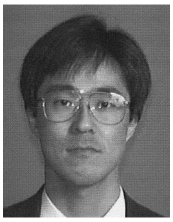
15 T. Nakamura, R. Miura, M. Oodo, and T. Ikegami, "Calibration of a DBF Receiving Array Antenna by Using a Reference Sequence, " Proc. WPMC'00, Bangkok, Nov. 2000.

16 WRC-2000 Final Acts, ITU, Istanbul, Jun. 2000.

17 ITU-R Doc. 9B/44, Nov. 2000.

18 ITU-R Doc. 9B/114, Oct. 2001.

19 M. Oodo and R. Miura, "A Study of Frequency Sharing and Contribution to ITU for Wireless Communication Systems Using Stratospheric Platforms," This Special Issue of CRL Journal.



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