ETC Gantry Test Solution and Comparative Analysis

Doewe Technologies Application Notes-004-V1.0

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1. Introduction

The ETC (Electronic Toll Collection) gantry system is a crucial facility for eliminating provincial boundary toll stations and implementing non-stop electronic toll collection. It possesses functions such as multi-path identification for passing vehicles and automatic fee calculation, enhancing the comprehensive perception of the operational status of the expressway network. By relying on gantry data, it can accurately obtain traffic flow, vehicle speed, and the overall operational status of the network.

This technology provides significant convenience for drivers and toll station staff, enabling automatic toll collection while also saving time. The ETC gantry system features functions like segmented tolling for passing vehicles, traffic surveys, video surveillance, and overspeed screening. After a vehicle passes under the gantry, the surveillance system installed on the gantry automatically identifies the vehicle and completes the toll calculation.

With the development of ETC applications, improving ETC service quality and reducing failure rates have become prominent issues. The reliability of communication between the On-Board Unit (OBU) installed on the vehicle's windshield and the Roadside Unit (RSU) on the ETC gantry system is particularly critical. Protocol conformance between the OBU and RSU is fundamental to the operation of the ETC system, encompassing core physical layer metrics, reliability, and communication process integrity (protocol conformance). Testing ETC gantries according to GB/T 20851-2019, JTG 2182-2020, and JTG 3520-2021 not only ensures standard compliance of related equipment but also guarantees the stability and reliability of the gantry system during daily use, laying the foundation for ETC application and development.

2. Test Standard Overview

The main test content of this solution is based on items 20-25 in Table 6.4.2 "ETC Gantry System Measured Items" under Section 6.4 "ETC Gantry System" of the《JTG 2182-2020 Highway Engineering Quality Inspection and Evaluation Standard Part 2: Electromechanical Engineering》. These items include: Communication Zone, RSU Working Signal Strength, RSU Working Frequency, RSU Occupied Bandwidth, RSU Preamble, and RSU Communication Process. Specific details are shown in the figure below:

20	通信区域	区域应满足车辆通行正确交易的需求	OBU 测试
21	RSU 工作信号强度	不低于 OBU、CPC 卡接收灵敏度，或应满足 ETC 车辆和 CPC 卡车辆通行时的数据交互要求	在 ETC 门架系统通信区域内自动采集 RSU 工作信号，测试 RSU 工作信号强度
22△	RSU 工作频率	信道 1：5.830GHz 信道 2：5.840GHz	在 ETC 门架系统通信区域内自动采集 RSU 工作信号，测试 RSU 工作频率
23△	RSU 占用带宽	≤5MHz	在 ETC 门架系统通信区域内自动采集 RSU 工作信号，测试 RSU 工作信号占用带宽
24	RSU 前导码	16 位“1”加 16 位“0”	在 ETC 门架系统通信区域内自动采集 RSU 工作信号，测试 RSU 工作信号前导码
25△	RSU 通信流程	符合最新规定的 RSU 与 OBU、RSU 与 CPC 卡的 DSRC 通信流程	在 ETC 门架系统通信区域内自动采集 RSU 工作信号，测试 RSU 工作信号通信流程

Figure 1: ETC Gantry System Measured Items Table (Excerpt)

The specific test methods mainly refer to《GB/T 20851-2019 Electronic Toll Collection - Dedicated Short-Range Communication》 and《JTG 3520-2021 Highway Electromechanical Engineering Test Procedures》.

3. ETC Gantry Test Solution Comparison

3.1 Real-time Test Solution Based on Suspending Traffic on the Test Section

3.1.1 **Solution Overview**

The real-time test solution based on suspending traffic on the test section is currently the commonly used test solution in the highway transportation industry. This solution first requires suspending vehicle traffic on the test section (approximately tens of meters before and after the ETC gantry lane under test). When testing specific items, the RSU needs to be adjusted to the corresponding test state, test equipment is used for real-time measurement, and test results need to be recorded.

3.1.2 **Equipment Used**

This solution typically requires a handheld spectrum analyzer + omnidirectional antenna. Both must have a frequency range covering at least the ETC communication frequency, and relevant antenna parameters (antenna K-factor, cable loss, antenna gain) need to be known.

3.1.3 **Test Procedure**

- **Communication Zone (OBU Test):**
  1) Set the DUT RSU to continuously transmit the working signal state.
  2) On the lane centerline of the test line, keep the OBU at 1.2m height above the horizontal ground. Slowly move the OBU from the centerline position towards both edges of the lane to find the boundary points where the RSU transmitted signal cannot communicate with the OBU. Use a tape measure to measure the distance from each boundary point to the lane centerline and record.

- **Communication Zone (Field Strength Test):**
  1) Set the DUT RSU to continuously transmit a carrier signal state. If carrier transmission cannot be set, use the continuous working signal state.
  2) On the lane centerline of the test line, keep the test antenna at 1.2m height above the horizontal ground. Slowly move the test antenna from the centerline position towards both edges of the lane to measure the RSU transmitted signal field strength. Find the boundary points where the field strength drops to the specified minimum value (113dBμV/m). Use a tape measure to measure the distance from each boundary point to the lane centerline and record.

- **RSU Working Signal Strength:**
  1) Place the test antenna at the test position within the RSU communication zone as required and start the test.
  2) Adjust the spectrum analyzer power amplitude scale to a suitable value. The measurement range should cover the signal under test.
  3) Set the sweep width to 5MHz, test the channel power, read the test value, and record.

Note: Ensure the maximum channel power within the communication zone is read. The DUT RSU can use its working signal as the signal under test.

- **RSU Working Frequency:**
  1) Place the test antenna at the test position within the RSU communication zone and start the test.
  2) Set the sweep width to 5MHz, read the frequency value at the main longitudinal mode peak, and record.

Note: The DUT RSU is best set to transmit a continuous carrier signal. If conditions do not permit, the working signal can be used as the signal under test.

- **RSU Occupied Bandwidth:**
  1) Place the test antenna at the test position within the RSU communication zone and start the test.
  2) Set the sweep width to 30MHz, measure the 99% power bandwidth, and read the occupied bandwidth result value.

Note: The DUT RSU uses the continuous working signal transmission state.

- **RSU Preamble:**
  1) Place the test antenna at the test position within the RSU communication zone and start the test.
  2) Set the sweep width to 0, switch to the time domain mode, observe the signal envelope, and identify the preamble.

Note: The DUT RSU uses the continuous working signal transmission state.。

- **RSU Communication Process:**
  1) Place the test antenna at the test position within the RSU communication zone and start the test.
  2) Set the spectrum analyzer to record mode, sweep width should be greater than 5MHz. Use the demodulation mode to output the demodulated encoded signal and start the test.
  3) Place a normally functioning OBU in the test position within the communication zone to interact with the RSU.
  4) Decode the stored encoded signal into information source code and record the output result.

Note: The test result is based on whether the output information source code conforms to the data structure of the Electronic Toll Collection Dedicated Short-Range Communication Application Layer Service Primitives. These primitives include BST, GetSecure.request, TransferChannel.request, SetMMI.request, Event_Report, etc.。

3.1.4 **Disadvantages of the Test Solution**

- Complex testing process, requiring high expertise from test personnel
- Occupies the lane for extended periods, posing a risk of traffic congestion
- Difficulty in interpreting information source code; identifying service primitives is extremely challenging for test personnel

3.2 Convenient Test Solution Based on Analyzing Recorded IQ Files

3.2.1 **Solution Overview**

The convenient test solution based on recorded IQ files is a streamlined approach that involves processing, analyzing, and parsing IQ files recorded by a spectrum analyzer or RF recorder. This solution maximizes the efficiency of ETC gantry testing, greatly simplifies the complexity of the testing process, and reduces the risk of traffic congestion caused by lane closures.

3.2.2 **Equipment Used**

This solution requires one of two equipment combinations:

1. Spectrum analyzer (supporting IQ recording function, bandwidth ≥5MHz, recording time ≥15s) + Omnidirectional antenna + ETC Transaction Process Analysis Software ProEye.
2. RF recorder + Omnidirectional antenna + ETC Transaction Process Analysis Software ProEye.

3.2.3 **Brief Test Procedure**

- **Communication Zone (Field Strength Test):**
  1) Set the Device Under Test (DUT) RSU to a state of continuous carrier signal transmission. If continuous carrier signal transmission cannot be set, it may be set to a state of continuous operational signal transmission instead.
  2) Positioned on the lane centerline within the test section, maintain the test antenna at a height of 1.2m above the horizontal ground plane. Slowly move the test antenna from the lane centerline position towards each of the two lane edges in turn. Measure the RF signal field strength emitted by the RSU and locate the boundary points where the field strength drops to the specified minimum value (113 dBμV/m). Use a tape measure to measure the distance from each boundary point to the lane centerline and record the values.

- **RSU Working Signal Strength / Working Frequency / Occupied Bandwidth / Preamble / Communication Process:**
  1) Install an OBU capable of normal communication with the DUT RSU on the test vehicle's windshield. Place the test antenna inside the test vehicle near the windshield, ensuring it can receive the downlink signal.
  2) Drive the test vehicle normally through the corresponding lane under the DUT ETC gantry. Activate the IQ recording function on the spectrum analyzer or RF

recorder *before* the test vehicle enters the ETC transaction zone. Stop recording *after* the transaction completes.

3) Open **ETC Transaction Process Analysis Software ProEye**, import the recorded IQ file, and analyze RSU Working Signal Strength, Working Frequency, Occupied Bandwidth, Preamble, and Communication Process.

3.2.4 **Advantages of the Test Solution**

- Greatly simplifies the complexity of the testing process, avoiding errors caused by real-time testing missteps.
- Core software provides test results with one click, lowering the skill requirements for test personnel.
- Avoids prolonged lane occupation, reducing the risk of traffic congestion.
- Accurately parses and locates information source code, solving the core difficulty of parsing application layer service primitives.
- Supports screenshot saving of data, facilitating data storage and analysis.

4. Core Test Software - ETC Transaction Process Analysis Software ProEye

4.1 Software Overview

ETC Transaction Process Analysis Software ProEye is a professional test software designed to analyze the ETC system communication process (protocol conformance). It primarily analyzes recorded IQ files containing the ETC RF interaction process. It supports common IQ file formats; supports parsing RF indicators, key interaction statements, and characteristic data at the application layer and device application layer. RF indicators include signal strength, carrier frequency, frequency tolerance, modulation index, occupied bandwidth, etc. Application layer and device application layer parsing can automatically search for key interaction statements, such as preamble, BST, VST, SetMMI.rs, SetMMI.rq, etc. This is used to determine if the ETC system's communication process is normal. Supports providing a C# API for secondary development.

4.2 Software Structure Diagram

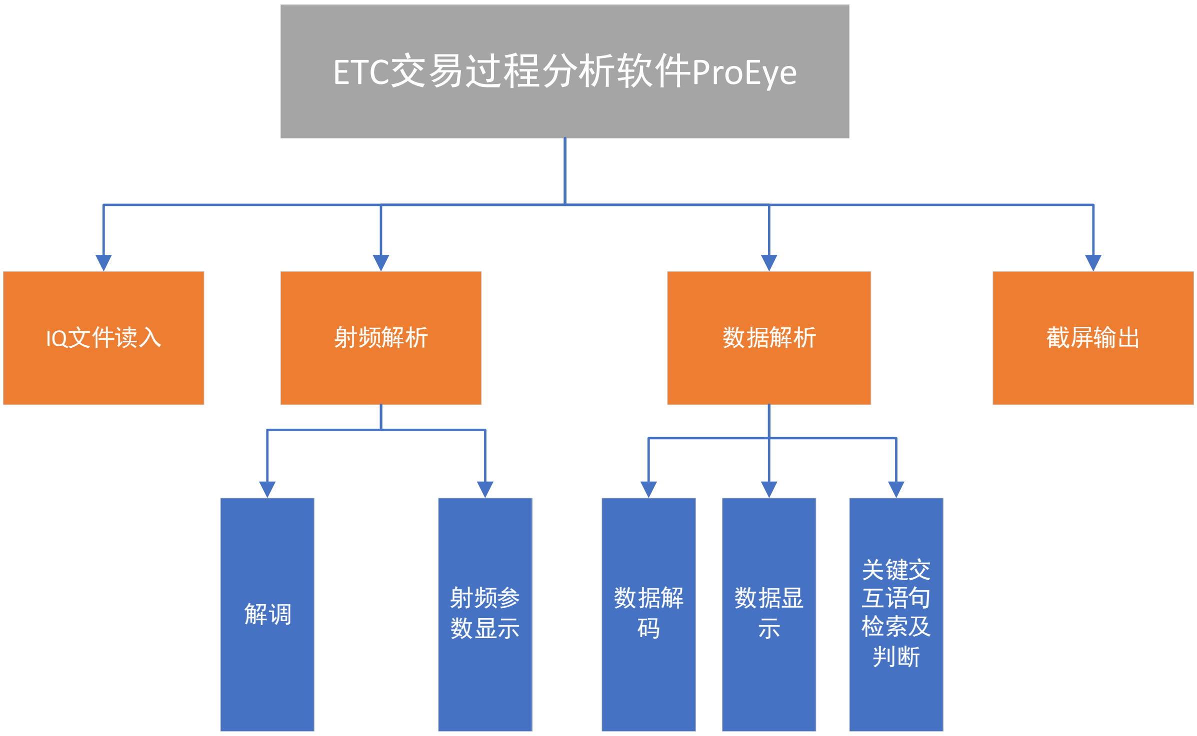

Figure 2: Software Structure Diagram

4.3 Software Interface Diagrams

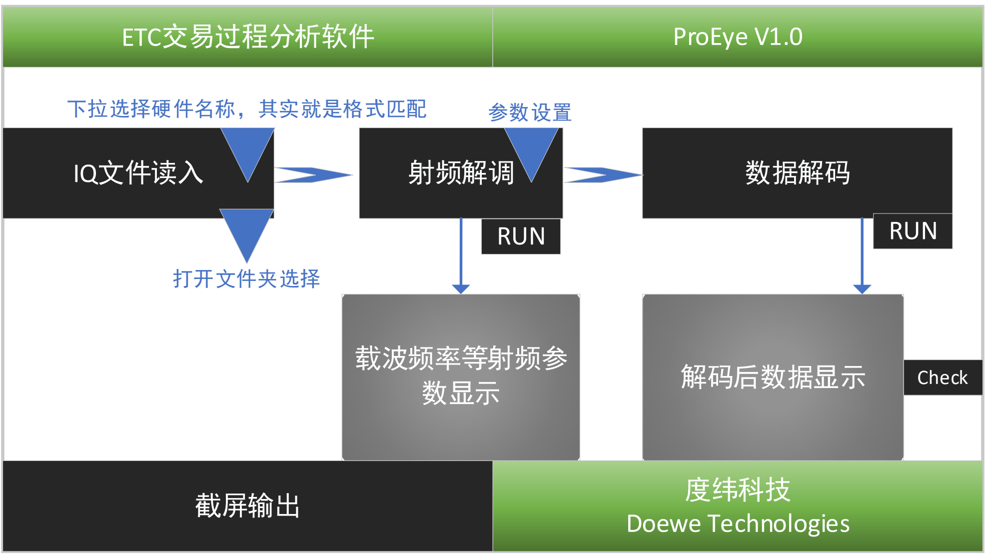

Figure 3: Software Main Interface Diagram

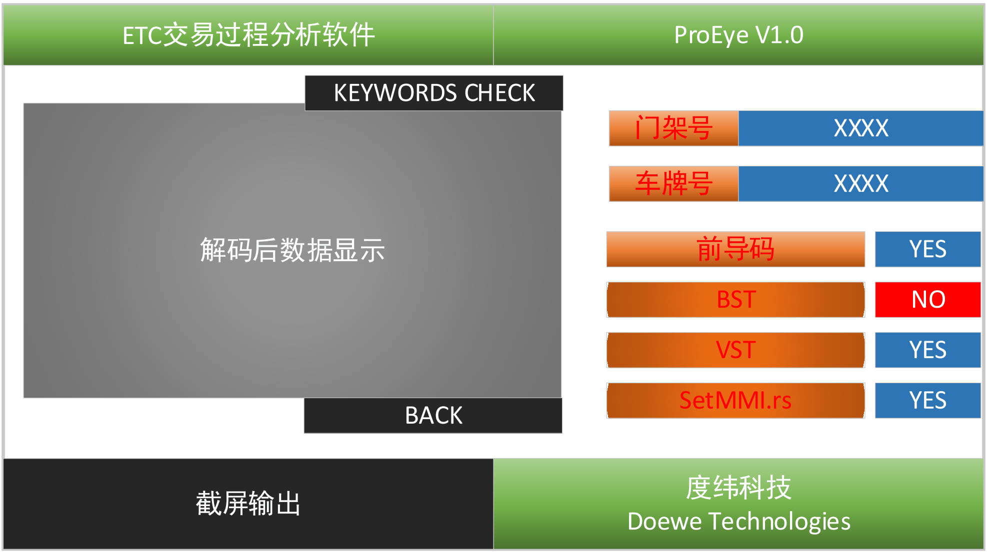

Figure 4: Data Parsing Sub-Interface Diagram