VEHICULAR ANTENNAS FOR SATELLITE COMMUNICATIONS

(Survey)

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Abstract

Antennas mounted at vehicles for satellite communications and direct broadcasting service are considered in the paper. The antennas have scanning beams with high gain as well as satellite tracking capabilities. Such antenna provides a wideband communication link via a satellite while a vehicle is in motion. Antennas are mounted on cars, buses, trains, ships, airplanes, *etc*.

General requirements to vehicular antennas are discussed in the paper. Main concepts of vehicular tracking antenna design are described. They are: active phased array antenna with 2-D electrical beam steering, planar array with mechanical rotation in azimuth and 1-D electrical scanning in elevation, and a reflector antenna or a planar array on a 2-D positioner providing mechanical beam scanning.

A survey on vehicular antennas developed worldwide in last decades is presented. Main trends of the antennas are discussed.

Keywords: Vehicular antenna, mobile antenna, low profile antenna, satellite communications.

1. GENERAL REQUIREMENTS TO VEHICULAR ANTENNA TERMINALS

In recent years, the wireless communication service has advanced from fixed narrow bands to mobile broadband services. Simultaneous work at transmitting (Tx) and receiving (Rx) modes in mobile communications systems for a long time is provided by application of two approaches: using of independent transmission and receiving antennas, combined Tx/Rx antennas with feeders including frequency filters and, if possible, splitters of orthogonal polarizations of transmitted and received signals.

Modern systems demand simultaneous work of many communication channels. The mobile antenna system should provide wireless internet services, wireless LAN and multimedia services, as well as high quality broadcasting services simultaneously at moving vehicles via satellites. In order to have a high speed of data transmission it is necessary to have enough high values of EIRP (product $P \times G_T$) and ratio G_R/T (P is a radiated power, G_T and G_R correspond to equivalent antenna gain under transmission and reception modes, T is a noise temperature). These parameters determine energy potential of the terminal.

It is necessary to ensure simultaneous functioning of the channels in *different frequency ranges* with a wide band in each of them. For increasing throughput of data transmission in the channels, signals of two orthogonal polarizations are used. These tendencies aggravate the problem of interference protection. For its decision low side-lobe level (SLL) of the antenna radiation pattern and a high isolation between the channels including polarization isolation are required.

Tracking should maintain direction to a satellite. Compactness of antenna demands to combine different functions in common devices (for example, simultaneous reception of information signals and creating the tracking channel).

High-production technology and modern electronic components are required for high quality of the antennas, but the commercial systems should not be very expansive.

So, it can be possible to formulate general functions and restrictions of antennas as follows:

Functions:

- Receive (transmit) signals from (to) satellites.
- Provide high gain for high speed data rate. (G ~ 25 - 40 dBi).
- Track satellite during a vehicle evolutions.

Restrictions:

- Low sidelobes, high isolation of channels.
- Low profile and streamline design.
- Small size and weight in case of small vehicles.
- Low power consumption.
- High reliability.
- Acceptable price.

The antenna design is determined by parameters of the antenna environment, in particular, limit inclination of a vehicle, angular velocity and speed of a vehicle. Operating temperature as well as available height are very critical too. All these parameters depend on a function and type of a vehicle (Table 1).

Table 1. Antenna Environments at Vehicles

Parameter	Min. value	Mid. Value	Max. value
Angular velocity, deg/s	10 (ship, train)	30 (bus, airplane)	100 (car, cutter)
Inclination, deg	6 (bus, train)	15 (ship, car)	25 (airplane)
Available height, m	0.1- 0.2 (train, car)	0.5 (airplane, bus, cutter)	1-2 (ship)
Speed of a vehicle, km/hour	50 (ship)	Up to 150 (car, bus, cutter)	400 (train), 1000 (airplane)
Operating temperture, C	-30/+50 (ship, train, bus, car)	-50/+60 (ship, train, bus, car)	-70/+70 (airplane)

2. Versions of tracking. Types of vehicular antennas

Mechanical control of the antenna (reflector antennas, passive arrays) by means of 2-D or 3-D positioner as opposed to wholly Az&El electrical scanning represent two ultimate cases of antenna tracking. The antennas form pencil beam in both versions.

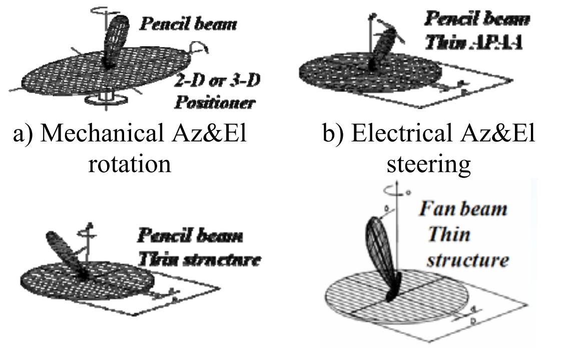
In the first case (Fig. 1a), the angular velocity of the antenna rotation is restricted by its persistence. More and more powerful positioners are required as the angular velocity and acceleration of a vehicle are increased.

Other ultimate case (Fig. 1b) provides practically inertialess beam scanning but it demands many expensive phase shifters (PS) in channels of phased array antennas. Insertion losses of PS and feed network lead to gain degradation of phased array antennas (PAA) in Tx-mode and Rx-mode. Active phased array antennas (APAA) including high power amplifiers (HPA), low noise amplifiers (LNA) and PS are necessary to obtain available energetic parameters.

Version 1a permits to direct the beam at arbitrary angle wirh respect to horizon, in particular, near the horizon. A problem arises in case of low-profile antennas which are placed on the roof of a car or a train because the antenna gain decreases strongly while the beam is inclined far from zenith. Hence it is dequired to form an appropriate conical radiation pattern (RP) of APAA element in version 1b. It is a hard task.

A compromise can be achieved if we use combined mechanical & electrical scanning pencil beam (Fig. 1c). In this case, array elements or subarrays can be inclined in order to increase the gain in directions far from horizon.

At last, a simplified mechanical control can be applied due to fan beam instead of pencil one. In this case a single Az positioner is sufficient (Fig. 1d). In both versions, a maximum of antenna RP is necessary to direct to a satellite or its vicinity including satellites near horizon.



a) Mechanical Az&El rotation
b) Electrical Az&El steering
c) Mechanical Az rotation Electrical El steering
d) Mechanical Az rotation No El steering

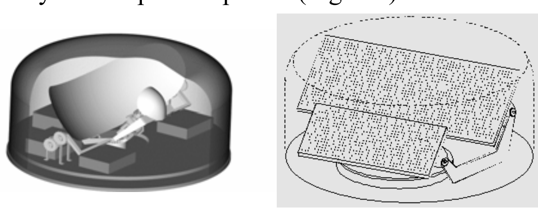
Fig. 1. Versions of tracking

From the above consideration we can conclude:

- Mechanical beam steering is acceptable for slow vehicles.
- Electrical satellite tracking is often required for fast vehicles
- Conical or biconical serving angle area is required Az - 0-360°, El_{min}~10º-30 º, El_{max}~60º-90 º
- Low profile antennas are indispensable in some applications.

Reflector antennas with mechanical beam steering occupy an important place in the area of mobile communication systems. It is possible to achieve a high gain and an admissible side-lobe level at minimum cost. Single reflector and Cassegrain antenna are widely known classic types. Lately, a shaped dual reflector antenna with an elongated main reflector and circular subreflector were applied in several projects. It has a low profile design along with a high gain fan beam. A feed operates at both a linear and a circular polarization and provides a low cross-polarization.

Important advantage of reflector antennas is a possibility to combine Tx- and Rx- modes as well as several frequency bands (Fig. 2a) while array antennas usually have separated panels (Fig. 2 b).



a). Joint Tx-&Rx-antenna
b) Separate Tx-panel&Rx-panel

Fig. 2. Versions of antennas with mechanical Az&El rotation for Tx and Rx channels

Rotary planer arrays permit to obtain extremely low profile that is very important for cars and trains.

Passive and especially active phased array antennas with only electrical scanning are attractive for the future due to low profile, high flexibility and no mechanical parts.

Many companies develop antennas for mobile communications. By-turn, each company has a large product mix. Below, only some examples are considered.

3. Reflector Antenna Vehicular Terminals

3.1. Single reflector antennas

For instance, vehicular reflector antennas for Ku-band are available from KVH Co., USA [1] (Fig. 3). Options: TracVision L3, G4, G6, G8. Aperture size of L3 is 30×60 cm. Beam pointing is performed by 2D- positioner. Long term tracking – step-tracking is used. Short term tracking – gyro.

Fig. 3. Antennas KVH TracVision.

3.2. Dual reflector antennas

This type of the reflector antenna is the most called-for. Some results of various antenna developments are given below.

● Mil-Sat proposes in markes SeaTel antenna options: 4010 – 5010, 6009, USAT 24, USAT 30. Marine Stabilized Dual Reflector Antenna System [2].

Fig. 4. Antennas of SeaTel

In particular, the model 4996 T (Fig.4), Ø 1.2 m 3-D Stabilized platform provides good satellite tracking. For this model: receive gain is 41.5 dBi @ 11.85 GHz, transmit gain is 42.5 dBi @ 14.25 GHz. Transmit Cross-Polarization Isolation (XPD) is > 35 dB @ 13.75 to 14.5 GHz.

● "The Connexion By Boeing SM (SBB)", 2003. Ultra-low Profile Airborne Reflector Antenna Subsystem for Broadband Satellite Communications was designed [3] (Fig. 5). G/T ~ 8 dB/ , EIRP ~ 47 dBW, SLL ~ -10 dB, XPL ~ -15 dB.

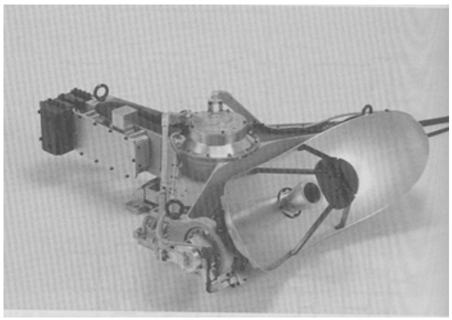


Fig. 5. Airborne Antenna for "The Connexion By Boeing SM (SBB)"

● Institute for Communications and Navigation, Germany, Alenia Spazio, Italy. 2003.

Dual Reflector Ku-band Antenna Terminal Mounted on Train [4] is shown in Fig. 6. Elongated main reflector size – 105 x 45 cm, Antenna Gain - 37.5 dBi, G/T = 11.5 dB/K, EIRP = 42.8 dBW.

Fig. 6. Antenna for train

● A number of novel antennas for vehicles were developed by ETRI (Korea) and APEX (Moscow) (this is a subsidiary of JSC "Radiophyzika"). Antennas are shown in Fig. 7 – 10.

One is mobile tri-band antenna system designed in 2005. The antenna [5] consists of shaped dual-reflector, a tri-band feed with a dual-band polarizer and orthomode transducer (OMT). The feed radiator comprises two parts: a dielectric rod for the Ka/K-bands and four patch elements operated at Ku-band. Main electrical performances are given in Table 2.

Table 2. Parameters of Tri-Band Antenna

Frequency band	Gain, dBi	Efficiency	Sidelobe level, dB
Tx: *Ka*-band	39.6	0.54	- 22.6
Rx: *K*-band	36.5	0.57	- 18.9
Rx: *Ku*-band	29.3	0.34	- 21.4

The antenna prototype is shown in Fig. 7.

Main features of the antenna:

- Tracking channel is combined with *Ku*-band channel.

- Cross polarization @ bore-site is minus 18.9 – 22.6 dB.
- An off-set scheme with a partial blockage which can provide a reasonable height of the antenna and side lobe level of RP has been chosen.

The antenna diameter is 0.7 m, height – 0.4 m.

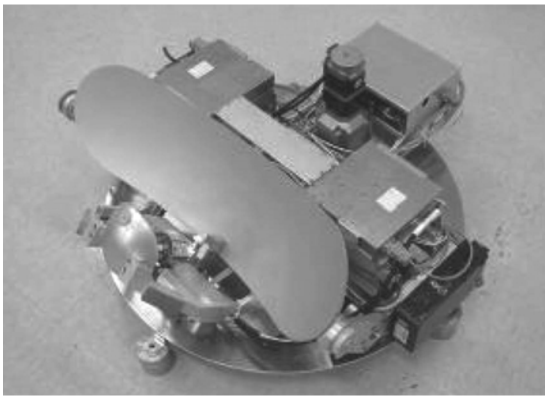


Fig. 7. Tri-band antenna system.

The antenna is designed to meet the international regulations for very small aperture terminals (VSAT) including ITU-R S.465-5 for beam pattern including side-lobe level.

Both indoor and outdoor tests of the antenna prototype have been performed. The mobile antenna system operates via the geo-stationary satellite Koreasat-3.

Similar four-band mobile antenna to be mounted on trains was designed in 2007.

3.3. HYBRID ANTENNAS

Hybrid antenna (HA) consists of a reflector prviding high gain and a small feed array for limited electrical beam steering.

● The HA for communication at Ka-band was designed in 2003 – 2004 by ETRI and APEX [6] (Fig. 8).

Fig. 8. Ka-band hybrid abtenna

The HA has the shaped reflector and the feeder having a linear phased array with 1x8 radiators. Reflector shaping is applied for the performance optimization. The number of feeder elements is optimized too.

HA provides electrical control of a beam pattern within ±3° around the basic angle of 45° in elevation as shown in Fig. 9.

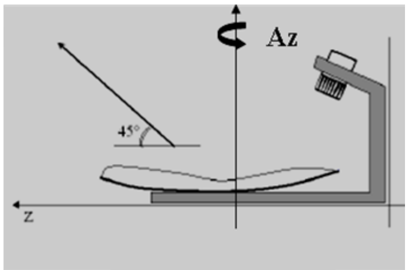


Fig. 9. Scheme of HA

Parameters of the antenna are given in Table 3.

Table 3. Parameters of the HA with shaped reflector and linear array.

Frequency, GHz	Gain, dBi	Polarization	L×W×H Cm
30.085-30.885	35	LHCP	60×50×50

● Dual reflector HA (ETRI, APEX, 2003-2004). This high gain antenna consists of a parabolic main reflector, a rotational flat subreflector and a planar phased array as a feeder [7]. Two-dimensional beam steering is obtained by means of the subreflector rotation (rough beam pointing) and phase control of the feed array consisting of 20 elements (fine beam pointing). The antenna prototype is shown in Fig. 10.

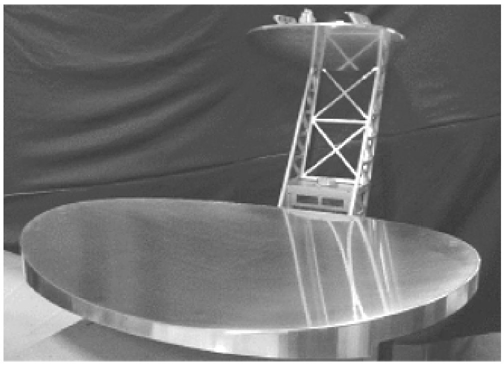


Fig. 10. Dual reflector hybrid antenna

Parameters of the HA are given in Table 4.

Table 4. Dual reflector HA parameters

Frequency, GHz	Gain, dBi	Polarization	Size,cm D=H
Tx: 30.085 – 30.885	45 (min)	LHCP	70
Rx: 20.355 – 21.155	43 (min)	RHCP	

Main features of the antenna:
- Two-dimensional beam steering within ±2° with respect to 45 ° elevation is realized by the subreflector and feed array.
- Sidelobe level meets ITU-R s.465-5,
- Cross polarization level 24 dB Min.

4. ROTARY PLANAR ARRAYS

Many projects, for instance [8-9], are devoted to this antenna type.

● The first collaborative work of ETRI and APEX was connected with rotary array [8]. The APAA was intended for reception TV-programs from the direct broadcasting satellite (DBS) at moving vehicles. Nevertheless this experience serves as a good basis for developments of communication systems. The APAA (Fig. 11) consists of active modules containing patch subarrays, low-noise amplifiers, and *pin*-diode phase shifters.

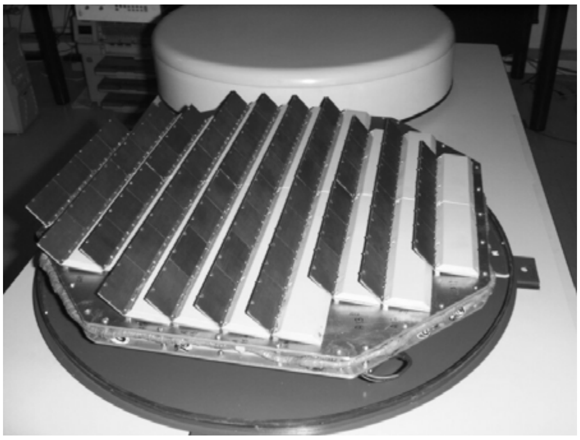


Fig. 11. Ku-band antenna for DBS (ETRI, APEX)

Antenna is installed on a mechanical positioner which gives 0^O-360^O azimuth beam pointing. Electrical beam steering $\approx 45^O \pm 15^O$ in elevation and $\pm 2.5^O$ in azimuth is realized. In *Ku*-band, the APAA forms two beams: one serves for TV reception, the other provides search and two-dimensional satellite tracking. The antenna has G/T = 10 dB/K. Its height is 115 mm, diameter - 750 mm.

Later, DBS antenna of a smaller size as well as Tx and Rx rotary active arrays for satellite communications were designed by ETRI.

Similar antenna for Ka-band was designed in Japan [9].

● Ultra low profile Tx-&Rx-PAA for Ku band [10] was designed in University of Waterloo (Fig. 12). It has

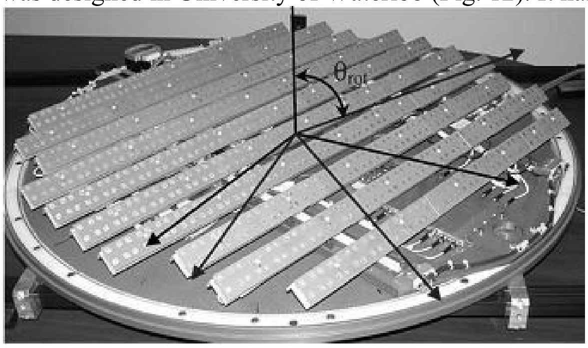


Fig. 12. PAA on the rotary platform

diameter 830 mm, height is 50 mm. Electrical beam steering in elevation around 45^O is due to phase control. Antenna gain is 31.8 dBi.

● The company ThinKom, USA, commercialy produces low-profile antenna for Ku-band communications [11], shown in Fig. 13.

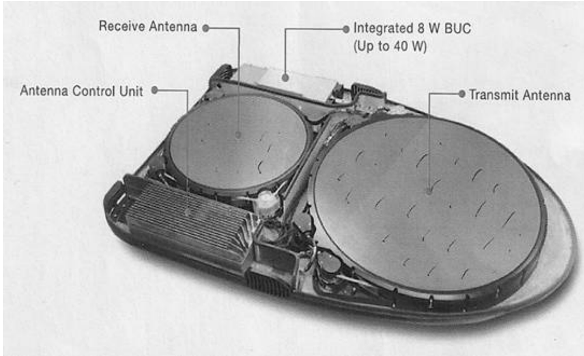


Fig. 13. The ThinSat®300 antenna system

Main parameters are presented in Table 5

Frequency, GHz	*PG, G/T*	Polarization	Size,cm L-W-H
Tx, 14.0-14.5	45 dBW	Dual track. linear	150×100×11
Rx,11.7-12.75	8 dB/K		

Track speed agility are 100º/sec, 300º/sec^2.

Other companies produce low profile attays too, for example [12].

● "ERA Technology Co." anounced planar PAA with *mechanical phase control* for El steering (Fig. 14) [13]. The antenna has dual polarization, dual band design with idependent control of elevation scan angle in each band.

The common aperture for each band is used.

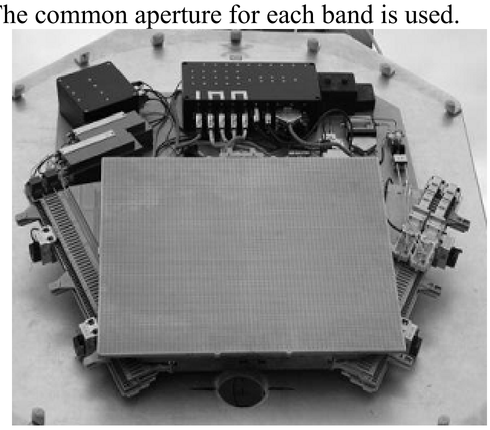


Fig. 14. ERA's "G3" antenna.

5. ACTIVE PHASED ARRAY ANTENNAS WITH ELECTRICAL BEAM STEERING

Two examples are shown below: 1) tested airborne Ku-band APAA for "The Connection by Boeing™ ". Each Unit serves for one sub-band, i. e. Tx-unit and Rx-unit are separate (Fig. 15) [14], 2) the announced by "Phazorsolutions" [15] structure - a low-cost conformal phased array antenna for trains and other vehivles (Fig. 16).

APAA with digital processing signals are very attractive. In this case, the received signal at the output of LNA's connected to each radiator of APAA is transformed to digital form. Then, Digital Beam Forming (DBF) is performed. Similar procedure takes a place in the Tx-mode too, but the transformation to the analog signal is performed at inputs of HPAs. Due to DBF, a flexible control of independent beams of arbitrary

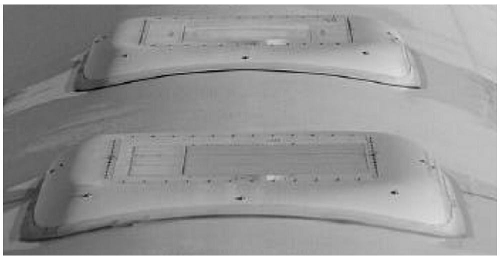


Fig. 15. Airborne APAA.
"The Connexion By Boeing TM "

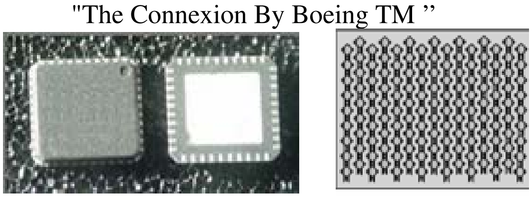


Fig. 16. Announced APAA structure.

directions and width is possible for each of them.

Development of such APAA made by ETRI, APEX and REIS for High Altitude Platform Station was presented in [16]. Vehicular APAA with DBF are the subject of researches now.

6. CONCLUSION

● From the Survey one can see, reflector antennas are simpler and hence cheaper compare to arrays. Arrays have ultra low profile.

● Reflector antennas combine Tx&Rx parts. Arrays, as a rule, have separate units for Tx and Rx parts.

●Reflector antennas can have both mechanical and limited electrical satellite tracking even close to horizon. Arrays can have fast electrical tracking in a wide scan sector. Satellite communications near horizon is one of the important tasks under the development of low profile arrays**.**

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