# Mobile Satellite Communication System High-Functioning Antenna

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The National Institute of Information and Communications Technology (NICT) developed a highly functional active phased array antenna (APAA) for a land mobile vehicle as a part of the mobile satellite communications system experiment using ETS-VIII satellite. The antenna is light weight, low profile and has a capability of automatic satellite tracking by using the electronic beam scanning. The effectiveness of the antenna was confirmed by the tests of basic performance, tracking performance and transmission performance by using the satellite signal.

## 1    Introduction

The Active Phased Array Antenna (APAA) is a high-functioning antenna that electronically controls the beam, changes directionality without mechanically moving the antenna and performs high-speed scanning. It is expected to be applied to mobile satellite communications since it can be configured to be thin and light-weight. It was mounted on a satellite in the Ka-band[1]. With regard to mounting on the mobile stations, it was mounted on a helicopter for communication experiment[2]. Both cases showed excellent performance. However, it has not become universal due to the high cost. NICT has accumulated practical examples for various type of APAA[2]–[4]. In an effort to realize the APAA, we have developed on-board S-band active phased array antenna (APAA) for experiments in mobile satellite communications with ETS-VIII[5]. For evaluating the effectiveness of this APAA, we obtained basic characteristics using satellite signals of this antenna, and tracking characteristics and transmission property in on-board "driving tests". This paper reports these results.

## 2    S-band Active Phased Array Antenna[5]

Figure 1 shows the appearance of the APAA that was developed (with the radome removed). This APAA is suitable for mass-production since it is modular. It weighs 18.7kg and has a thickness of 117mm. It has the characteristics of a low position in view of mounting it on the roof of a vehicle for on-board use. As the APAA was used in an experiment using ETS-VIII, it was designed so that the desired gain of 12dBi or more is obtained within ±10 of and elevation angle of 48 degrees in anticipation of satellite angle fluctuation and error due to the movement of the vehicle. A self-diplexing antenna[6] for transmission and reception using a circular patch and a ring patch was adopted in the element antenna. Array configuration using 18 elements allows 12dBi or more gain in the direction of satellite. The tracking speed is 30 degrees /sec so that it is operated correctly by the angular speed in vehicle turning. Figure 2 shows a single element unit. One unit consists of s transmission/receiver antenna corresponding to one
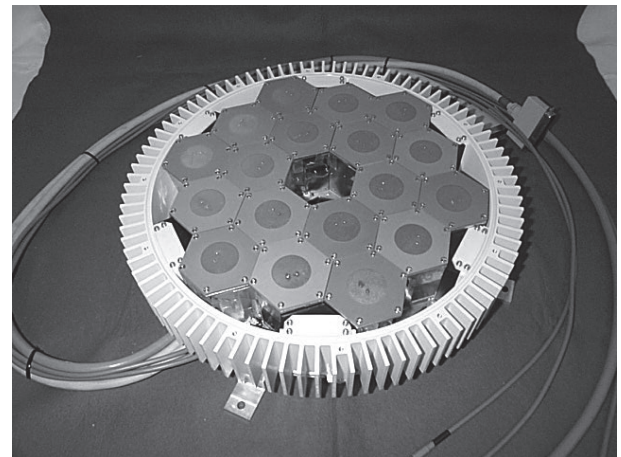


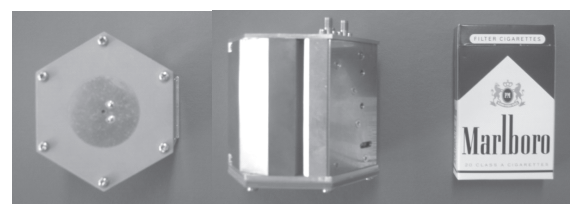**Fig. 1**    S-band active phased array antenna



**Fig. 2**    One element unit

element, a transmission solid state power amplifier (SSPA), a reception low noise amplifier (LNA) and transmission/ reception phase shifters. The modular structure can be disassembled into single elements, so it is easy to add and fix elements. A continuously variable phase shifter using a double balanced mixer is adopted for a shifter, which alleviates quantization error. Since the amplitude of each element signal can be changed individually by changing the output level of the phase shifter, non-uniform amplitude distribution can be given to an array antenna. This function can be used for suppressing side lobe level of the radiation pattern of an array antenna.

This APAA uses the closed loop method for tracking a satellite, where the satellite signal is automatically tracked using the reception signal of the receiver antenna. Transmission from the transmission antenna occurs only when the receiver antenna is tracking the satellite. Transmission is automatically stopped during non-tracking status (e.g., automatic search mode). The direction of the transmission antenna is the same as that of the receiver antenna.

Figure 3 shows the operation flow of closed loop tracking. The operation flow is characterized by multiple operation modes corresponding to signal conditions. At first, initial searching is performed for the direction of the satellite by the wide range search mode. If threshold level set is detected, the operation flow goes tracking mode. In the tracking mode, directionality is finely changed with the azimuth angle and elevation angle to track the maximum reception level direction. If the reception level goes under the threshold, it is considered that the signal level has been lost. In that case, the tracking range is enlarged gradually by three searching modes. If the signal level is detected again, the flow returns to tracking mode. The three searching modes include the wait mode (antenna directionality is correct, however, satellite signal is stopped; directionality is maintained for some time), the local search mode (in the case of a vehicle, the change of satellite elevation angle is small so the elevation angle is not changed and only the azimuth angle is scanned to search for the signal), and the global search mode (the direction of the satellite is determined by the two axes including the azimuth angle and the elevation angle). There are two types of signal for tracking. In "sum pattern" signal, tracking is performed so that total sum of the array reception signal is maximum. In "difference pattern" signal, an array pattern (null) is formed in the direction of the bore site direction and controlled so that the signal level is zero. Other than
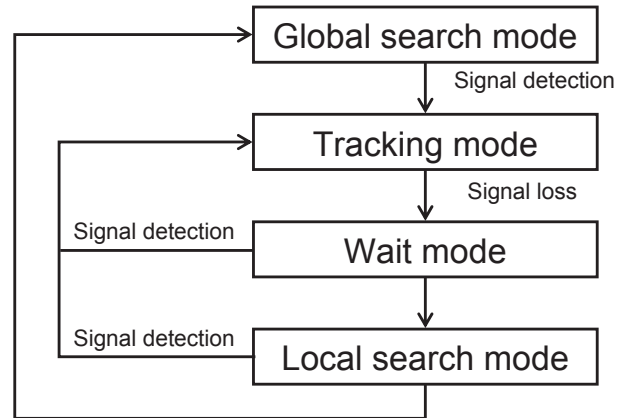


**Fig. 3** Closed loop tracking operation flow



**Fig. 4** Appearance of the antenna on the vehicle

these, open loop automatic tracking is possible, where the satellite's azimuth and elevation is supplied from outside. As shown in Fig. 4, this antenna is mounted on the vehicle, and tracking characteristics, etc. are researched as shown in Section **3**.

## 3 Experiment

### 3.1 Basic characteristics

(a) Radiation pattern

Figure 5 shows the receipt of the continuous wave beacon transmitted from ETS-VIII, and the result of obtaining the sum pattern and difference pattern in order to evaluate the radiation pattern when the APAA is operated. The peak of the sum pattern width is approximately 30 degrees. The peak of the sum pattern and null of the difference pattern are almost in the same direction. Thus, it was confirmed that the radiation pattern was normally formed in usage.
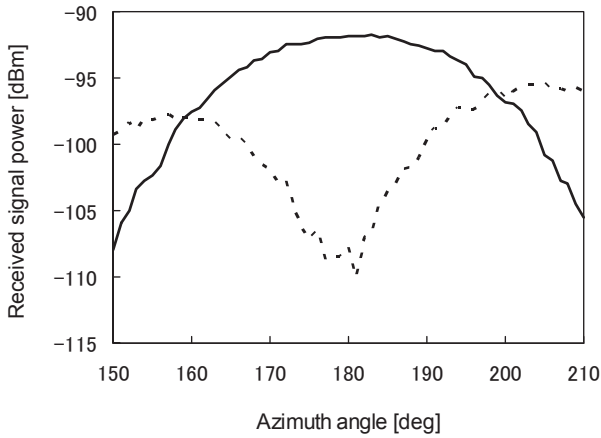
**Fig. 5**  AZ plane pattern



**Fig. 6**  An example of angular characteristics of tracking error of sum pattern

(b)  Basic tracking characteristics

The continuous wave beacon transmitted from ETS-VIII was received by the APAA mounted on the rotation platform in the azimuth direction (AZ) and elevation direction (EL). Tracking characteristics were verified by changing the rotational speed of the rotation platform. Tracking error was defined as the difference between the rotational table indication and angle detected by the APAA. The tracking error for sum pattern tracking and difference pattern tracking was obtained. Figure 6 shows AZ angle vs. tracking error at a rotation speed of 30 degrees/sec of the sum pattern as an example of measurement. Table 1 shows the rms value of the tracking error in tracking speed. The tracking error in sum pattern is approximately 2 degrees. The tracking error in difference pattern is 2-3 degrees. In each case, the error is small compared to the beam width, and there is no dependency on tracking speed. Figure 7 shows tracking error dependency on $C/N_0$ (received signal power vs. noise power density ratio). The higher the $C/N_0$ of received signal, the lower the tracking error. From these results, it is confirmed that the APAA has enough basic tracking performance.

## 3.2  Tracking characteristics during driving

In order to evaluate the tracking characteristics of the APAA using satellite signals, a continuous wave beacon was transmitted from the ETS-VIII satellite and tracking characteristics of the signals received by the APAA were obtained for the closed loop method including the sum pattern and difference pattern methods using an antenna on a vehicle driving in an urban area of Kashima city, Ibaraki prefecture. Figure 8 shows the test course.
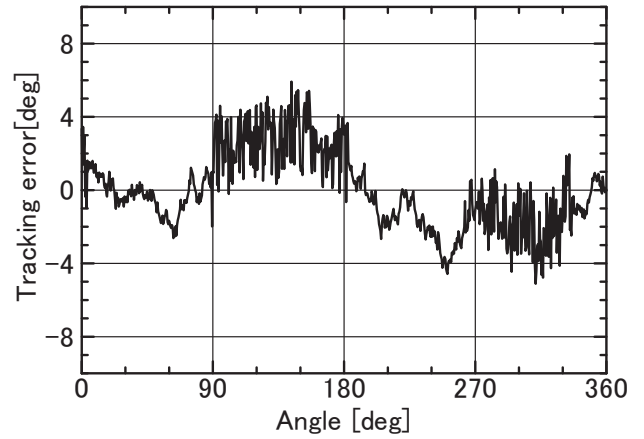
Table 1  Tracking error measurement results

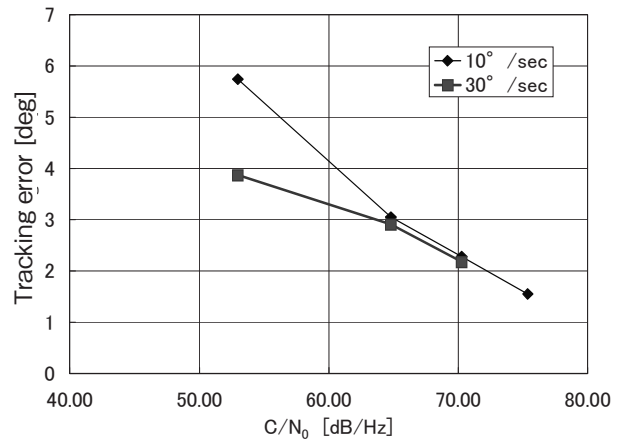| Tracking angular velocity [deg/sec] | Tracking error [deg] (sum pattern) | Tracking error [deg] (difference pattern) |
|---|---|---|
| 10 | 2.3 | 3.1 |
| 20 | 2.2 | 2.2 |
| 30 | 2.2 | 2.9 |



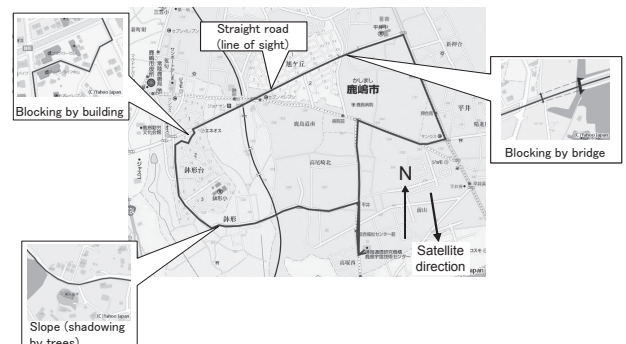**Fig. 7**  Dependency of tracking error on $C/N_0$



**Fig. 8**  Test course (The map in the figure is used by permission of yahoo.)

Environments evaluated were; a line-of-site environment where the satellite is seen to be without obstacles, a blocking environment where radio waves are blocked by buildings or elevated bridges, or a shadowing environment where some of radio waves from the satellite are blocked by trees. Values were obtained for the received power value during closed loop tracking, the level meter value of the APAA (it is correlated with the received power value and recorded as reference value), and the AZ and EL values of antenna directionality. As the reference value of direction of the satellite during driving, the tracking system by the open loop method[8][9] using satellite direction information from the magnetic sensor and the vehicle speed pulse sensor was constructed, to obtain the AZ value of satellite direction (an EL value was not obtained since the vehicle drove on flat land). In the measurement values, the level meter value, the AZ and EL values are synchronized. The level meter value and received power value have a time lag of 2-4 seconds due to the difference between both clocks. However, they are correlated.

### (a) Visibility environment

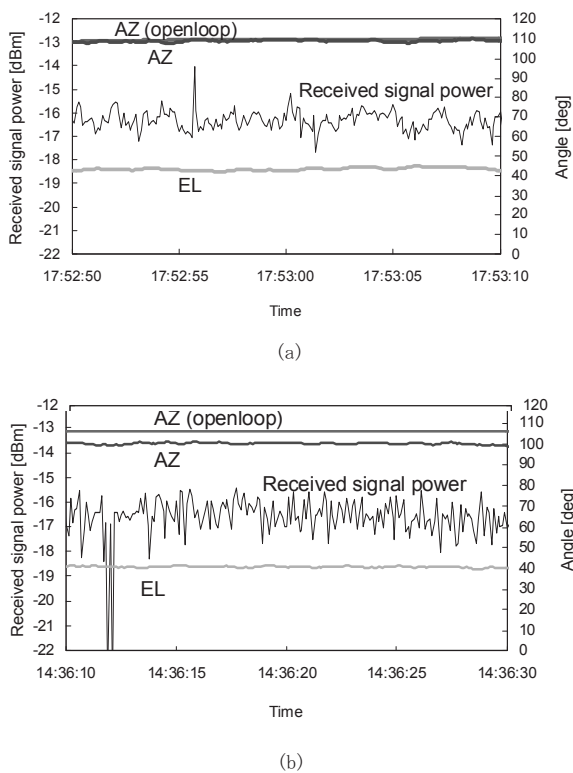Figure 9 shows the tracking characteristics during straight driving concerning the visibility environment. In the figure, each of the received signal powers, AZ, EL, and AZ (open loop) indicates the received power value during closed loop tracking, the AZ and EL values of antenna directionality and the AZ value of satellite direction by open loop tracking. In the sum pattern methods and difference pattern methods, stable received power is recorded and the satellite is tracked well. The fluctuation in received power of the closed loop method is larger than that of the open loop method (not shown in this paper). This arises because directionality is continuously changed by the step track method in closed loop tracking mode.

### (b) Blocking by buildings and elevated bridges

Figure 10 shows the tracking characteristics of various tracking methods when the satellite was blocked by buildings. The level meter in the figure indicates the level meter value of the APAA (range: 0-100%). Fluctuation characteristics of the AZ and EL of sum pattern and difference pattern tracking show activation of the wait mode (tracking is stopped at the same position), the local search mode (automatic searching is performed only by AZ) and global search mode (automatic search is
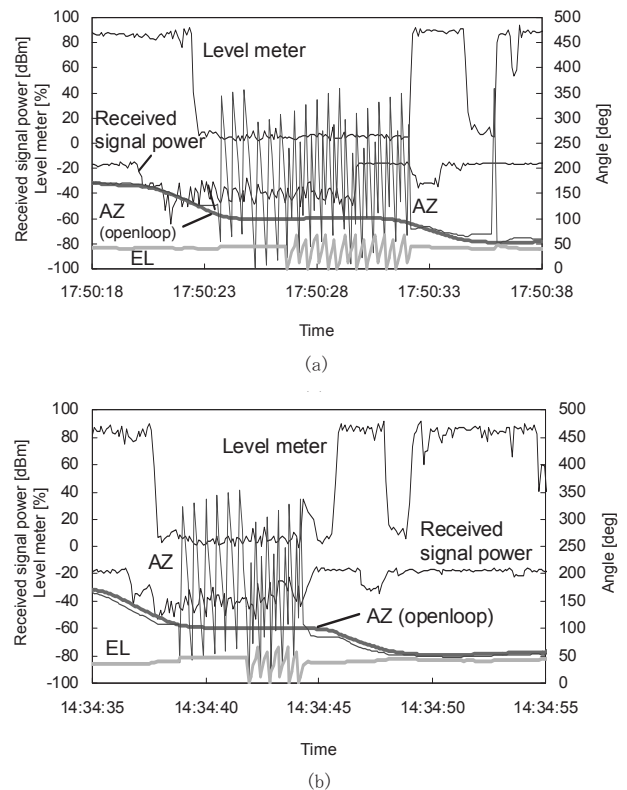


(a)



(b)

**Fig. 9** Tracking characteristics of straight driving in a good visibility environment
(a) Sum pattern method
(b) Difference pattern method



(a)



(b)

**Fig. 10** Tracking characteristics when blocked by buildings
(a) Sum pattern method
(b) Difference pattern method

performed by AZ and EL). The AZ indication value after received power is recovered is almost the same as the AZ indication value of the open loop measured at the same time. From the result shown above, it was confirmed that tracking control of the sum/difference pattern functioned normally.

Figure 11 shows the tracking characteristics of various tracking methods when the satellite was blocked by elevated bridges. Received power is reduced twice as a result of blocking by two elevated bridges. In the first blocking for 1 second, the received power was recovered by performing one AZ automatic searching (local search mode). In the second blocking for 4 seconds, the AZ and EL were automatically searched (global search mode) and the received power was recovered. The AZ indication value of sum/difference pattern was almost the same as the AZ indication value of the open loop measured at the same time. From the result shown above, it was confirmed that tracking control of the sum/difference pattern was functioning normally.

(c) Shadowing by trees

Figure 12 shows the tracking characteristics in an environment shadowed by trees. Received power is reduced

by shadowing of trees for the sum/difference pattern. In the latter half of the time period where received power is significantly reduced, the AZ and EL are automatically searched (global search mode) and the received power is recovered. It was confirmed that the tracking control of the sum/difference pattern was functioning normally. It was also confirmed there was no large difference from the sum/difference pattern of automatic search operation.

## 3.3 Transmission characteristics

In order to confirm the operation of the transmission function of this APAA, the transmission action from reduced reception level by blocking to recovery was evaluated.

In order to measure the reception and transmission links at the same time, the forward link (Ka-band Kashima earth station → ETS-VIII→ S-band APAA) and the return link (S-band APAA → ETS-VIII→ S-band Kashima earth station) were used. The forward link was used for tracking the APAA and tracking conditions (power, antenna directionality) were recorded. Transmission was performed from the APAA by the return link. It was received by the S-band Kashima earth station and its power was recorded.

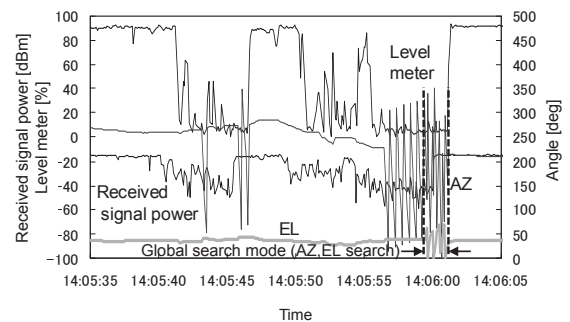An artificial blocking situation was made by driving in
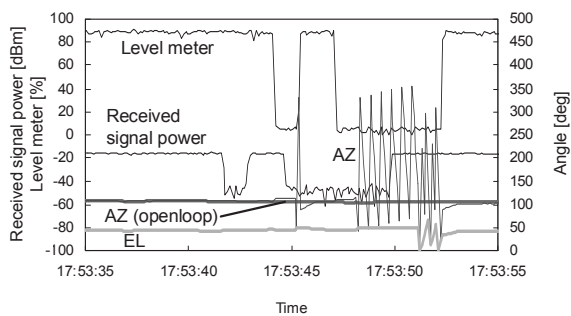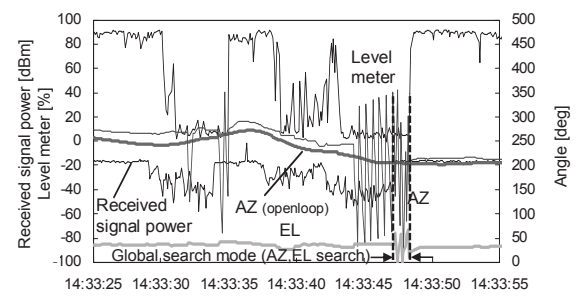


(a)
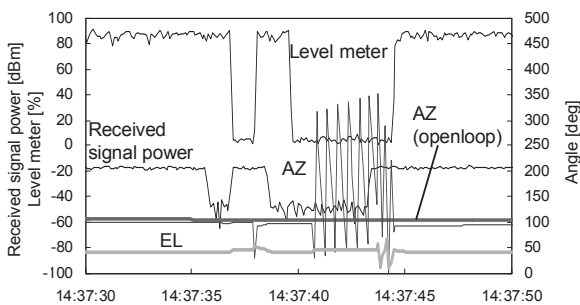


(b)

**Fig. 11** Tracking characteristics when blocked by elevated bridges
(a) Sum pattern method
(b) Difference pattern method



(a)



(b)

**Fig. 12** Tracking characteristics during shadowing by trees
(a) Sum pattern method
(b) Difference pattern method

the Kashima Space Technology Center, NICT. Figure 13 shows the results of evaluation by closed loop tracking (difference pattern) with open loop as reference. During difference pattern tracking, the earth station reception level follows shut-off to recovery of reception level of the onboard APAA. This indicates that transmission was stopped during blocking and re-started when reception level was recovered. Based on the fluctuation characteristics of antenna directionality, tracking stopped when reception level was cutoff, antenna directionality was searched, and transmission restarted after blocking was recovered.

In open loop tracking, shown as reference, reception level reduction by blocking and recovery are observed on the side of the onboard APAA. This arises from the antenna is always directed to the satellite position calculated by the high functioning antenna using information from magnetic sensor and vehicle speed pulse sensor in the case of open loop tracking. The same change of reception level is observed on the earth station side. That happens because the open loop tracking does not stop the transmission signal. Meanwhile, the closed loop tracking enters searching mode when the reception level of the onboard APAA is less than the threshold. So, level fluctuation is steep.

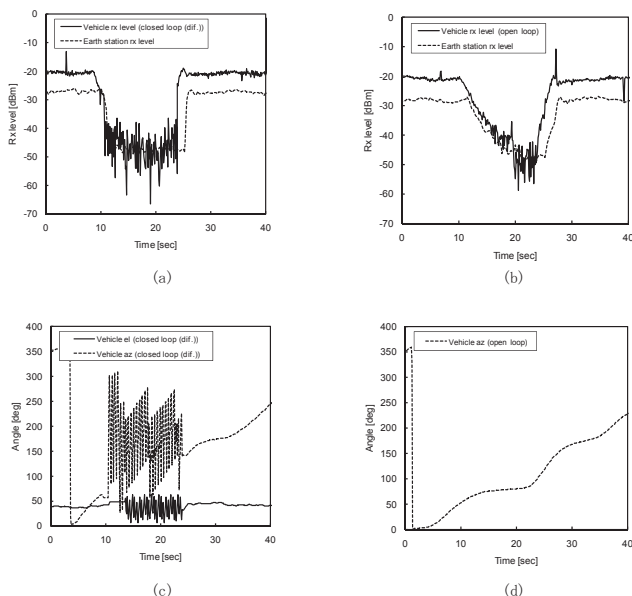As the above results show, the transmission function of this APAA is effective.



**Fig. 13** Antenna directionality and reception level during blocking
(a) Receipt level of closed loop tracking
(b) Receipt level of open loop tracking
(c) Antenna directionality of closed loop tracking
(d) Antenna directionality of open loop tracking

## 4 Summary

As part of the mobile satellite communication experiment using ETS-VIII, we developed a thin and light weight high functioning APAA onboard vehicle. In this APAA, the closed loop tracking method is used for automatically tracking satellite direction and multiple search modes that enlarge search range gradually to realize an effective resolution of satellite direction are adopted. In order to confirm the characteristics of this APAA, basic characteristics of this antenna were obtained using satellite signals, and tracking and transmission characteristics by an on-board "driving test". With regard to basic characteristics, a radiation pattern was normally formed in usage condition, the tracking error was acceptably small compared to beam width in a tracking property test using a rotation table, and the APAA did not have tracking speed dependency. So, it was confirmed that this APAA had adequate basic performance. For tracking characteristics, tracking action was evaluated by driving on the test course in Kashima city, Ibaraki prefecture. As a result, the stable receipt power value was recorded both in sum/difference pattern tracking when the satellite could be seen without obstacles. In a blocking environment where radio waves from the satellite were blocked by buildings and elevated bridges, or a shadowing environment where a part of the radio waves from the satellite were blocked, a signal was recovered through automatic search by shifting three search modes (wait mode, local search mode and global search mode). From this result, we can see that the tracking action of this APAA was functioning effectively. With regard to transmission characteristics, the blocking condition was made artificially using buildings and closed loop tracking (difference pattern) was performed. As a result, transmission stopped when blocking occurred and restarted when recovered, as the design of this APAA. As the above results show, it was confirmed that this APAA functioned well as a mobile satellite communications antenna.

*References*

1  M. Yajima, T. Kuroda, T. Maeda, M, Shimada, T. Hasegawa, S. Kitao, and K. Hariu, "Ka-band Active Phased Array Antenna, " Journal of the NICT, Vol. 53, No. 4, pp. 49–55, Dec.2007. (in Japanese)

2  Y. Fujino, M. Satoh, S. Nagai, S. Taira, Y. Ozaki, E. Watanabe, M. Sawa, and Y. Tanaka, "Development of Helicopter Satellite Communication System for the Disaster Information Transmission," IEICE Trans. Com., Vol. J91-B, No. 12, pp. 1611–1619, Dec. 2008. (in Japanese)

3  S. Kitao, H. Nakaguro, A. Akaishi, and N. Kadowaki, "Development Results

of Partial Model of a Ka-band Active Phased Array Antenna for Gigabit Satellite," Technical Report of IEICE, Vol. AP98-114, pp. 51–56, Nov. 1998.

4 M. Tanaka, S. Yamamoto, N. Obara, and H. Saito, "Ka-Band Mobile-Vehicular Active Phased Array Antenna for Mobile Satellite Communications," Journal of the CRL, Vol. 46, No. 4, pp. 127–134, Dec. 2000. (in Japanese)

5 A. Miura, S. Yamamoto, and M. Satoh, "Land Mobile Station for ETS-VIII Mobile Satellite Communications Experiments," Journal of the CRL, Vol. 49, Nos. 3/4, pp. 145–151, Dec. 2003. (in Japanese)

6 T. Shiokawa, F. Watanabe, M. Yasunaga, N. Goto, Y. Chatani, and H. Abe, "Microstrip Array Antenna for Aeronautical satellite Communications," Technical Report of IEICE, Vol. AP86-60, pp. 23–27, 1986. (in Japanese)

7 A. Miura, Y. Fujino, S. Taira, N. Obara, M. Tanaka, T. Ojima, and K. Sakauchi, "S-band active phased array antenna with analog phase shifters using double-balanced mixers for mobile SATCOM vehicles," IEEE Trans. Antennas Propagat., Vol. 53, No. 8, pp. 2533–2541. Aug. 2005.

8 S. Yamamoto, K. Tanaka, K. Suzuki, and H. Wakana, "An Antenna Tracking Method for Land-Mobile Satellite Communications System," Technical Report of IEICE, SANE94-54, pp. 35–41, Oct. 1994. (in Japanese)

9 S. Yamamoto, K. Tanaka, H. Wakana, and S. Ohmori, "An Antenna Tracking Method for Land-Mobile Satellite Communications System," IEICE Trans. Com., J77-B-II, No. 6, pp. 307–316, June. 1994. (in Japanese)

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