4-6-3 Parabolic Reflector Antenna Mounted Inside Folding Case

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We developed a folding parabolic reflector antenna for a portable earth station to conduct high speed data communication experiments on the Engineering Test Satellite VIII (ETS-VIII). This antenna is mounted inside a thin folding case, designed to be the antenna carrier, and can easily be folded and unfolded because the reflector is made of a flexible reflector material. We performed experiments to verify the electrical performance of the antenna. Even though the antenna has a flexible reflector, the experimental results show that the expected antenna performance can be achieved for the communication experiments for the ETS-VIII satellite.

Keywords
Engineering Test Satellite VIII, High speed data communication experiments, Portable earth station, Folding parabolic reflector antenna

1 Introduction

Among the scheduled experiments with the Engineering Test Satellite VIII (ETS-VIII), the Communications Research Laboratory (CRL) is planning high-speed data communication experiments for S-band multimedia mobile satellite communications, using mobile and portable earth stations [1]. The CRL has proposed several antennas for the portable earth stations and is in the process of conducting the relevant R&D.

It is desirable that a portable earth station operate efficiently with low power, in light of the required mobility and flexibility in operation. Accordingly, a high-gain antenna is required. A parabolic antenna is one example; it features a simple structure and aperture area may be freely selected to obtain the necessary gain. This type of antenna is therefore often used in portable earth stations. However, the rigid metal structure and the relationship between antenna size and gain present limitations in terms of dimensions.

In particular, when the parabolic antenna is used for emergency communications in the event of disaster, the need for an antenna that provides both the necessary gain and portability is heightened, as it must be easily transported in all kinds of conditions. In order to meet this need, we have proposed and produced a prototype parabolic reflector antenna that can be mounted in a folding case. This paper discusses the structure and electrical characteristics of the parabolic reflector antenna developed.

2 Desired specifications of the antenna

The ETS-VIII will be equipped with onboard base-band switches for high-speed data communications [2]. The switches control transmission signals at a transmission rate of 1024 kbps without forward error correction. To utilize the transmission power of the satellite and earth stations, the combination of Convolution coding and Viterbi decoding is adopted as a forward error correction (FEC) technique. An automatic repeat request (ARQ) technique is also applied as error correction in addition to the FEC in order to reduce the received signal level degradation due to the shadowing effect on the mobile satellite channel.

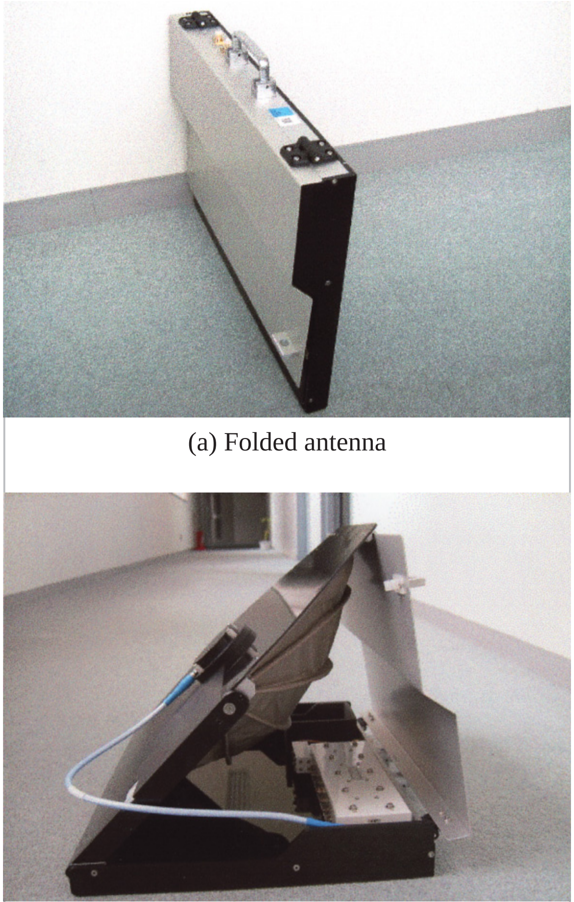
The earth stations intended for the high-speed data communication experiments include vehicle-mounted mobile stations and portable earth stations. The portable earth stations will be designed to transmit power of 10 W in the S-band. Calculating the link budget with this transmitting power and with a transmission rate of 1024 kbps before error correction, available up/down link margin of several decibels is expected when Tx and Rx antenna gain is greater than 12 dBi. We therefore established a desired TX and RX antenna gain of 12 dBi or greater for the parabolic reflector antenna discussed herein. In addition, the frequency bands required for communication experiments with the ETS-VIII are 2655.5–2658.0 MHz for Tx and 2500.5–2503.0 MHz for Rx. The required antenna polarization is left-hand circular polarization (LHCP) both for Tx and Rx.

3 Outline of the prototype antenna

Fig.1 shows pictures of the prototype antenna. In Fig.1 (a) the antenna is folded in the case and in Fig.1 (b) the antenna is deployed. The antenna is the front-fed spherical reflector antenna that can be mounted in a folding case and consists of a folding case, a reflector made of conductive woven fabric, the primary radiator of a microstrip patch antenna with parasitic element, and an RF diplexer. Here we will discuss the structure and characteristics of each component.

3.1 Folding case

Fig.2 shows a schematic drawing of the exterior and interior structure of the prototype antenna. The folding case is 400 mm wide, 300 mm long, and 30 mm thick. It has a handle for easy portability. Two RF SMA—connectors are placed beside the handle (indicated in the upper left in Fig.2 (a)). These connectors are connected to the Tx and Rx connectors of the diplexer inside the case and facilitate connection of the Tx and Rx cables from the portable earth station to the antenna. Fig.2 (b) shows the internal structure of the case when the case is open. The diplexer is fastened in the upper right of the case and the primary radiator is stored in the upper left of the case. The conductive fabric reflector is folded in half for storage in the remaining space.



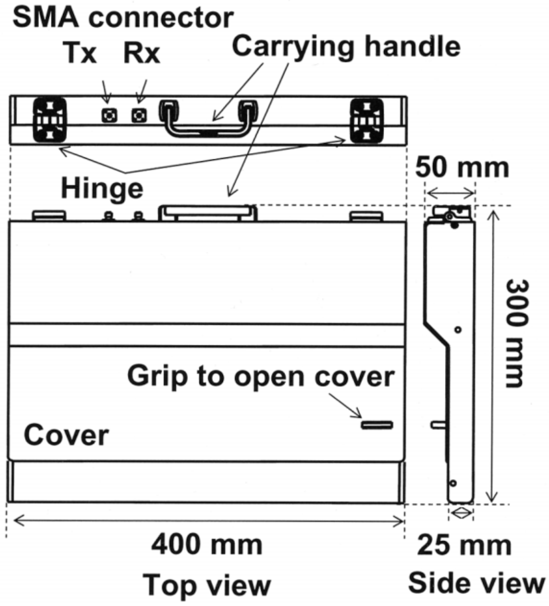
(a) Folded antenna

(b) Deployed antenna

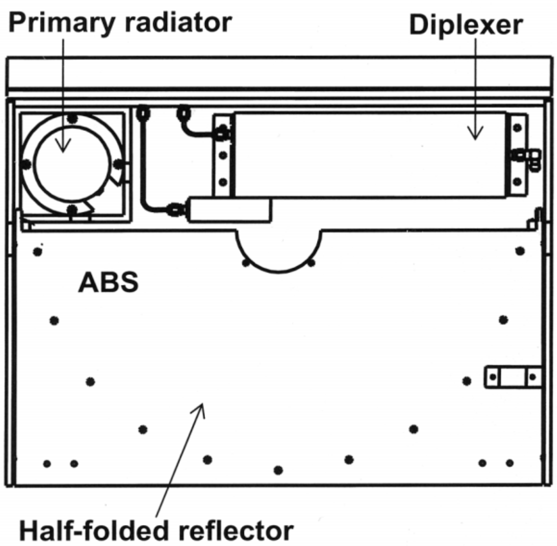
Fig.1 Pictures of prototype parabolic reflector antenna

3.2 Reflector deployment method

Fig.3 illustrates the deployment of the reflector, a process similar to the opening of a round folding fan. First, open the case and erect the reflector, still folded in half, oriented in the direction indicated by arrow (1) in Fig.3. Next, unfold the reflector in the direction indicated by arrow (2) in Fig.3, using the rotating mechanism attached to both sides of the reflector, as if opening a round folding fan.



(a) Exterior structure of the case



(b) Interior structure of the case

Fig.2 *Exterior appearance and interior structure of the prototype antenna*

Then, tilt the case cover in the direction indicated by arrow (3) while orienting the reflector in the direction indicated by arrow (4). Hook the tip of the reflector to the case cover as shown in Fig.4 (b) to fix the reflector surface toward the satellite radio-wave source.

3.3 Structure of the reflector

Fig.4 shows the structure of the deployed prototype antenna. Fig.4 (a) is a front view of the antenna observed in the line of sight parallel to the ground. Fig.4 (b) is a side view

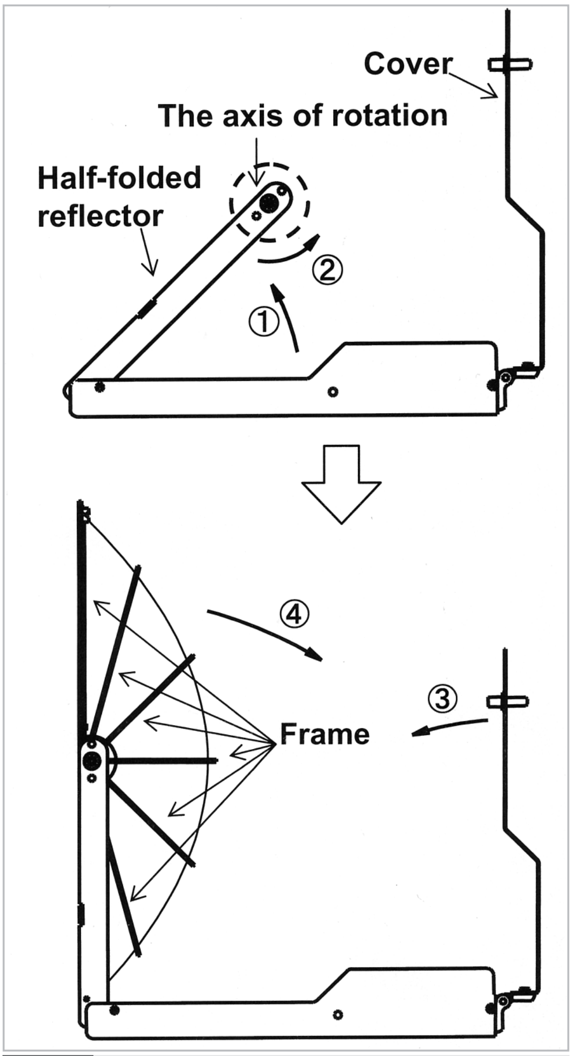
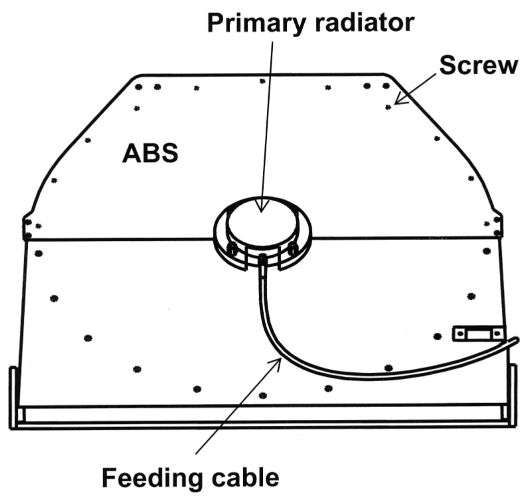


Fig.3 *Deployment mechanism of the prototype parabolic reflector antenna (side view)*

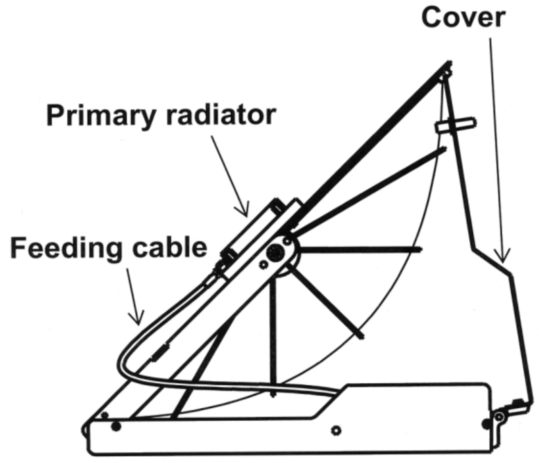
observed in a similar manner.

The reflector features an aperture diameter of 350 mm. The reflector surface is made of conductive woven fabric. Seven parabolic metal frames support this material in a parabolic shape. The back of the reflector has regularly-spaced slender pouches for the insertion of the metal frames. Two frames are inserted into the pouches to form the circumference of the reflector and five frames are inserted into the pouches to form the paraboloid surface of the reflector.

The reflector rim and the tips of the metal frames are attached to an ABS board 2 mm in thickness (Acrylonitrile Butadiene Styrene, a radio-transparent material) to hold the entire structure in place. The ABS board is designed



(a) Front view



(b) Side view

Fig.4 *Structure of the deployed prototype antenna*

to fold in half. This structure allows the user to fold the reflector into the case simply by folding the ABS board. This also renders the reflector wind and water resistant, allowing for outdoor use.

A circular hole with a diameter of 61.2 mm is cut in the center of the ABS board; the primary radiator is screwed into this hole. This method simplifies the installation of the primary radiator and allows it to be held in a steady position. The angle from the feed axis to the reflector rim is 90 degrees, that is, the F/D ratio is 0.25.

3.4 Conductive woven fabric

The conductive woven fabric used for the developed antenna has excellent softness and flexibility and is usually used as an electromagnetic interference (EMI) shield. It is of PET/Cu+Ni (base/metal) construction with a thickness of 125 μm, weight of 72 g/m^2, and a surface resistance of 0.05 Ω/sq. The reflection characteristics of the fabric were investigated; results indicate a return loss of $-$0.03 dB and a transmission loss of $-$70 dB in the S-band. These values were measured by connecting the coaxial-waveguide adapter (for the S-band) to the input/output ports of the network analyzer, inserting the conductive woven fabric between the adapters, and wrapping the adapters and the fabric with copper tape to prevent surface-current leakage.

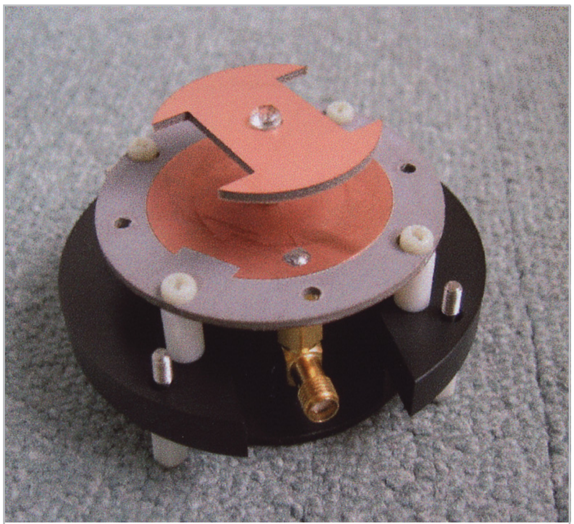
3.5 Primary radiator

In view of the limited storage capacity within the case, a microstrip patch antenna having the features such as a small size, low-profile and lightweight is used for the primary radiator. Fig.5 shows a picture of the primary radiator and its structure.

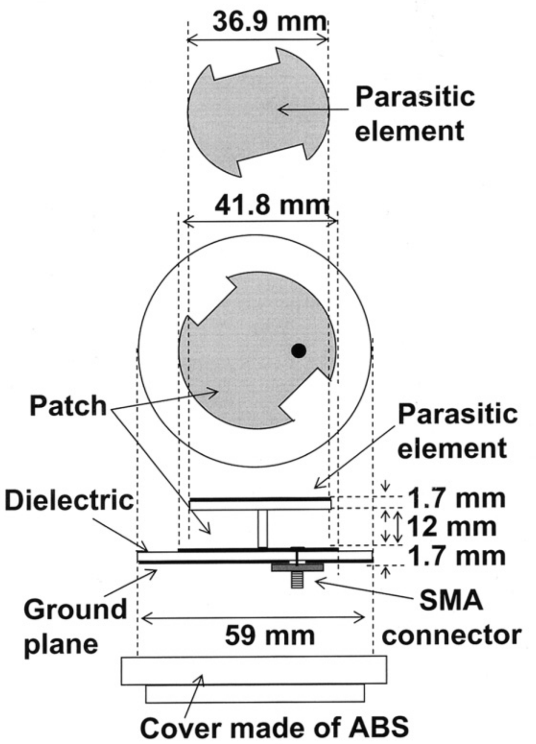
The primary radiator uses a circularly polarized single-fed circular patch antenna with parasitic element. The parasitic element is mounted at a height of 12 mm from the feed patch and fitted with a plastic spacer. The radii of the feed patch and the parasitic element are 20.9 mm and 18.45 mm, respectively. The radius of the feed patch antenna substrate is 29.5 mm. The substrate is of Arlon's PTFE with a thickness of 1.7 mm and a dielectric constant of 2.6. A similar substrate is also used for the parasitic element. The truncated segment of the parasitic element is determined by optimizing the axial ratio and the V.S.W.R characteristic when attached to the reflector. The ground of the patch antenna is enclosed with ABS resin for protection from wind and water.

3.6 RF diplexer

This antenna unit also contains a diplexer (indicated in the upper right of Fig.2 (b)). The RF diplexer is 200 mm wide, 63 mm long, and 40 mm thick. The pass band is ±15 MHz for Tx and ±25 MHz for Rx at the center frequen-



(a) Picture of the primary radiator



(b) Schematic diagram of the primary radiator

Fig.5 *Configuration of primary radiator*

cy (2657.5 MHz for Tx and 2502.5 MHz for Rx). Insertion loss is 1 dB or less in the Tx and Rx frequencies, V.S.W.R is 1.3 dB or less, and isolation is 75 dB or greater. The maximum allowable input power is 20 W.

4 Antenna electrical characteristics

Fig.6 shows the radiation patterns of the prototype parabolic antenna. The solid curve in the figure corresponds to the radiation pattern at a frequency of 2.5025 GHz, and the dashed curve corresponds to the radiation pattern at 2.6575 GHz.

As the reflector of the prototype parabolic antenna is made of flexible conductive woven fabric, random reflector surface errors are expected, despite the seven reflector supports. This random surface error causes phase fluctuation at the aperture surface and impairs the electrical performance of the antenna, including reduced gain and an increase in the sidelobe. The asymmetry observed in the sidelobe in Fig.6 is considered to be due to this random surface error.

Table 1 details the electrical performance of the prototype parabolic antenna. The measured electrical values satisfy the specifications already discussed, with verified target gain of

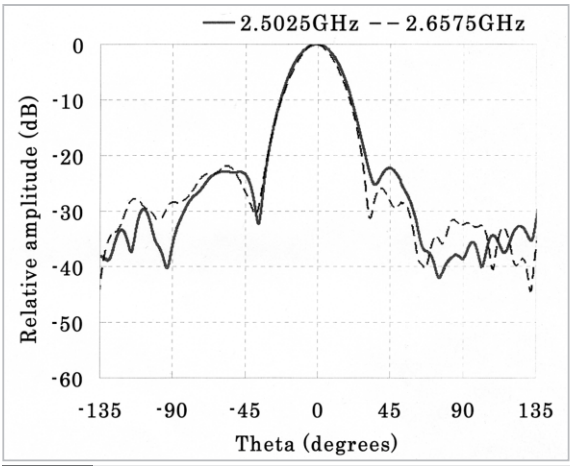


Fig.6 *Radiation patterns of the prototype parabolic antenna*

Table 1 *Performance specifications of the prototype parabolic antenna*

Frequency	Tx: 2657.5 ± 2.5 MHz
	Rx: 2502.5 ± 20 MHz
VSWR	< 1.5
Axial ratio	< 2 dB
Gain	Tx: 13.78 dBi, Rx: 13.69 dBi
	(at diplexer output)

12 dBi or greater, as required for use in the ETS-VIII high-speed data communication experiments, and confirmed compliance with remaining specifications (such as those relating to frequency band and polarization). Aperture efficiency obtained based on the gain indicated in Table 1 is approximately 30%.

In accordance with the feed antenna radiation pattern characteristics, the aperture efficiency of parabolic antennas highly depends on the tradeoff relationship between the aperture taper efficiency and the spillover efficiency. The maximum aperture efficiency is achievable when the primary radiator is set for an edge illumination of about −11 dB [3]. The maximum achievable aperture efficiency thus obtained for a single reflector with a nearly rotationally symmetric feed pattern is approximately 75%. If an open-ended waveguide is used as the primary radiator, the maximum aperture efficiency is approximately 60% [3].

Aperture efficiency obtained with the gain indicated in Table 1 is lower than that achieved with an open-ended waveguide. This may be due to various causes, including the random surface errors caused by the flexible reflector surface and the blocking loss attributable to the primary radiator. However, considering the mechanical structure of the antenna system under study (for example, 90-degree angle between the feed axis and the reflector rim), a certain trade-off in electrical performance is inevitable. We will study this problem in further depth.

5 Summary

We have reported on the structure and performance of a prototype parabolic reflector antenna mounted inside a folding case, designed as a Tx and Rx antenna for portable earth stations to be used in the high-speed data communication experiments planned for the ETS-VIII.

We have demonstrated that the use of a flexible conductive woven fabric for the antenna reflector material allows for a lightweight antenna capable of storage in a thin case that is easily carried. The electrical performance of the prototype was measured, with results indicating that the model satisfies the desired values and specifications of the ETS-VIII experiments, although aperture efficiency is somewhat low.

This antenna will be used in the communication experiments in the basic experimental phase following the launch of the ETS-VIII. We are proceeding with further preparations to ensure smooth execution of post-launch experiments, including studies on improving antenna performance and demonstration experiments using portable earth stations.

References

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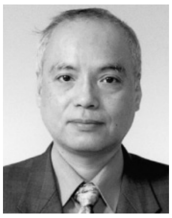

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