

Research Article

System Design and Engineering Implementation of Vehicle Transponder for A-SMGCS

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Global aviation transport industry has entered the stage of rapid development, and the air traffic flow is exploding at an incredible rate. The Asia-Pacific region is the core of the future growth of the aviation industry. The growth of the fleet is expected to reach 50%, especially in China. Nearly 4,000 new aircrafts are expected to be delivered in the next 10 years, with the fleet increasing by more than 100%. The practitioners of modern aviation regard ensuring aviation safety and improving the efficiency of aviation operations as two important themes to promote the surge development of aviation. To solve the effective surveillance, guidance, and control of flights and vehicles operating on the surface in complex airports, the global airports are recommending Advanced-Surface Movement Guidance and Control System (A-SMGCS) to realize the effective management of the airport scene and improve the safety of the surface operational capability. Airport surface security management objectives include aircraft, vehicles, and other moving targets, almost all aircraft has an operative transponder, and the vehicles need the similar function transponder to indicate its identification in A-SMGCS, so it can be guided effectively by a given procedures. This paper introduces a vehicle transponder system design from appearance structure and electrical performance and implements engineering modification on a vehicle. In an airport with A-SMGCS, two methods of fixed reference point and manoeuvre test are selected, and the performance indexes of the transponder are recorded and compared. Finally, it is concluded that the transponder meets the performance parameters specified by FAA technical standards; it can be used as a qualified vehicle transponder to provide vehicle positioning information for the A-SMGCS system.

1. Introduction

With the increase of the number of flights and the airport complexity, the scale of airport facilities, terminal building, apron, cargo warehouses, hangar, and so on is continuously expanding, the airport surface management is facing increasingly security challenges, the area of invisible area of ATC tower is also gradually increasing, and the blind spot concentrated in the apron will pose a significant security threat to the safe operation of the airport surface [1]. According to the Federal Aviation Administration (FAA), potentially severe incidents and acci-

dents involving aircraft and vehicles at the airport occur. Many of these events occur during periods of reduced visibility for flight crews and the air traffic controllers.

The traditional airport surface movement radar has the following disadvantages:

- (a) The inherent lack of identification ability of primary radar cannot identify and track ground targets independently, so it needs to be used together with SSR. To some extent, it is highly dependent on other systems, which reduces the reliability of the system

- (b) The coverage ability of surface surveillance radar is relatively small. Because of multipath effect and ground object reflection, there are many false targets, and there are also blind areas
- (c) Surface surveillance radar is sensitive to weather. High winds and heavy rain generate a lot of clutter, and as a primary radar, unconcerned targets within the airfield will be detected and shown in the system

To ensure the safety of airport operations under the conditions of high density, complex surface environment, and low visibility, and at the same time to improve the efficiency, capacity, and order of scene operation and meet the needs of future airport operations, many ANSPs are turning away from surface movement radar and looking toward a novel technology. Benefits from the application of automation technology, computer network, and other high-tech technologies in the civil aviation field, the construction of systems such as HUD (Head Up Display) and A-SMGCS (Advanced Surface Movement Guidance and Control System) makes it possible to increase airport capacity in current low visibility conditions and in complicated and high-density airports [2, 3]. So, ICAO proposed an A-SMGCS, which is based on existing international standards and already available products and technologies, as shown in Figure 1.

The main task of A-SMGCS is to lead the landing aircraft from the runway through the taxiway to the parking position of the apron according to the designated procedure. Similarly, it also guides the aircraft to the takeoff runway through the taxiway from the parking position of the apron and all other movements on the airfield, including from the apron to the maintenance area and so on. Improving the efficiency and security of airport surface operations and management is the ultimate objective of A-SMGCS. Therefore, all maneuvering has some risk of accidents which comes from aircrafts or vehicles [4]. Therefore, A-SMGCS must guide vehicles simultaneously.

A-SMGCS can identify, locate, and track aircrafts and vehicles, and then, it can provide situational awareness of airport surface traffic. A-SMGCS has many advantages, but the premise is that both aircraft and surface vehicles must provide A-SMGCS with information sources to indicate their identity and exact location. Therefore, at least all targets should be installed with a cooperative transponder.

The worldwide civil aviation community has recognized MLAT [5, 6] and ADS-B [7–9] as the updated surveillance technologies that surpass SSR radar by providing more accurate air traffic surveillance information with lower investment and operation maintenance costs. The transponder receives the GNSS signal, encodes the message according to the ASTERIX Category 21, and then broadcasts the ADS-B message on the 1090 MHz Extended Squitter data link. The ADS-B and MLAT stations receive and decode the message to get the position data of aircraft and vehicles, ultimately realizing the timely and accurate air traffic surveillance [10].

At present, according to the regulations of aviation administration departments of various countries, most aircrafts carry a 1090 MHz transponder, which can be used as a positioning terminal of A-SMGCS to provide positioning services for A-SMGCS. However, many vehicles in the airport do not have

the transponder's positioning function and cannot offer positioning services for vehicles running in the scene in A-SMGCS.

In this paper, we mainly address the design and development of a vehicle terminal transponder for the A-SMGCS system, which can be installed on the vehicle and broadcast its DF message, including vehicle ID, longitude, latitude, and velocity [11, 12], to realize the unified supervision of aircraft and surface vehicles. Finally, we select an airport constructed with an A-SMGCS system, complete the project implementation, and test the transponder performance.

2. Requirement Analyses

The surveillance service is one of the most basic and minimum services that A-SMGCS can provide, and it is the premise of the realization of all other services. To some extent, all other service, performance of surveillance service is crucial to the realization of other services. The A-SMGCS vehicle transponder terminal shall provide surveillance services for the vehicle, including the broadcasting of vehicle position information, vehicle ID, call sign, and velocity for the ADS-B receivers and the MLAT ground station to receive and locate the vehicle position [13, 14].

We have consulted the general international technical standards, rules, and regulations, such as RTCA D0-260B, ED-87, and ED-117A.

According to the above technical documents and regulations, detailed requirement analysis is carried out for the vehicle transponder providing vehicle positioning function in the A-SMGCS system, and the following requirement description for the vehicle transponder is drawn up:

The vehicle transponder shall be single integrated equipment containing GPS antenna and receivers and ADS-B transmitters, all enclosed within a cover. The enclosure shall be tampered-proof, water-proof, and properly sealed from sand, dust, and water [15, 16].

- (a) The vehicle transponder shall be rugged and suitable for use in a field environment that may be hot, cold, wet, and dusty
- (b) The vehicle transponder shall transmit at a frequency of 1090 ± 1 MHz
- (c) The output power shall be between 18 W and 20 W
- (d) The vehicle transponder shall transmit mode-S extended squitter ADS-B messages in downlink format 18 (ES/NT)
- (e) The vehicle transponder shall transmit mode-S extended squitter ADS-B messages with information that includes but not limited to the following:
 - (i) Surface position (BDS 0,6)
 - (ii) Identification and category (BDS 0,8)
 - (iii) Aircraft operational status (BDS 6,5)

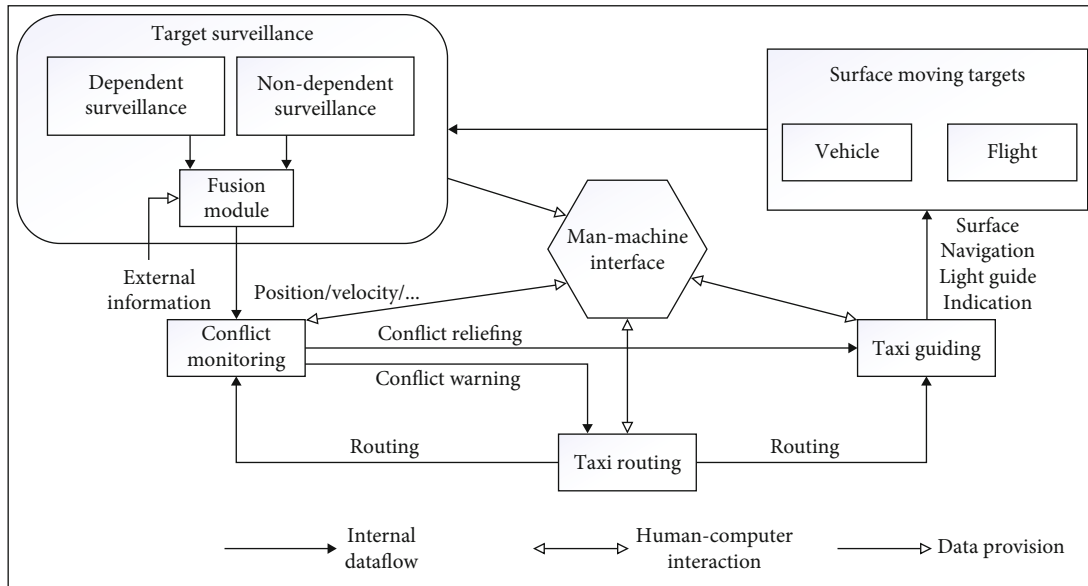


FIGURE 1: A-SMGCS principals.

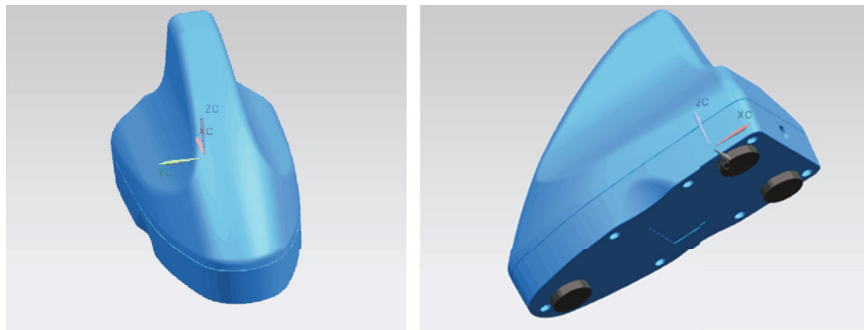


FIGURE 2: 3D outline drawing of the vehicle transponder.

- (f) There shall be an option to configure the vehicle transponder to broadcast ADS-B surface position (BDS 0,6) messages at a fixed rate of 0.5 seconds, i.e., 2 reports per second
- (g) The period from switching on the supply voltage to the transmission of the output message with valid position information shall be less than 45 seconds
- (h) The operation of the vehicle transponder shall not cause any interference at all times to the continuous operations of any existing facilities at the airport during installation, tests, and operation

3. Design Scheme

Vehicles equipped with transponders can improve the safety, efficiency, and sustainability of airport surface operations [17, 18]. This chapter describes the overall design scheme of the vehicle transponders from several aspects such as

structural design, electrical design, software development, and human-computer interaction.

3.1. Structure Design. The design of the vehicle transponder is customized to facilitate the installation at the top of the vehicle. The bottom of the vehicle transponder is designed with three magnetic solid adsorption units with a rubber pad attached to the magnet's outer layer to ensure that the vehicle transponder is firmly absorbed on the vehicle's top.

With this streamlined body design, it can meet the aesthetic requirement and reduce the wind resistance and impact of the surface wind with the ADS-B vehicle transponder installed on top of the vehicle. The design of the ADS-B vehicle transponder is shown in Figure 2.

The vehicle transponder casing is made of PC/ABS, which consists of polycarbonate and ABS alloy. The excellent properties of the two materials, including the moulding of ABS materials and the mechanical properties of PC, can withstand high impact and high temperature, anti-ultraviolet (UV), and other stuff. The balance's excellent mechanical properties can withstand distortion at high heat temperature (80~125°C) and

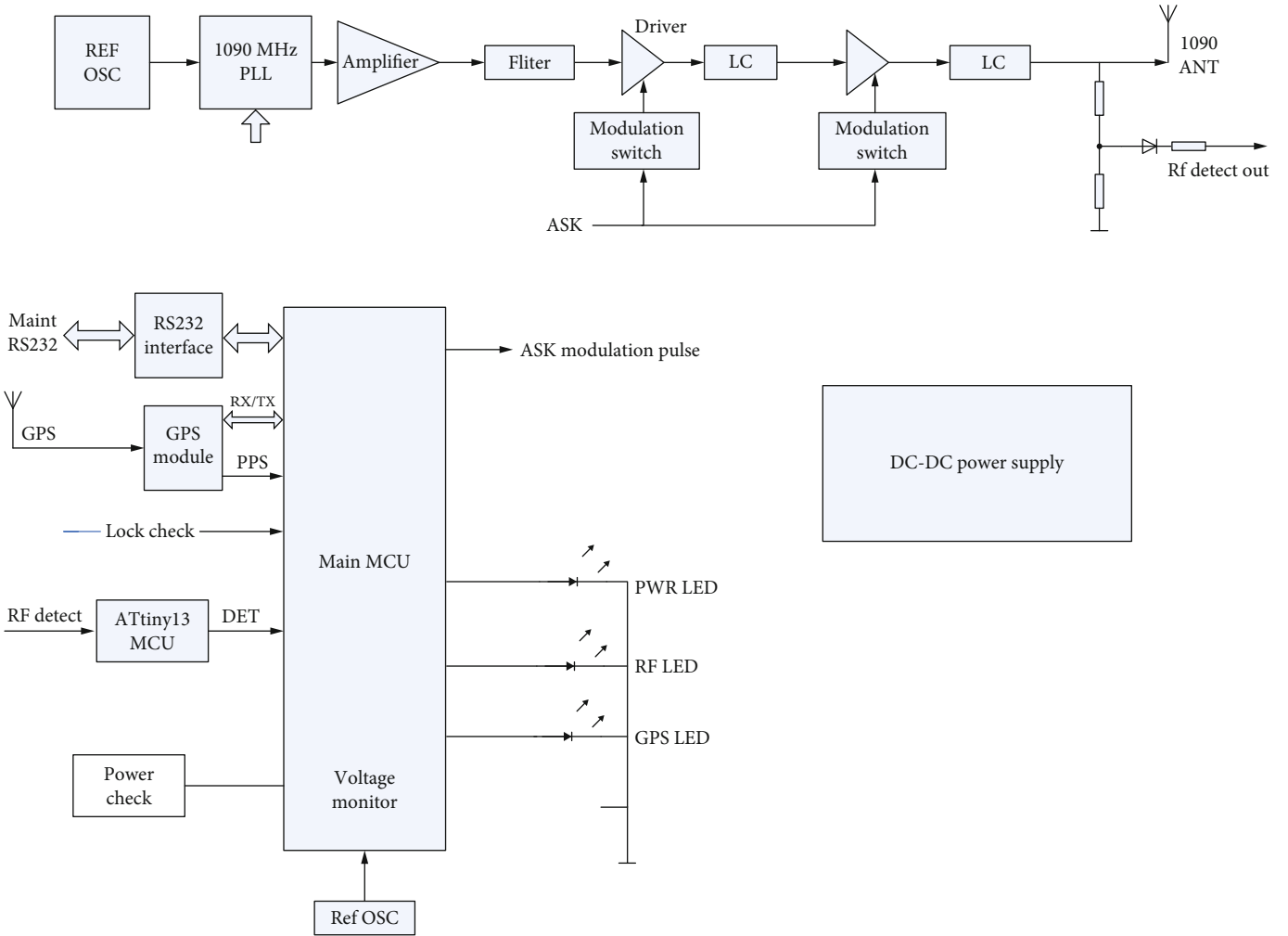


FIGURE 3: Electrical system diagram of the vehicle transponder.

flame resistance (UL945VB). The ADS-B vehicle transponder casing surface is coated with anti-ultraviolet paint spray treatment, enabling the colour of the product to last when operating for long hours. The casing gaps are joined using natural rubber to do sealing treatment with tear-resistant antacid and antialkali corrosion. Hence, the vehicle transponder has high structural strength, reduces degradation, is resistant to high and low temperature, and has no electromagnetic shielding effect [19–21].

The internal structure of the RF unit with the entire metal shielding cavity shall form the foundation for the PCB and device installation. The system power supply and signal processing shall be in a PCB form and reside in the metal cavity. The GPS receiving antenna is placed and mounted in front of the vehicle through the cables. The ADS-B transmitting antenna is vertically mounted on the antenna port of the transmitter assembly. The assembly of the antenna is shown in Figure 3. The RF antenna specifications are shown in Table 1. The PCB components are sprayed with three paint proofs to adapt to high temperature, high humidity, salt fog, and another working environment.

TABLE 1: RF antenna specifications.

Frequency	1090 ± 2.5 MHz
VSWR	≤2
Input impedance	50 Ω
Gain	2dBi
Polarization	Vertical
Max power	10 W
Interface	SMA-J
Degree of coverage	Omnidirectional
Operating temperature	-10 °C~+60 °C

3.2. Electrical Design. The vehicle transponder mainly consists of a transmitter module, RF antenna, GPS receiver, signal processing unit, power supply, indicator lights, and external interfaces. The external interface is designed for the power supply, parameter settings, and local maintenance through the RS232 interface [22, 23].

The system block diagram of the ADS-B vehicle transponder is shown in Figure 4. The overall architecture of the transponder's framework is then described in detail.

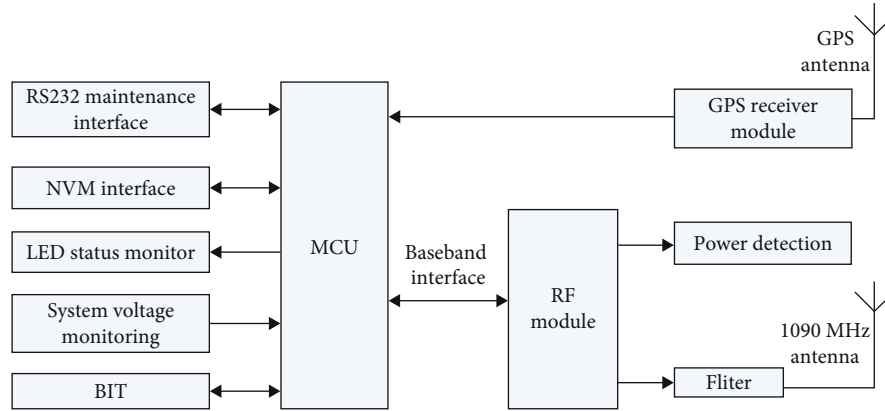


FIGURE 4: System block diagram of vehicle transponder..

The vehicle transponder electrical system diagram is shown in Figure 3.

3.2.1. *Power Supply.* The ADS-B vehicle transponder is powered by the vehicle cigarette lighter. The power supply module converts the unstable DC power input from the vehicle into the DC power supply required by the ADS-B vehicle transponder.

3.2.2. *Main Control Unit (MCU).* The ADS-B vehicle transponder consists of an MCU that performs system monitoring, GPS information processing, ADS-B information coding, maintenance operations, status instructions, and there forth.

3.2.3. *RF Module.* The RF module completes the entire 1090ES mode of the oscillation source, PPM modulation, pulse power amplification, and the final transmission output of about 20 W through the transmitter antenna.

3.3. *External Interface Design*

3.3.1. *Working Cable.* The working cable is mainly supplied to the vehicle transponder to supply the DC power supply from the vehicle to the transponder’s low-frequency connector. We are using the connector of the two cores, Pin 1and Pin 2.

Low-frequency cable power supply pin assignment is shown in Table 2.

3.3.2. *Configuration Cable.* The configuration cable is mainly used for parameter configuration; compared with the working cable, it used the serial communication pin.

Configure cable pin assignment is shown in Table 3.

3.4. *Ergonomic Design.* The vehicle transponder is easy to operate and does not require any human intervention during its normal operation. After it is powered on, it will work automatically following the design process and hence reducing the operator workload [24].

The vehicle transponder is designed with an external indicator light, which is convenient for the user to observe the operation status of the ADS-B vehicle transponder during the process [25, 26]; the indicator lights are shown in Figure 5; the status of the indicator light is shown in Table 3.

TABLE 2: Power and RS 232 connector.

	PIN	DB9
Power	1, GND	
	2, VCC	
Communication	3, TX	3
	4, RX	2
	5, GND	5

TABLE 3: GPS antenna specifications.

Frequency	1575.42 ± 1.1 MHz
VSWR	≤1.5
Input impedance	50 Ω
Gain	4.5dBi
Polarization	Right-handed circular polarization
Max power	200 W
Interface	SMA-J
Degree of coverage	Omnidirectional
Operating temperature	-40°C~+70°C



FIGURE 5: Device indicator.

The ADS-B vehicle transponder parameters are adjusted and configured by a cable and computer on-line operation. Once set, the parameters are permanently stored in the device, and there is no need to configure each time the device is powered up.

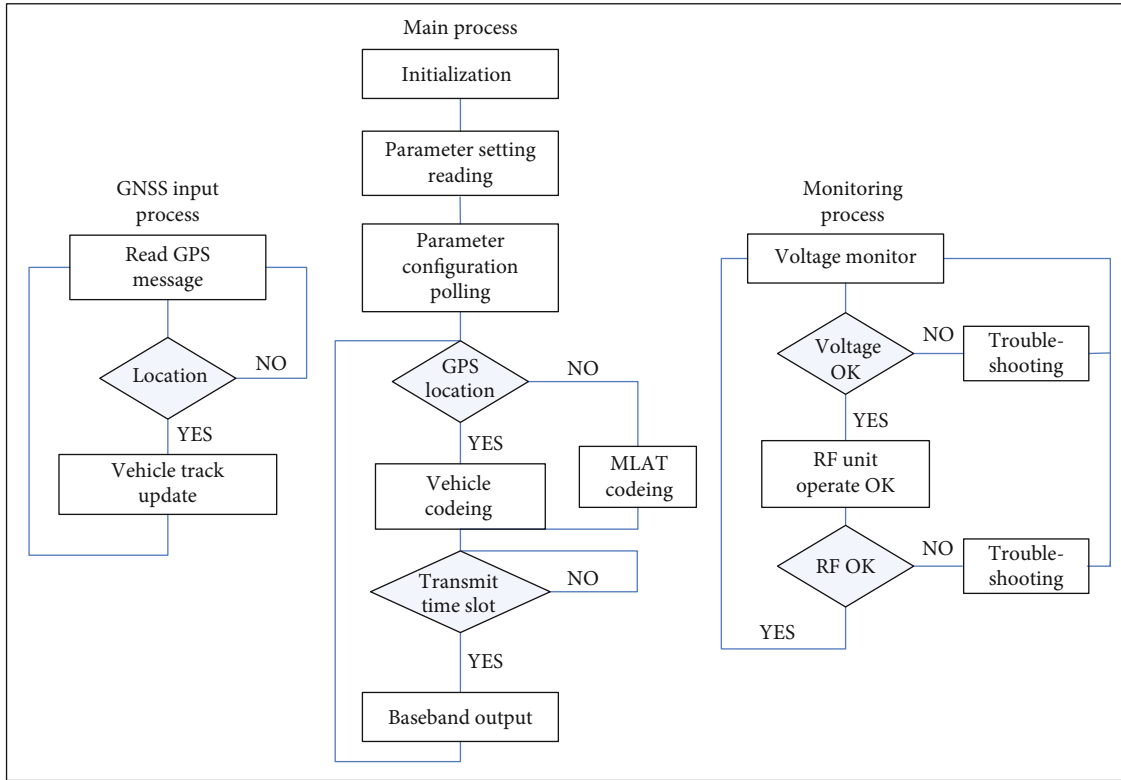


FIGURE 6: Software flow chart.

TABLE 4: Device indicator status description.

Indicator	Status	Function description
PWR	On	Operating normally
	Off/flashing	Fault
GPS	On	Operating normally
	Off/flashing	GPS not positioned Note: transponder still broadcasts with no position info
RF	Flashing	Operating normally
	Off	Fault
ERR	On	Fault
	Off	Operating normally

TABLE 5: Record of fixed test.

Test	Fixed test
Test description	
Offset (m): test description	Approx. 3 m.
Conclusion	PASS

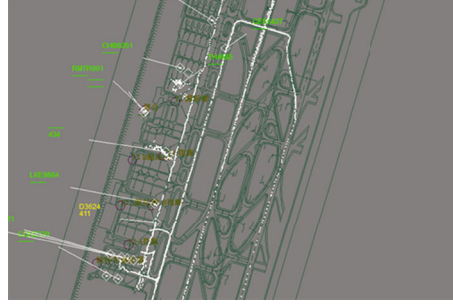


FIGURE 8: Traffic state of the airport surface in A-SMGCS.

4.1. Fixed Test. To test the vehicle transponder positioning accuracy, the transponder was placed directly on top of a surveyed point, as shown in Table 4. The precise latitude and longitude information of the location of the airport is provided. At the airport's surveillance terminal, the vehicle transponder latitude and longitude information is determined and compared with the longitude and latitude information of the actual point. Reported latitude and longitude of the transponder are to be compared with the surveyed latitude and longitude. The test is considered PASS if the vehicle transponder's error and the actual point is less than 10 meters. The test records are shown in Table 5.

4.2. Motion Test. To test and verify the positioning accuracy of the transponder in the normal driving process of the vehicle and the reliability of the equipment's operation, we placed the vehicle transponder and reference transponder on the top of the same vehicle and drove the vehicle with progressive speed from 40 km/h, 60 km/h, and 80 km/h, on the straight road as well as cornering. Recorded broadcast message success rate, start-up time, detail messages, trajectory and so on. If all records are satisfied with the requirement of the technique specification, then the test is pass. All test results are shown in Figure 7.

5. Engineering Implementation

Select an airport that has been built for A-SMAGCS, install a transponder on the roof of the airport vehicle, and supply power to the vehicle transponder through the cigarette lighter. Users can set the transponder parameters such as transponder ID, ICAO information, and vehicle category through the customized software installed on the computer, according to the actual user environment. After power on, the monitoring terminal of A-SMGCS monitors controls and guides the vehicle motion track equipped with the transponder [17, 18].

The specific implementation is shown in Figure 8; the D3624 icon displayed on the terminal of A-SMGCS is the driving track of the vehicle equipped with a vehicle transponder.

6. Conclusion

The modern airport is composed of different areas and multipurpose buildings, and it is designed to serve the needs of

both aircrafts and vehicles. The surface conflict is any occurrence at an airport involving an aircraft, vehicle, person, or object on the ground that creates a collision hazard or results in a loss of separation.

The vehicle transponder developed in this paper can be used as a cooperative positioning equipment to provide positioning services for vehicles running in the A-SMGCS system. It is a necessary facility to prevent collisions and ensure smooth and free traffic during the A-SMGCS system's operation for a vehicle.

Installing relevant transponders on targets, the A-SMGCS can acquire the movement status of all aircrafts and other vehicles running on the airport surface and share the information with other management systems; then, the apron controller can surveillance, guide, and control aircrafts and vehicles in concise and effective way with the aid of Apron Control Management at airport.

After testing in some large complicated airports, the result shows that this vehicle transponder is capable of supplying the controllers, pilots, and drivers with the vehicles' accurate position, helping them find their path to the destination without causing conflict.

Data Availability

The test data used to support the findings of this study are currently under embargo, while the research findings are commercialized. Requests for data, 12 months after publication of this article, will be considered by the corresponding author.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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