KA BAND EXPERIMANTAL AERO EARTH TERMINAL

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1. Introduction

Ka band is widely used for satellite communication systems. The features of Ka band utilization are its broadband frequency allocation and its low radio interference from/to the terrestrial links. Ka band has been utilized for the fixed satellite service (FSS) using N-STAR and Superbird in Japan, where such services as voice, data and video are provided. In order to expand Ka band utilization, it has been planned to experimentally demonstrate the mobile satellite service (MSS) in the area of aero application. As an example, it is desired that the video data of disaster scene is taken by camera mounted on aircraft is directly transmitted to a base station via a satellite. To this end, is necessary Ka band aero earth terminal mounted on the aircraft. Here, we present a newly developed experimental Ka band aero earth terminal. The antenna is of reflector type, which main reflector diameter is 350 mm. The antenna is a shaped Cassegrain antenna with an Az/El mount. A 100 W high power amplifier (HPA) and a 160K low noise amplifier (LNA) are used as RF amplifiers. The technical features of this terminal are the compact design and high the efficiency radiation characteristics. The terminal has been verified to meet requirements on the ground testing and mounted on an aircraft “Gulf stream II”.

2. Design approach

2.1 Antenna design requirements

The compact design is mandatory requirement for aero application. Especially, the height of antenna related to the height of radome is important issue from the aspect of aerodynamics. Assuming the type of aircraft to be installed, it is required that the height of radome shall be less than 600mm. As for Ka band, are allocated both frequency bands of 29.745 GHz - 30.185 GHz (0.44 GHz) in transmit band and 18.745 GHz - 19.185 GHz (0.44 GHz) in receive band. The required EIRP (Effective Isotropic Radiation Power) and G/T are 50 dBW and 8.2 dB/K, respectively. The resultant antenna gains are 36 dBi and 34 dBi for the transmit and the receive bands, respectively, where a 100W HPA and a 160K LNA are assumed. Those figures are required such antenna aperture diameter as around 300 - 400mm. Concerning the sidelobe requirement, the 90% of sidelobe peaks shall satisfy RR-29 regulation. As polarization requirement, it is necessary to equip with single polarization function, where transmit is LHCP and receive is RHCP. The beam steering shall be plus minus 180 deg. in Azimuth and 15 - 75 deg. in Elevation. The speed of beam steering is typically 30deg./s in any direction.

2.2 Antenna type selection

There are two kinds of candidates for aero earth terminal antennas, the one is a reflector antenna and the other is an array antenna. As for the reflector antenna, a Cassegrain configuration is appropriate since high gain and low noise characteristics are rather easily obtained compared with other type of antenna. A parabola configuration has a drawback in the transmit performance since the feeder between a transmitter and an antenna causes large transmission loss. The Cassegrain antenna can achieve compact configuration because it can cover both transmit and receive frequency bands by using a single dish. Although the drawback of this type is limitation of the beam steering coverage and the beam steering speed caused by mechanical steering scheme, this mechanical solution can satisfy the above requirements in this case.

As for the array antenna type, an active phased array is one of candidates. This type of antenna has such feature as electrically beam steering scheme. Then, it seems to be appropriate to apply it to the mobile application, especially aero application. It is, however, difficult to cope with both Tx and Rx bands by a single antenna aperture. Thus, we need to separate it into a transmit and a receive antenna. This causes large impact because of its physical dimension. Furthermore, its sidelobe characteristics are poorer than that of the reflector type antenna. In addition, although depending on element number, the antenna cost is critical issue. Usually, the active phased array antenna is much more expensive than the reflector antenna.

The other candidate for the array antenna is a planar slotted waveguide array antenna. In this case, an individual antenna for each Tx or Rx is also required because the slotted waveguide array antenna is unable to cover the above broadband characteristics. This results that the size of the slotted waveguide array antenna is larger than that of the reflector antenna. This antenna is also mounted on antenna pedestal and mechanically steered. This antenna has the same drawback of the reflector antenna.

As can be seen from Table 1, showing a summary of the antenna trade-off, we finally choose the mechanical solution by using the Cassegrain antenna.

3. Antenna design

3.1 Reflector design

On designing the Cassegrain antenna with small aperture, we have to investigate radiation patterns from a subreflector carefully. The shaping ability of the subreflector depends on its diameter normalized by wavelength. We have pursued marginal behavior of Cassegrain configuration. After investigation of subreflector shaping ability by calculation, we finally determine the subreflector diameter having 5 times of the wavelength. The designed radiated aperture field pattern from the subreflector are shown in Fig. 1(a) and 1(b) together with the desired aperture field pattern. The difference between the desired and the designed patterns are less than several dB.

The designed antenna is the shaped Cassegrain antenna, which the diameters of the main reflector and the subreflector are 350mm and 75mm, respectively.

3.2 Horn design

It is usual to adopt a corrugated horn as a primary horn for the Cassegrain antenna. The corrugated horn is well known having low sidelobe and low cross polarization characteristics. However, it has complicate structure and results in the expensive manufacturing cost. Then, we developed a double-flared multi-mode horn.

As for the shaped-beam circular horn, there are typically a dual-mode horn and a multi-mode horn. The dual mode horn, where TE_{11} and TM_{11} modes are appropriately combined with each other, is unable to adopt for this case because the whole frequency band (Tx and Rx) is too broad to realize low sidelobe and low cross polarization characteristics. Then, we add an another higher mode of TE_{12} mode to the above two TE_{11} and TM_{11}. To this end, we design the double-flared multi-mode horn, where the first flare-angle change excites TM_{11} and the second one does TM_{11}, TE_{12} and TE_{11}(re-excitation). By choosing the diameter of a circular waveguide and its length between those two changes appropriately, we can obtain low sidelobe and low cross polarization characteristics across the designated frequency bands. The designed horn dimensions are 30mm in aperture diameter and 75mm in length.

3.3 Antenna mount with antenna control

The antenna mount is of either Az/ El mount or X/Y mount type. In general, the Az/ El mount can be compact construction compared with X/Y mount. However, it has a drawback for steering ability, i.e., the Az/El mount is unable to track the satellite in zenith direction.

Another issue is provision for rotary joint installation. We need to consider this point on selection of antenna mount.

Herein, the beam steering requirement is plus minus 180 deg. in Azimuth and 15-75 deg. in Elevation. Then, we select the Az /El mount with Az rotary joints. In Elevation movement, we use a flexible waveguide for Tx path and a flexible coaxial cable for Rx path.

The antenna mount with AC–motors is controlled by using IRS (Inertial Reference System) information provided from the aircraft. The drive speed for each axis is more than 30 deg./s.

4 Overall performance

In Table 2, the overall performance is summarized. The overall performance is estimated with the associated HPA and LNA. The HPA is a TWT amplifier, whose nominal output power is 100W. The HPA is installed in the cabin and the wavegude feeder is provided from HPA output to the antenna feed via the Az rotary joint. The LNA is of GaAs MMIC type, whose noise temperature is 160 K. The LNA is installed at output of antenna feed which is connected to the horn. Fig. 2 shows a photograph of the antenna.

The antenna aperture efficiency is approximately 60% across 20 GHz and 30GHz band. This is considered to be upper limit for the Cassegrain antenna with small aperture such as 25λ. The measured radiation patterns are shown in Figs. 3(a) and 3(b).

5. Conclusion

The experimental aero earth terminal with mechanical steering mechanism is developed and its performances are verified through ground testing. This antenna has been mounted on the aircraft “Gulfstream II” and will be demonstrated for actual testing using a Ka band satellite.

Table 1 Antenna Trade-off

Solution	Mechanical solution			Electrical solution
Antenna type	Cassegrain	Palabola	Passive array	Active phased array
Design feasibility for small size antenna	With condition	Feasible	Feasible	Feasible
Aperture efficiency	Excellent	High	High	Low
Noise temperature	Low	Low	Low	Not sufficient
Antenna configuration	Single dish	Single dish	Dual aperture	Dual aperture
Antenna height	Not sufficient	Not sufficient	Not sufficient	Low profile
Conclusion	o	x	x	x

Table 2 Aero earth terminal performance summary

	Transmit band	Receive band
Frequency	29.745-30.185 GHz	18.745-19.185 GHz
Antenna aperture diameter	350 mm	
Antenna height incl. radome	600 mm	
Antenna mount type	Az/El mount	
Angular travel	Az: plus minus 180 deg. El: 15-75 deg.	
G/T		8.2 dB/K
EIRP	50 dBW	
Sidelobe characteristics	Satisfy RR 29	
Video encoder	2.8,5.7,8.5 Mbps	
Modulation	QPSK	

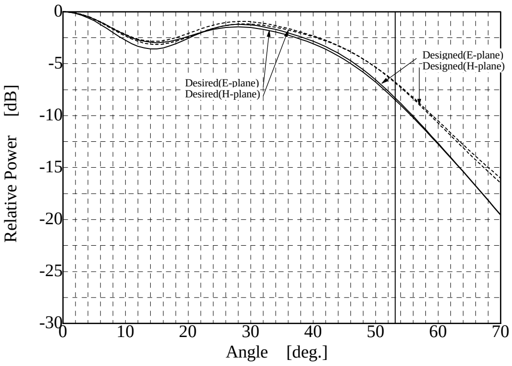

Fig.1(a) Radiation patterns of subreflecter (18.745GHz)

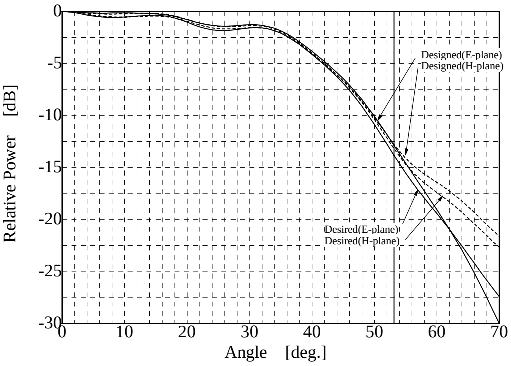

Fig.1(b) Radiation patterns of subreflecter (29.745GHz)

Fig. 2 Aero earth terminal

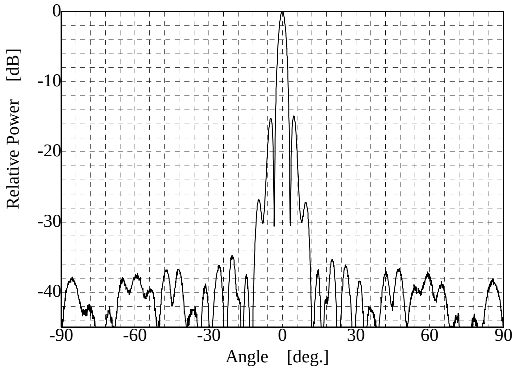

Fig. 3(a) Antenna radiation pattern （18.965GHz）

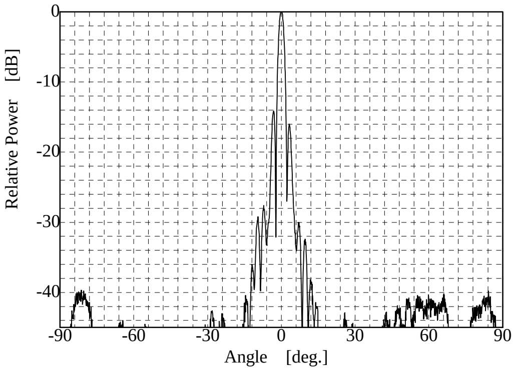

Fig. 3(b) Antenna radiation pattern （29.965GHz）